Application Procedure

Institutional Admissions Requirements

The general requirements for admission to graduate study at the university are listed below.

1. The applicant must show official evidence of having earned a baccalaureate degree or its U.S. equivalent from an accredited college or university. If an international transcript does not adequately demonstrate that an applicant has the equivalent of an American bachelor's or master's degree, the Office of Graduate Admissions will require such verification by an independent service such as the Center for Educational Documentation (http://www.cedevaluations.com/), Boston, MA (617-338-7171).

2. The degree must have been earned with a satisfactory scholastic average to demonstrate that the applicant has had adequate preparation for the field in which graduate studies are to be undertaken.

3. Certain graduate programs require graduate entrance examinations. The applicant must have obtained a satisfactory score on the appropriate entrance examination if required for admission by the program or department to which admission is sought. The official score report must be submitted; a photocopy of the examinee’s report is unacceptable.

4. The Commonwealth of Massachusetts requires that all full-time graduate students (9 or more credits) must be immunized against measles, mumps, rubella, tetanus, and diphtheria. In addition, all students in programs in the health professions, regardless of age or enrollment status, must show proof of immunization. Students will not be permitted to register for courses at the University unless proof of immunization has been sent directly to the Director of Health Services, University of Massachusetts Lowell, Lowell, MA 01854 978-934-4991.

Departmental Requirements

The rules, regulations, and policies delineated by the University constitute only the minimum requirements for admission, retention, and graduation. Each department may have additional requirements mandated by the unique nature of its programs. It is the responsibility of the graduate student to be aware of the minimum requirements of the University and, in addition, to fulfill the special requirements of the particular program in which he or she is enrolled.

Application Procedure for Graduate Admission

Applicants can apply using the online application.

Master’s & Doctoral Application

- Application Deadline
- Types of Admission
- Graduate Certificate Application Procedure
- Non Degree Status
- Graduate Readmission/Deferral Policy

Master’s & Doctoral Application Information

A non-waivable and non-refundable application fee must be received before the application is processed. Each applicant must file the following documents:

1. A completed application form.
2. Official transcripts of all undergraduate and graduate records.
3. Letters of recommendation written by individuals qualified to judge the ability of the applicant to carry on graduate work and research as requested by the department. Refer to the department page to learn about the number of required recommendations.
4. Official scholastic test scores specified for various degree programs at the University (see individual departmental requirements). An applicant who has earned a graduate degree from an accredited university may petition the department graduate coordinator to waive the scholastic test requirements (e.g. GRE).

5. The official score report for an institutionally approved language test for students from countries where English is not the national language. The thresholds for English tests are set by the department.

   Institutionally approved English tests: TOEFL, IELTS, Duolingo. All test scores must be official and sent directly by the testing agency.

Application Deadline

The University of Massachusetts Lowell Graduate Admissions Office has a "rolling admissions" policy. However, some programs have early, fixed application deadlines. Consequently, the applicant is strongly urged to contact the department of interest to determine the last date on which applications may be received. In general, early applications will ensure that all materials are processed on time and that a student who wishes to apply for a teaching assistantship will be given due consideration. Many programs will fill available openings several months before the beginning of the semester. A student who has been accepted into a graduate program must attend within a year of acceptance or may, at the discretion of the department, be required to submit a new application. Application files for individuals who do not matriculate will be retained for only two years from the date of application.

Types of Admission

A student may be admitted to graduate study at the University of Massachusetts Lowell under one of the two classifications listed below.

1. Matriculated status: A student who has met all requirements for admission to a degree program and who has been recommended by the department in which he or she proposes to study as a degree candidate.

2. Matriculated with conditions: A student who has not fully met the requirements stipulated by the program may be admitted as a prospective candidate for a degree with specified conditions to be met in the future. Such a student must have as an initial objective the satisfactory completion of all requirements for full matriculation.

Graduate Certificate Candidate Application Information

Graduate certificate programs are designed for students holding a baccalaureate degree in a field related to the certificate program. A student who wishes to apply to a certificate program must complete the Graduate Certificate Application, submit the appropriate application fee, and submit an official transcript indicating the conferral of a bachelor’s degree. The graduate record exam (GRE) and letters of recommendation are not required.

A student in a certificate program who wishes to enroll in a master’s or doctoral program is ineligible to receive credit towards a degree until he or she files a formal application and is then admitted as a matriculated student.

The maximum number of graduate credits a student may complete while enrolled in a graduate certificate is 12 credits.

Non-Degree Status

An individual without advanced degree objectives may take courses in certain programs with non-degree status. A student who wishes to take courses as a non-degree student must submit an official transcript indicating the conferral of a bachelor’s degree. A student in non-degree status is ineligible to receive credit towards a degree until he or she files a formal application and is then admitted as a matriculated student.

The maximum number of graduate credits a student may complete with non-degree status is 12 credits.

NOTE: International students are not eligible for non-degree status.

Graduate Readmission/Deferral Policy

1. A matriculated student who formally withdraws in good standing from the university may request readmission within two years by completing only the cover page of the graduate application.

2. A newly accepted student dropped from a
graduate program for failure to register may be
re-admitted by submitting a new application
cover page and fee within two years of
acceptance date.
3. A matriculated student who fails to maintain
continuous enrollment and has not formally
withdrawn may be readmitted by submitting a
new application cover page and fee within two
years of being dropped from the program.
4. A student may request a deferment of enrollment
up to one year beyond the date when he or she
was scheduled to begin his or her graduate
program. If the one-year time period is exceeded,
the student must submit a new application and
fee. Deferral must be requested before the start of
the semester for which the student is accepted.

Financial Assistance & Assistantships

FINANCIAL ASSISTANCE

- Applying for Financial Aid
- Other Types of Assistance

The Solution Center
University Crossing Lobby
220 Pawtucket Street, Suite 131
Lowell, MA 01854
Telephone: 978-934-2000
Office Hours: Monday - Friday: 8:30 a.m. to 5 p.m.

Applying Financial Aid

The University requires students to file a Free Application for
Federal Student Aid (FAFSA). Students may apply for the
FAFSA online at www.FAFSA.ed.gov
(http://www.FAFSA.ed.gov). It is recommended that students
save time by requesting personal identification numbers called
Federal Student Aid PINs before the student applies for aid.
The PIN can be used to electronically sign the FAFSA,
electronically sign certain loan contracts, and access online
information about federal student aid the student has received.
The PIN must be requested online at www.studentaid.ed.gov

Copies of students and spouses federal income tax, W2 forms
and other forms may be requested by the Financial Aid Office
to verify information provided on the FAFSA. Many forms
requested are available on The Solution Center website. All
information requested by the Financial Aid Office is required
to complete the application process and is held in strictest
confidence.

Eligibility Requirements

To receive financial aid from the various student aid programs,
a student must:

- Have demonstrated financial need to qualify for need-
based aid programs. Need is defined as the cost of
attendance minus the expected family contribution
derived from filing the FAFSA. Students may also be
eligible for non-need based aid programs, such as the
Federal Direct Unsubsidized Loan program and
meritorious awards.
- Be a U.S. citizen or eligible non-citizen.
- Have a valid Social Security Number.
- Make satisfactory academic progress.
- Have a high school diploma or a General Education
Development (GED) certificate, pass a test approved by
the U.S. Department of Education, meet other standards
the state of Massachusetts establishes that are approved
by the U.S. Department of Education, or complete a high
school education in a home school setting that is treated
as a home school or private school under state law.
- Be a matriculated student enrolled in a degree granting or
approved certificate program. Students enrolled in non-
degree programs are not eligible for financial aid.
- Be enrolled at least half-time each semester. (Minimum of
six credits for graduate students).
- Cannot be in default or in over payment on a federal
student loan.
- Register with the Selective Service, if required
(www.sss.gov)

Determining Financial Need:

Demonstrated financial need is the difference between the cost
of attendance and the expected family contribution. The cost of
attendance (COA) includes direct expenses such as tuition and
fees, and also includes indirect such as room, board, books and
transportation. The expected family contribution (EFC) is determined by the federal needs analysis formula and is calculated by completing a Free Application for Federal Student Aid (FAFSA).

Types of Financial Aid:

**William D. Ford Federal Direct Subsidized/Unsubsidized Loan Program**: The primary source of financial aid recommended for graduate students is the William D. Ford Federal Direct Student Loan Program. This program allows the student to borrow up to $20,500 per year at a low interest rate in subsidized and/or unsubsidized loans. Eligibility for a subsidized or unsubsidized direct loan is determined from the information provided on the FAFSA. A student may receive a subsidized loan and an unsubsidized loan for the same enrollment period. A subsidized loan is awarded on the basis of financial need. A student will not be charged any interest before repayment begins or during authorized periods of deferment. An unsubsidized loan is not awarded on the basis of need. A student will be charged interest from the time the loan is disbursed until it is paid in full. If a student allows the interest to accumulate, it will be capitalized that is, the interest will be added to the principal amount of the loan and additional interest will be based upon the higher amount. For more information about graduate student aid visit the Solution Center at [www.uml.edu/thesolutioncenter/financial-aid/Receiving-Aid/Types-Aid/graduate/loans.aspx](https://www.uml.edu/thesolutioncenter/financial-aid/Receiving-Aid/Types-Aid/graduate/loans.aspx).

**William D. Ford Federal Direct PLUS Loan Program**: A non-need based federal loan offers up to the cost of attendance minus financial aid per academic year to qualified graduate students and parents/stepparents of undergraduate dependent students. Interest rate is fixed and repayment begins 60 days after the second disbursement. Refer to the Direct Loan website [https://studentaid.gov/help-center/answers/article/federal-direct-loan-program](https://studentaid.gov/help-center/answers/article/federal-direct-loan-program) for current interest rates. A FAFSA is not required to apply for the PLUS loan; however, students are encouraged to file a FAFSA so that they can receive the maximum aid available. Parents may download an application online from [The Solution Center](https://www.uml.edu/thesolutioncenter/financial-aid/Receiving-Aid/Types-Aid/graduate/loans.aspx). Applications should be returned to the financial aid for processing. This is a loan that needs to be repaid by the parent/stepparent.

**Other Types of Assistance:**

**Federal Professional Nurse Traineeship Grant Program**: Federally funded grant available to graduate nursing students. Award amounts vary and are dependent upon funding. Please contact the School of Nursing for more information.

**Federal Teach Grant**: Federally funded grant available to qualifying graduate education majors enrolled in coursework or plan to complete coursework toward a career in teaching in a high need subject area. Contact the Graduate School of Education for more information.

**Deans Fellowships**: $2,000 awards granted to eligible, newly admitted full-time, in-state Masters candidates not receiving a teaching or research assistantship.

**Provosts Fellowships**: $4,000 awards granted to eligible, newly admitted full-time, out-of-state and international Masters candidates not receiving a teaching or research assistantship.

### ASSISTANTSHIPS

#### Teaching and Research Assistantships

A limited number of teaching and research assistantships are available for matriculated, full-time (minimum of 9 credits/semester) graduate students. All assistantships are subject to the agreement between UMass Lowell and UAW/Graduate Employees Organization. Teaching assistantships are assigned by the student’s department; therefore, queries regarding teaching assistantships should be directed to the departmental graduate coordinator [https://www.uml.edu/Graduate-Student-Services/coordinators.aspx](https://www.uml.edu/Graduate-Student-Services/coordinators.aspx) or chairperson (see [www.uml.edu/Grad/coordinate.aspx](https://www.uml.edu/Grad/coordinate.aspx) for a list). Research assistantships are available through special arrangements with individual research advisers. Individuals interested in research assistantships should contact departmental faculty members concerning the availability of this form of financial aid.

#### Qualifying for an Assistantship

To ensure that assistantships are awarded to the most qualified individuals, the University has established the following requirements:

1. 1. No teaching/research assistantship may be awarded to a graduate student with incompletes, F’s, or U’s on his or her transcript.
2. 2. No teaching/research assistantship may be awarded to a graduate student who fails to maintain good academic standing [https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf](https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf) (a grade point average under 3.0 on the official transcript). See the Academic Standing information at [www.uml.edu/catalog/graduate/policies/Academic_Stan ding.htm](https://www.uml.edu/catalog/graduate/policies/Academic_Standing.htm).
3. 3. No University-funded teaching/research assistantship
may awarded to a master’s degree candidate if he/she has completed the total number of credits required for his/her program.

4. Level III teaching/research assistantships may only be awarded to graduate students who have reached doctoral candidacy (i.e. completed all course work, oral/written and language examinations) and are enrolled in dissertation research.

Teaching and Research Assistants are awarded either a semester or a yearly contract. The current negotiated agreement between The University of Massachusetts Lowell Board of Trustees and the Graduate Employee Organization is posted on the Human Resources website. Current stipend levels may be found there as well.

Graduate Student Assistantships

A limited number of student assistantships may be available in the departments. Students in this category are paid an hourly rate and are obligated to pay their own tuition and fees. All queries concerning assistantships should be directed to the graduate coordinator (https://www.uml.edu/Graduate-Student-Services/coordinators.aspx) in the student’s department.

Doctoral Programs Offered

Listed by Degree Earned

- Doctor of Education
- Doctor of Engineering
- Doctor of Nursing Practice
- Doctor of Philosophy
- Doctor of Physical Therapy
- Doctor of Science

Doctor of Education

- Leadership in Schooling (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Mathematics & Science Education (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Doctor of Philosophy in Engineering (Ph.D.)

- Chemical Engineering (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Civil Engineering (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Computer Engineering (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Electrical Engineering (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Energy Engineering (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Mechanical Engineering
- Mechanical Engineering/Civil Engineering
- Mechanical Engineering/Chemical Engineering
- Mechanical Engineering/Civil & Environmental Engineering
- Mechanical Engineering/Energy Engineering
- Mechanical Engineering/Industrial Engineering
- Mechanical Engineering/Manufacturing Engineering
- Mechanical Engineering/Manufacturing Engineering
- Mechanical Engineering/Manufacturing Engineering
- Mechanical Engineering/Manufacturing Engineering
- Plastics Engineering

Doctor of Nursing Practice (DNP)

- Nursing

Doctor of Philosophy (Ph.D.)

- Applied Psychology and Preventative Science
- Applied Biology (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
Biomedical Science; Developmental & Evolutionary Biology; Quantitative Biology & Biophysics; and Cellular & Molecular Biology

- Biomedical Engineering & Biotechnology (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Business Administration (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Management
- International Business
- Accounting
- Leadership
- Finance
- Management Information Systems

- Chemistry (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  - Biochemistry
  - Environment
  - Green Chemistry
- Computer Science
  - Computational Mathematics
- Criminology and Criminal Justice (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  - Crime, Criminals
  - Community
  - Global Perspectives on Crime
  - Justice
  - System
  - Policy
  - Technology
  - Criminal Justice
  - Victims, Crime & Justice

- Earth System Science (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Global Studies (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  - Security
  - Human Rights
  - Socio-Economic Development
  - Comparative Cultures
- Marine Sciences & Technology (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Nursing (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Pharmaceutical Science (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Physics (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  - Applied Mechanics
  - Energy

Doctor of Physical Therapy (DPT)
- Physical Therapy

Doctor of Science
- Public Health
- Epidemiology

Master's Programs Offered
Listed by Degree Earned

- Master of Arts
- Master of Business Administration
- Master of Education
- Master of Music
- Master of Public Administration
- Master of Public Health
- Master of Science
- Master of Science in Engineering
- Education Specialist

Master of Arts (MA)
- Community Social Psychology (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Criminal Justice (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- History (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Peace & Conflict Resolution (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Security Studies (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
Master of Business Administration (MBA)
- General Business
- Accounting
- Business Analytics
- Entrepreneurship
- Finance (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Healthcare
- Information Technology (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- International Business
- Managerial Leadership
- Marketing

Master of Education (M.Ed.)
- Curriculum & Instruction
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  Autism Studies
- Curriculum & Instruction: Initial Certification
- Curriculum & Instruction: Science Education, beyond initial
- Curriculum & Instruction: Math Education, beyond initial
- Educational Administration
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  Principal Non-licensure
- Educational Administration
- Higher Education
- Principal Non-licensure
- Reading & Language
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  Teacher of Reading
  Non-licensure

Master of Music (MM)
- Music Education
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  Community Music
- Sound Recording Technology
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Master of Public Administration (MPA)
- Public Administration (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  - Human Service Management
  - Public Humanities and the Arts
  - Justice Administration

Master of Public Health (MPH)
- Public Health (https://www.uml.edu/Health-Sciences/Public-Health/Programs-of-Study/masters/MPH.aspx)
  - Dietetics
  - Epidemiology
  - Healthcare Management
  - Nutrition
  - Social and Behavioral Sciences

Master of Science (MS)
- Accounting
- Applied Biomedical Sciences
- Autism Studies
- Biological Sciences
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  Bioinformatics
  Biotechnology Education, Communication and Outreach Option (This program does NOT lead to teaching licensure)
- Biomedical Engineering & Biotechnology (PSM)
- Biomedical Engineering & Biotechnology (PSM)
- Business Analytics
- Chemistry
  Chemistry & Polymer Science (PSM)
  Pharmaceutical Biochemistry (PSM)
- Computer Science
  Software Entrepreneurship - Not Accepting new applications
  Co-op Option in Engineering
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
  Engineering Management
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
Entrepreneurship
Environmental Studies
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)Atmospheric SciencesAtmospheric Sciences (PSM)Environmental Engineering SciencesEnvironmental Geoscience (PSM)

Finance
Health Information Management
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)Health InformaticsHealth Management

Information Technology
Marine Sciences & Technology
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)Coast & Ocean AdministrationScience/Technology (PSM)

Nursing Adult / Gerontological NursingFamily Health Nursing

Pharmaceutical Science
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Physics (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Public Health (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Radiological Science & Protection

Security Studies

Master of Science in Engineering (M.S.E.)

Chemical Engineering
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)Leadership

Civil EngineeringLeadershipEnvironmentalGeoenvironmentalGeotechnicalStructuralTransportation

Computer Engineering
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)LeadershipOptics

Electrical Engineering
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)Leadership

Energy Engineering
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)LeadershipNuclearSolar

Mechanical Engineering
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)Leadership

Plastics EngineeringLeadershipCoatingsAdhesivesFibers & CompositesSynthetic Fibers

Education Specialist (EdS)

Administration, Planning & Policy
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Curriculum & Instruction
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)Education of Diverse Populations

Reading & Language
(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Bachelor’s to Master’s Programs
Earn Two Degrees in as Little as Five Years

Eligibility
Course Credits

How to Transition

Francis College of Engineering Expanded Bachelor’s to Master’s Policy

NOTE: A course with a Pass/No Credit election cannot be applied to the university’s Bachelor’s to Master’s Program.

In order to encourage outstanding UMass Lowell undergraduate degree students to continue their studies towards an advanced degree, qualified students may transition to the the Bachelors to Masters Degree Option (Bachelor’s to Master’s programs include the Fast Track to Teaching and Plus 1 programs.)

This option carries distinct benefits. No graduate application is required for UMass Lowell’s Bachelor’s to Master’s programs. In addition, many departments offer course credit benefits. (For detailed information regarding specific course credit benefits, please see the Graduate Coordinator in the respective masters degree granting department.)

The transcripts of the students who declare their intention to transition to master’s programs will be reviewed by the graduate coordinator to ensure the GPA and prerequisite requirements are met. Students should also provide one letter of recommendation to support their transition to the master’s program. Refer to the Bachelor’s to Master’s (https://www.uml.edu/Academics/undergraduate-programs/bachelors-masters.aspx) page for more information.

Eligibility

Any UMass Lowell undergraduate junior or senior with a grade point average of 3.0 or better may apply to a Masters degree program at UMass Lowell under the Accelerated Bachelors to Masters Degree Option. However, to be accepted into this option the following minimum conditions must be met (individual departments may have more stringent requirements):

1. The student must have a cumulative grade point average of 3.0 or above at the time the baccalaureate degree is conferred in order to maintain eligibility for this option.
2. The student must apply for and receive his/her baccalaureate degree before matriculating into the graduate program.
3. Once accepted, a student is expected to begin his/her graduate studies in the semester immediately following conferral of the baccalaureate degree unless the student submits a written request for deferral. A student is allowed to defer for a maximum of one year from the date of acceptance. For example, if accepted for the Spring 2020 semester, an individual can defer to either the Fall 2020 or Spring 2021 semesters. A student defers acceptance by submitting a written request to the Office of Graduate Admissions (mailto:Graduate_Admissions@uml.edu). All deferral requests must specify which semester the student wishes to enroll. Students who are confirmed to transition to the Bachelors to Masters Degree Option who opts not to enroll in at least one course within the graduate department to which they have been accepted in the semester immediately following conferral of the bachelors degree and who does not submit a deferral request forfeits his/her rights to benefits under this program. Should the student decide to begin his/her studies at a later time he/she will be required to the graduate program and submit all required admission materials.

Course Credits

The graduate degree granting department may allow course credit benefits; however, the following requirements apply:

1. Any graduate courses taken by a baccalaureate degree student that are credited towards the Masters degree must have been obtained with a grade of B or better.
2. A graduate level course used to fulfill both an undergraduate degree requirement and a undergraduate minor requirement is also eligible to be used in the Master’s, but only up to the maximum number allowed for the specific Master’s degree.
3. Only courses of 5000 level or higher may count toward the Masters degree.
4. Transfer credit is not accepted for graduate certificates. The Bachelor’s to Master’s program benefits do not include credits toward a graduate certificate.
5. As defined by the graduate degree granting department, a maximum of 12 graduate credits (5000 level or above) may be used for the masters degree as follows:
Up to 12 credits may be transferred provided these graduate credits were taken in excess of the university minimum of 120 baccalaureate degree credits, or, for programs requiring fewer than 33 credits, a maximum of up to six credits of graduate (5000 level or higher) courses may be used by a student in the Accelerated Bachelor’s to Master’s Degree Option for both the graduate and undergraduate degrees; or,

for program requiring 33-35 credits, at the discretion of the affected department, a maximum of up to nine credits of graduate (5000 level or higher) courses may be used by a student in the Accelerated Bachelor’s to Master’s Degree Option for both the graduate and undergraduate degrees; or,

for programs requiring 36 or more credits, at the discretion of the affected department, a maximum of up to twelve credits of graduate (5000 level or higher) courses may be used by a student in the Accelerated Bachelor’s to Master’s Degree Option for both the graduate and undergraduate degrees.

Students must petition to have specific courses (5000 level or above) taken during their undergraduate career apply towards their graduate degree via an Academic Petition.

6. A course with a Pass/No Credit election cannot be applied to the University’s Bachelor’s to Master’s Program.

7. A course with a Pass/No Credit election cannot be applied to the University’s Bachelor’s to Master’s Program.

The Francis College of Engineering participates in the UMass Lowell Bachelor’s to Masters Program and expands this benefit to applicants from other ABET-accredited engineering programs. All applicants from ABET-accredited institutions who meet the UMass Lowell BS/MS admissions criteria may transfer (double count) eligible graduate-level credits taken for the completion of their undergraduate degree program at their home institution to their UMass Lowell (UML) masters degree program. The maximum number of credits to be transferred will be the same as are allowed by UMass Lowell Francis students who graduate from the College of Engineering. Additionally, all Bachelor’s to Masters rules and regulations, including minimum grade requirements, must be met.

Eligibility

Applicants for this expanded program must have a minimum undergraduate cumulative GPA of 3.0 in appropriate engineering majors from other ABET-accredited institutions. As with current admissions policy in Engineering, the GRE may be waived for applicants meeting these criteria (minimum GPA from ABET-accredited engineering program).

Double Counting

Consistent with the current transfer policy, only graduate courses with grades of B or better may transfer. Also consistent with current policy, each department decides whether a course from another institution may or may not fulfill a departmental program requirement.

How to Transition to Bachelor’s to Master’s Programs

Undergraduate students are requested to apply to transition by submitting the application for transition found on the Undergraduate Bachelor’s to Master’s page (https://www.uml.edu/Academics/undergraduate-programs/bachelors-masters.aspx). Students normally apply to transition in the second semester of their third year as an undergraduate (up until the last day of classes in their final semester before graduation).

Francis College of Engineering Expanded Bachelor’s to Master’s Policy
Kennedy College of Sciences

The UMass Lowell Kennedy College of Sciences fosters critical and creative thinking for future solutions to environmental, economic and human problems, while helping students to develop the capacity to respond to a changing world.

A wide range of ongoing research and project opportunities exist within the various degree programs, and interdisciplinary study is emphasized. Graduates of these programs are heavily recruited both regionally and nationally by industry and governmental agencies.

Faculty in the Kennedy College of Sciences (https://www.uml.edu/Sciences/faculty-list.aspx)

NOTE: links to department catalog section at bottom of this page.

Graduate Programs Offered

Master of Science (MS) - degree awarded in the following fields:

- Bioinformatics Science (no longer accepting applications)
- Biotechnology Option
- Education, Communication and Outreach Option (This program does NOT lead to teaching licensure)
- Chemistry
- Computer Science
- Environmental Studies
- Atmospheric Sciences (Concentration)
- Marine Sciences and Technology
- Professional Science Master’s Option (Coastal and Ocean Administration, Science and Technology)
- Mathematics
- Applied Mathematics Option
- Mathematics for Teachers Option
- Probability and Statistics Option
- Scientific Computing Option
- Professional Science Master’s Option (Industrial Mathematics)
- Physics
- Optical Sciences Option
- Radiological Sciences and Protection
- Professional Science Master’s Option (Radiological Protection)

Doctor of Philosophy (PH.D.) - degree awarded in the following fields:

- Chemistry
  - Biochemistry Option
  - Environmental Studies Option
  - Green Chemistry Option
- Computer Science
  - Mathematical Science Option
- Earth System Science
- Marine Sciences and Technology
- Physics
  - Applied Mechanics Option
  - Atmospheric Sciences Option
  - Energy Engineering Option
  - Radiological Sciences Option
- Polymer Science
- Polymer Science/Plastics Engineering Option

Links to Department Sections in This Graduate Academic Catalog:

- Biological Sciences (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Chemistry
- Computer Science
- Environmental, Earth & Atmospheric Sciences
- Marine Sciences and Technology (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Mathematical Science (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
• Radiological Sciences and Protection
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
BIOL.5000 Professional Experience (Formerly 81.500) - Credits: 3

3 Credits will be given to individuals who present evidence of having at least one full year of current experience in an academic, hospital, or industrial laboratory setting, or in secondary school science teaching.

BIOL.5050L Bioinformatics - Credits: 4

There is a growing need for bioinformaticians in research and industry as datasets are getting bigger and more complex, making computational methods necessary for analysis. This hands-on course introduces principles, databases, software, and programming for the analysis and interpretation of molecular datasets. Emphasis is on practical assignments using computational approaches from a biologist’s perspective. Topics include genome assembly, variant detection, comparative genomics and transcriptomics, metagenomics, as well as data retrieval from databases and basic programming using Bash and R. A term project and computer-based exercises are designed to showcase the capabilities and limitations of bioinformatics tools used in genome research, as well as to develop skills in coding literacy.

BIOL.5062 Bioinformatic Tools in Sequence Analysis - Credits: 3

This hands-on course introduces databases, approaches, and software for the analysis and interpretation of molecular sequences. Practical assignments and a term project emphasize the application of computational approaches from a biologist’s perspective. Topics include genome assembly, transcriptomic analysis, and data retrieval from databases using both graphical user interfaces and basic computer programming using Bash and R. The class assignments are all computer-based exercises that are designed to showcase the capabilities and limitations of bioinformatics research and tools used in sequence analysis, as well as to develop skills in coding literacy.

BIOL.5062L Bioinformatic Tools in Sequence Analysis Lab - Credits: 1

This lab accompanies the Bioinformatic Tools in Sequence Analysis lecture, with hands-on practical assignments to achieve a firmer understanding of bioinformatics tools and principles. Assignments and a term project emphasize the application of computational approaches from a biologist’s perspective. Topics include genome assembly, transcriptomic analysis, and data retrieval from databases using both graphical user interfaces and basic computer programming using Bash and R. The class assignments are all computer-based exercises that are designed to showcase the capabilities and limitations of bioinformatics research and tools used in sequence analysis, as well as to develop skills in coding literacy.

BIOL.5072 Data Science for Biologists - Credits: 3

Like many other areas of science and business, biology is increasingly defined by increasing amounts of available data. The ability to analyze, visualize, and make inferences from this data will become increasingly valuable for future biologists. Data science can be defined as the intersection between computer science, applied statistics, and knowledge of the application domain—in this case, biology. In this class we will apply methods such as generalized linear models, multi-level models, unsupervised learning, and basic neural networks to biological problems. Hands-on activities using Python will give students experience with steps of data science project, including simulating, exploring, visualizing, drawing conclusions with statistics, and creating a reproducible analysis.

BIOL.5072L Data Science for Biologists - Credits: 1

Like many other areas of science and business, biology is increasingly defined by increasing amounts of available data. The ability to analyze, visualize, and make inferences from this data will become increasingly valuable for future biologists. Data science can be defined as the intersection between computer science, applied statistics, and knowledge of the application domain—in this case, biology. In this class we will apply methods such as generalized linear models, multi-level models, unsupervised learning, and basic neural networks to biological problems. Hands-on activities using Python will give students experience with steps of data science project, including simulating, exploring, visualizing, drawing conclusions with statistics, and creating a reproducible analysis.

BIOL.5080 Cell Biology for Teachers (Formerly 81.508) - Credits: 3

This online course will examine the structure and function of cells and the regulation of cellular processes characteristics of living organisms. Students will explore the complexity of the eukaryotic cell and gain an understanding of the mechanisms of cellular control and regulation. Course activities will make connections to state frameworks and national standards, and lead to the development of grade-appropriate curriculum materials for use in the elementary and middle school classroom. Class activities will include discussions, quizzes, lesson plans, web reviews, current events, and a final project.

BIOL.5090 Photobiology (Formerly 81.509) - Credits: 3

Biological process involving light in plants and animals. Topics include mechanisms of light absorption, energy transduction, light reactions in photosynthesis, functions of color in flowering plants, visual systems and structural and pigment coloration in animals, pigmentation in animals affecting camouflage and reproductive strategies. In addition, the
genetics involved in responses to light such as photoperiods, circadian rhythms, and seasonal cycles will be covered.

**BIOL.5170 Vertebrate Animals in Biological Research (Formerly 81.517) - Credits: 3**

Vertebrate Animals in Biological Research: History, Protocols, Regulations and Techniques is a lecture, discussion, and techniques based course to cover the principles of vertebrate animal research in biology. This course covers topics ranging from the history of animal research, ethics, regulations, institutional compliance, experimental design, research techniques, disease models, and animal welfare during research. The course will involve literature review and discussions regarding all topics being covered as well as the creation of an IACUC protocol. The protocol will then be reviewed in a mock IACUC meeting. There will also be hands on portions involving research techniques using training analogues and familiarization with animal research tools.

**BIOL.5190 Biochemistry I (Formerly 81.519) - Credits: 3**

Primarily for M.S. students in biological sciences. Lecture and text assignments on the subjects of protein, carbohydrate, lipid, enzyme and membrane biochemistry will be supplemented with research journal readings.

**BIOL.5200 Biochemistry II (Formerly 81.520) - Credits: 3**

This course will focus on protein dynamics where students will gain facility with thermodynamics of protein folding/misfolding, catalysis, kinetics and binding equilibria as they apply to proteins and other molecules in biological systems. The central theme of this course is that living systems can be understood in terms of the fundamental principles defining the structure and energetics of biological molecules. Attention will be given to quantitative aspects of enzyme kinetics and molecular binding. Examples of how these principles apply to the understanding and treatment of human disease will be discussed.

**BIOL.5210L Biochemistry Techniques (Formerly 81.521) - Credits: 2**

Biochemistry Required of M.S. students in the Biotechnology Option. Emphasis on common techniques and instrumentation employed in modern research laboratories.

**BIOL.5225 Advanced Topics in Biochemistry - Credits: 2**

This seminar course will focus on the detailed discussion of structure of proteins and other biological molecules, and how the structure determines the function of biological molecules. Students will be first introduced to each topic by the instructor through a short introductory lecture, then will be assigned to read an original research paper on the topic. During the next class, a group of preassigned students will present the paper to the class, followed by the class discussion of the paper. Students who are not presenting will be expected to read each paper before class, then ask questions and participate in the discussion of that paper during class.

**BIOL.5230 Biology of Global Change (Formerly 81.523) - Credits: 3**

**BIOL.5260 Evolutionary Biology (Formerly 81.526) - Credits: 3**

Lectures deal with the patterns and processes of biological evolution. Covers the history of evolutionary thought, the evidence for evolution, the generation and maintenance of population-level variation, natural selection, adaptation, sexual selection, speciation, phylogenetics, molecular evolution, the fossil record and extinctions. In addition to lecture and textbook material, the course surveys classic and contemporary primary literature from evolutionary biology. A written paper and/or seminar presentation will be required.

**BIOL.5280 Molecular Biotechnology: Recombinant Protein Production (Formerly 81.528) - Credits: 3**

Proteins are major targets of Pharmaceuticals, and are themselves increasingly used as therapeuticals. However both basic research and the pharmaceutical industry depends on availability of purified proteins that are often difficult to isolate from native sources. In this lecture course, students will learn basic and advanced theoretical background in expression and purification of recombinant proteins. It will cover a variety of expression systems, including prokaryotic and eukaryotic cells. The course will also address traditional and new methods in recombinant protein purification. Furthermore, students will be introduced to some downstream applications such as crystallization screens and biochemical/biophysical studies. Student will choose a term project for oral and written presentation.

**BIOL.5290 Recombinant Protein Production Techniques (Formerly 81.429 & 81.529) - Credits: 4**

This course introduces students to the principles and practice of recombinant protein expression and purification’s. Proteins are major targets of pharmaceuticals, and are themselves increasingly used as therapeuticals. However both basic research and pharmaceutical industry depends on availability of purified proteins that are often difficult to isolate from native sources. This course will provide both didactic and
laboratory instruction. It is comprised of a series of lecture and laboratory exercises, with an emphasis on practical techniques and hands-on experience of recombinant protein purification. The course will cover a variety of expression systems, including prokaryotic and eukaryotic cells, and address traditional and new methods in protein purification.

BIOL.5300 Cancer Genomics - Credits: 3
Cancer is usually the result of genetic alterations acquired over a lifetime that enable a tumor to grow and spread. As a result, each tumor is unique and involves a complex combination of mutations--a part of the reason that cancers can be so hard to treat. To better understand the characteristics of these diseases and discover appropriate treatments, institutions have comprehensively profiled the genomic changes across thousands of people’s tumors. That data is available for anyone with the right skills to analyze. In this class, we will delve into the world of the genomics of cancer, as a way to learn how cancers develop, how molecular profiling technologies generate data about these cancers, and how bioinformatics approaches can harness these data to gain insight and discover treatment.

BIOL.5320 Genomics (Formerly 81.532) - Credits: 3
This course surveys the field of genomics, examining current technologies and their biological applications. Lectures cover genome organization, genome sequencing and annotation, functional genomics, evolutionary genomics, transcriptomics, proteomics and the role of bioinformatics in organizing and interpreting genomic data. Students will be expected to submit written papers and to make oral presentations.

BIOL.5340L Genomics Laboratory (Formerly 81.534) - Credits: 1
A series of molecular laboratory and computer-based bioinformatics exercises providing practical experience in the collection and analysis of genomic-level data.

BIOL.5360 Behavioral Ecology - Credits: 3
Animals learn songs, practice agriculture, and craft tools. They build elaborate structures without a blueprint and migrate across the globe without a map. This course explores the mechanistic and evolutionary causes of animal behavior. A combination of lectures, discussions, and animal demos will introduce students to major themes in the field, while emphasizing experiments and ecological context as fundamental to the study of behavior. Students will discuss historic debates and emerging research on the evolution of exaggerated sexual ornaments and defensive structures, sensory bias, heritability of behavior, reciprocity & kinship, and the emergence of animal societies. By the end of the course, students will be able to interpret the behaviors of animals in the evolutionary framework.

BIOL.5370 Biology and Evolution of Arthropoda (Formerly 81.537) - Credits: 3
A detailed examination of phylum Arthropoda from developmental, ecological, genetic, morphological and paleontological perspectives. Specific topics include arthropod origins and relationships to proto-arthropods, the evolution of segmentation, and current perspectives on relationships within the phylum.

BIOL.5380 Advanced Genetic Analysis - Credits: 3
This course explores fundamental concepts in classical and molecular genetics. We will examine how studies in genetic model organisms (including budding yeast, Drosophila, and C. elegans) have yielded remarkable insight into a host of biological mechanisms, including cell-signaling pathways, animal development, and gene regulation. Special emphasis will be placed on how geneticists design and interpret their studies. The semester will cover strategies ranging from the classical (screens, selection, complementation, and conditional mutants) to the modern approaches enabled by the genomic revolution (genetic engineering, gene misexpression, and genome-wide association studies).

BIOL.5390L Biology and Evolution of Arthropoda (Formerly 81.539) - Credits: 1
An exploration of protoarthropod and arthropod diversity using live and preserved specimens of the major taxa including Tardigrada, Onychophora, Chelicerata, Crustacea, Myriapoda and Hexapoda. Students will learn to collect, dissect, identify, handle and care for live specimens.

BIOL.5420 Advanced Cell Biology (Formerly 81.542) - Credits: 3
This is an advanced course in cell biology. In this course we will examine different areas of eukaryotic cell biology including: membrane structure and function, cell adhesion, intercellular communication, signal transduction, chemotaxis, receptor-mediated endocytosis and intracellular trafficking. Mechanisms underlying relevant human diseases will also be discussed. Upon completion of the course the student will have a strong understanding of cell biology, develop critical thinking processes, proficiency in scientific reading and how to communicate material succinctly.

BIOL.5470 Evolution in Context for Teachers (Formerly 81.547) - Credits: 3
This course empowers life science teachers of all levels with the skills and knowledge to more effectively foster student understanding of evolution by natural selection. By exploring
evolution in multiple contexts, the Darwinian framework for how life evolved (and continues to evolve) are presented in an interactive and engaging manner. Teachers learn to use virtual resources to enhance their students learning while digging deep into some of the most profound and interesting science conducted in the last 100 years. Evolution in context makes the science of evolution come alive in a real and relevant manner. From the historical and scientific to the environmental and political, Teachers will learn about evolution in ways they never imagined.

**BIOL.5480 Form Feeds Function in Vertebrate Evolution - Credits: 4**

This course will provide you with a solid comparative knowledge of how vertebrates including humans have evolved, focusing on how anatomy (form) feeds function (physiology, biomechanics) in movement biology (cardiorespiratory, sensing, locomotion, feeding). It is only by understanding our evolutionary history that you understand e.g. how vertebrates became Olympian movers, how humans became bipedal, why we use parts of the ancestral jaw to hear, and how we avoid choking when we swallow. Such knowledge is key for medical and veterinary school, but will also support you in biomedical and biotechnology fields as well as in various general science disciplines. This course emphasizes modes of thought, including the differences between evidence and inference, and between correlation and causality.

**BIOL.5490L Biology of Muscle - Credits: 4**

This course takes integrative approaches to exploring architecture, physiology and mechanics of vertebrate skeletal muscle as the main driver of movements in organisms including humans. Combining presentations and discussions of important publications with simple experiments and report-writing, the course hones a specialist-level understanding of how the organ structure is constructed, how cell-level phenomena govern contraction, how the nervous system controls muscle function, how muscle contractions are constrained by physics, and how muscle as an organ structure is able to mitigate those constraints. We will also build and use actuators inspired by muscle function.

**BIOL.5550 Entomology - Credits: 3**

This course explores the diversity, evolution, and behavior of insects. Insects are pollinators, undertakers, and parasites. They are master architects, and the inventors of flight and agriculture. Their societies can tower over elephants or fit in the palm of your hand. Plagues of locusts have shaped human history and wars have been won on the backs of fleas. This course emphasizes natural history as the foundation of innovation in entomology. Students will develop a solid understanding of the principles of insect biology that can be applied to medical, forensic, veterinary, agricultural, conservation and academic fields.

**BIOL.5550L Entomology Lab - Credits: 1**

This laboratory focuses on insect classification, development and behavior. Students will travel to local field sites to study and collect insects. Each student will curate a professional insect collection and develop a working knowledge of insect taxonomy through dissection and comparison of preserved specimens, including economically and medically important insects. Students will also rear a variety of social and solitary insects under experimental conditions and report their results. Labs on behavior will focus on insect communication, parental care, eusociality, and orientation.

**BIOL.5570 Metazoan Parasitology (Formerly 81.557) - Credits: 3**

An introduction to the diversity of metazoans (animals) that parasitize humans, livestock, other animals (both vertebrate and invertebrate), and plants. Lectures emphasize the morphology, form and function, physiology, systematics, evolution, lifecycles and pathogenesis of several major parasitic groups.

**BIOL.5590L Metazoan Parasitology Laboratory (Formerly 81.559) - Credits: 1**

The purpose of the laboratory is to provide students an opportunity to identify and work with a variety of parasites that we discuss in lecture. We will work with preserved specimens, slide material, necropsies, and live specimens. Students will learn how to identify parasites and appreciate where they live in the vertebrate body.

**BIOL.5600 Stem Cell Biology (Formerly 81.560) - Credits: 3**

The molecular and genetic characteristics of stem cells and their developmental potential will be explored. Lectures and readings will cover the development of embryonic, fetal and adult stem cells, and will examine their use in treating human disorders receiving widespread attention, including neurodegenerative diseases, heart disease, spinal cord injury and leukemia. The ethical, legal and social implications of stem cell research will also be discussed. Additional library investigation and a term paper or seminar will be required.

**BIOL.5620 Cardiovascular Physiology (Formerly 81.562) - Credits: 3**

This course will focus on human cardiovascular physiology in normal and diseased states. The objective of Cardiovascular Physiology is to reinforce the concept that that the
cardiovascular system can be understood in terms of fundamental biophysical and cellular physiological principles. Quantitative aspects will be reinforced with problem sets in the accompanying lab course 81.563. Key concepts in the course will be placed in a medical context showing the underlying physiological concepts that lead to disease states such as: altered blood pressure, heart failure, valvular disease and arrhythmias.

**BIOL.5630L Cardiovascular Physiology Lab (Formerly 81.563) - Credits: 1**

Cardiovascular Physiology Lab is designed to supplement Cardiovascular Physiology 81.562. The objective of the course is to teach cardiovascular system function using problem sets as well as clinical and pathophysiological examples.

**BIOL.5670 Molecular Biology (Formerly 81.567) - Credits: 3**

A study of the principles and specialized techniques of cloning, purifying, and manipulating recombinant DNA molecules.

**BIOL.5690L Molecular Techniques (Formerly 81.569) - Credits: 4**

Laboratory experiments and independent projects designed to illustrate current techniques and instrumentation used in genetic engineering. Included are restriction mapping, cloning, plasmid purification, blot hybridization, and DNA sequencing. Students are introduced to computer software utilized for DNA sequence analysis and manipulation.

**BIOL.5720 Virology (Formerly 81.572) - Credits: 3**

A study of bacterial, animal, and plant viruses, including viral structure, modes of replication, biochemistry of the infected cell, genetic properties, and viral oncogenesis. Emphasis is on virus-cell interaction at the molecular level.

**BIOL.5760 Cell Culture (Formerly 81.576) - Credits: 4**

A series of lecture and laboratory exercises that will focus on the in vitro culture and analysis of multiple cell type commonly used in biomedical research laboratories. The lecture component will review methodologies used to establish immortalized cell lines, medium component for specific cell types, and techniques for genetically manipulating and analyzing cell lines. The laboratory exercises will emphasize the mastery of sterile techniques used to grow both established cell line and primary cultures, and molecular tools used for introducing recombinant genes and for analyzing cell growth and differentiation.

**BIOL.5800 Developmental Biology (Formerly 81.580) - Credits: 3**

An in depth discussion of contemporary topics related to reproduction and embryogenesis. Lecture material is supplemented with reading assignments in a recently published textbook and current literature taken from research journals. Emphasis is on the dynamic nature of the interactions between developing cells as well as the events that occur during fertilization, implantation, and the development of the mammalian embryo which lead to birth. Students examine how studies with nonmammalian model systems such as Drosophila and Xenopus have enhanced our knowledge of mammalian development. Among the topics discussed are the role of adhesion molecules, HOX genes, apoptosis, hypomethylation of genes, axis formation and hormonal control of differentiation. Class participation is expected. Critical scientific reading and thinking is encouraged by having students present to the class published original research papers on topics of current interest in the field of developmental biology.

**BIOL.5810L Developmental Biology Lab - Credits: 1**

This course provides hands on experience in current methods and model systems used to investigate questions in developmental biology. Students will be exposed to a wide variety of embryonic systems, including intensively studied genetic model systems (e.g., C. elegans, zebrafish, mouse) and others with well-established experimental attributes (e.g., chick, sea urchin). Analytical and experimental techniques used to explore invertebrate and vertebrate development include embryological manipulation, molecular and cell biology approaches. Conceptual topics include cell specification and differentiation, pattern formation, morphogenesis, and comparative embryology. This lab supplements the Developmental Biology lecture (BIOL.5800).

**BIOL.5820 Cancer Biology (Formerly 81.582) - Credits: 3**

A study of the genes and proteins implicated in the cause of human cancer and discussion of the complex behaviors of cancer cells that differ from their normal counterparts in human tissue. Lectures and original research papers will be used.

**BIOL.5840 Comparative Vertebrate Embryology - Credits: 3**

A comparative study of vertebrate embryological development focusing on the morphological development (e.g., Differentiation of tissues, organs, and systems) of vertebrates. Evolutionary relationships of the classes of vertebrates will be investigated through their anatomy. This course builds on
concepts taught in Developmental Biology, providing more detailed analysis of tissue development in a comparative context.

**BIOL.5860 Experimental Design and Analysis in Life Science - Credits: 3**

Through discussion of practical issues arising in biology research, reading of the literature and performing applied exercises students will move principles of sound experimental design, analysis and presentation from their "recognition vocabulary" to their "active vocabulary". The objective is for students successfully completing this course to be able to serve as a statistical consultant for researchers (including themselves) wishing to conduct experiments requiring moderately complex statistical designs.

**BIOL.5880 Structural Biology (Formerly 81.588) - Credits: 3**

Structural basis of the molecular biology of cells and the regulation of cellular processes will be discussed. This course will cover the fundamental knowledge about protein, nucleic acid and membrane structure in relation to central systems in biology. Topics to be discussed include structural enzymology, macromolecular assemblies for replication, transcription, translation, membrane proteins, signal transduction, cell motility and transport, cell-cell interactions, the immune system, and virus structure. Students will choose a recently published primary research article for an oral presentation, and will lead a class discussion on that topic.

**BIOL.5890 Practical Protein Crystallography (Formerly 81.589 & 81.489) - Credits: 4**

This course provides grounding in the principles and practice of protein x-ray crystallography. The course will be unique in format and provide both didactic and laboratory instruction. It is comprised of a series of lecture and laboratory exercises, with an emphasis on practical techniques and hands-on experience of modern protein crystallography. The course will cover the fundamental knowledge about x-ray physics, instrumentation and geometrical diffraction, protein crystallization, macromolecular data collection and processing, phase estimation and improvement, model building and refinement, and model assessment. Student will also be given a recently published structural paper for writing a report on the subject.

**BIOL.5892 Crystallography and Structural Bioinformatics - Credits: 3**

This course provides grounding in the principles and practice of protein x-ray crystallography, with some applications in structural bioinformatics and drug discovery. This course is comprised of a series of lecture with an emphasis on practical methodologies of modern protein crystallography and structural bioinformatics. The course will cover the fundamental knowledge about x-ray physics, instrumentation and geometrical diffraction, protein crystallization, macromolecular data collection and processing, phase estimation and improvement, model building and assessment, and some exploration of bioinformatics tools employed in molecular docking and virtual screening.

**BIOL.5894L Crystallography and Structural Bioinformatics Lab - Credits: 1**

This lab course provides grounding in the principles and practice e-ray crystallography, with some applications in structural bioinformatics and drug discovery. It covers topics correlated with the co-requisite lecture course BIOL.5892.

**BIOL.5940 Immunology II, Current Topics - Credits: 3**

This course will focus on recent advances in the field of immunology including the study of immune development and activation, response to infection, vaccines, immunoregulation, cancer immunotherapy, and immune dysfunction. Expanding upon the foundational immunologic concepts covered in BIOL.4930/BIOL.5930, students will gain knowledge of the innate and adaptive immune system at the structural, molecular, cellular, and functional levels. The objectives of Advanced Topics in Immunology are to gain a comprehensive and practical understanding of current immunological principles in research and clinical/applied sciences, learn to critically read and evaluate scientific literature, learn to interpret data, and design experiments that rigorously test hypotheses.

**BIOL.5945 Host-Pathogen Interactions - Credits: 3**

This transdisciplinary course will examine the interface between pathogens and their hosts a multiple levels. We will begin with molecular and cellular interactions between host and pathogen species and will expand to include ecological patterns, behavioral biology, and host-pathogen co-evolution. Following an introduction to infectious disease, microbiology, and immunology, we will critically read and evaluate scientific literature. The objectives of Host-Pathogen Interactions are to gain a comprehensive and practical understanding of host-pathogen dynamics, patterns of disease ecology, and host-pathogen co-evolution. Students will learn to critically read and evaluate scientific literature, interpret data, and design experiments.

**BIOL.6030 Graduate Colloquium Biology (Formerly 81.603) - Credits: 1**

Presentations of current topics by visiting scientists and staff.
Required of all graduate students.

**BIO**L.6040 Professional Communication in Science and Technology (Formerly 81.604) - Credits: 3

The course instructs students in developing effective writing and speaking skills required for preparation of publishable scientific manuscripts and presentations. The importance of clear, concise writing style and delivery of presentations to both research, scientists and non-scientists is emphasized. Guest speakers discuss commercialization of technology, intellectual property, and electronic literature searches/citation. Experimental design, statistical analyses, research grant preparation, and poster presentations are also reviewed. Outside readings are used to critically evaluate contemporary issues related to disclosure, conflict of interest, publishing ethics, biosecurity, and electronic science collaborations/team research.

**BIO**L.6050 Graduate Proposal Writing Seminar - Credits: 1

The primary purpose of this course is to enable students to apply their broad biological sciences perspectives and intellectual skills to solve complex problems and to catalyze new discoveries. To achieve these goals, students will gain effective skills in preparing professional proposals. Key concepts in the course highlight hypothesis formation and proposal development. This approach will help bridge the gap between classroom-based and research-based curriculum components of the Applied Biology PhD program. Exposure to the diverse range of specialties represented by students studying in the biological sciences field will enrich and diversify student knowledge.

**BIO**L.6060 Applied Biology I - Credits: 1

This is the first in a two-semester sequence of courses that will introduce students to the range of research topics being addressed at UMass Lowell as well as to professional applications of Biology. Applied Biology is at the forefront of scientific research and technological development and underpins a number of growing industries. This course will provide an opportunity for students to learn about key areas in Applied Biology including Microbiology, Biochemistry, Biotechnology, Genetics, Evolution, and Healthcare. To achieve these objectives this course will be divided into three topic blocks (4-5 weeks each) where a faculty member will provide a didactic overview of that topic, and will then bring in guest lecturers who will use half the class time.

**BIO**L.6070 Applied Biology II - Credits: 1

This is the second course in a two-semester sequence of courses that will introduce students to the range of research topics being addressed at UMass Lowell as well as to professional applications of Biology. Applied Biology is at the forefront of scientific research and technological development and underpins a number of growing industries. This course will provide an opportunity for students to learn about key areas in Applied Biology including Microbiology, Biochemistry, Biotechnology, Genetics, Evolution, and Healthcare. To achieve these objectives this course will be divided into three topic blocks (4-5 weeks each) where a faculty member will provide a didactic overview of that topic, and will then bring in guest lecturers who will use half the class time.

**BIO**L.6660 Selected Topics in Molecular and Cellular Biology (Formerly 81.666) - Credits: 3

Topics will focus on the central dogma of molecular Biology (DNA to RNA to protein) and how they relate to the structure and function of the cell. Course material will be taken directly from the current, primary literature with emphasis on student presentations and discussion. Multidisciplinary groups will select topics of interest to present to the class, and topics will vary by semester depending on student interests. Student groups will be expected to organize presentations into background and discussion sections and will lead class discussions.

**BIO**L.7070 Internship Biology (Formerly 81.707) - Credits: 1

**BIO**L.7080 Graduate Course Review (Formerly 81.708) - Credits: 1

Internship or co-op.

**BIO**L.7100 Supervised Instruction in Undergraduate Biology Education - Credits: 1-3

Graduate students will assist with the preparation of course materials, teaching and/or grading in selected courses offered by the Department of Biological Sciences. Students will be expected to work well independently, while also working under the supervision of a faculty mentor. Through these activities, the student will learn about materials used, as well as teaching and learning techniques implemented in undergraduate biology education. Required for the MS in Biological Sciences option: Education, Communication, and Outreach.

**BIO**L.7210 Special Problems In Biology (Formerly 81.721) - Credits: 1-3

**BIO**L.7310L M.S. Project in Biology (Formerly 81.731) - Credits: 1-9

**BIO**L.7430 Master’s Thesis - Biology (Formerly 81.743) - Credits: 1-9
BIOL.7530 PhD Dissertation Biological Sciences
(Formerly 81.753) - Credits: 1-9
BIOL.7590 PhD Dissertation Biochemistry (Formerly
81.759) - Credits: 9
BIOL.7690 Continued Graduate Research (Formerly
81.769) - Credits: 9
Department of Chemistry

The following graduate programs are offered:

- **Doctor of Philosophy in Chemistry**
  Specializations include: Analytical, Inorganic, Organic, Physical
  Option in Biochemistry, Option in Environmental Studies, Option in Polymer Science or Polymer Science/Plastics Engineering

- **Master of Science in Chemistry**
  Specializations include: Analytical, Biochemical, Inorganic, Materials, Organic, Physical, Polymer Science

- **Master of Science in Chemistry - Professional Science Master's (PSM) Options**
  Specializations: Chemistry and Polymer Science, Pharmaceutical Biochemistry

- **Graduate Certificates**
  Chemistry

6. Students not meeting these requirements are invited to enroll in the Graduate Certificate Program (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf) and reapply.

**Master's Programs in Chemistry**

Specializations are offered in analytical, biochemistry, inorganic chemistry, material chemistry, organic chemistry, physical chemistry, and polymer science. This program provides opportunity for advanced study and research training in chemistry, both general and specialized. Provision also is made for the student to elect certain advanced subjects in related fields of mathematics, physics, and engineering.

The Department of Chemistry also offers two Professional Science Master’s Options in Chemistry (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf) (one in chemistry and polymer science and the other in pharmaceutical biochemistry) which have different requirements than those outlined below.

**Program General Requirements for all Chemistry MS:**

- **Masters Degree with a research thesis:**
  - Taking courses including at least 3 different specializations of chemistry
  - 30 credits 6 courses of 3 credits each (graduate level courses of 5000 level or higher) And 4 courses/12 credits of research
  - GPA >/= 3.0
  - Selection and fulfillment of one of the following specializations

- **Masters Degree without a thesis, by course work only:**
  - Taking courses including at least 3 different specializations of chemistry
  - 30 credits 10 courses of 3 credits each (graduate level courses of 5000 level or higher) GPA >/= 3.0
  - Selection and fulfillment of one of the following specializations

**Requirements / Chemistry Program Specializations:**

**Analytical Chemistry Option:**
REQUIRED two of the following courses:

- CHEM.5140
  (https://www.uml.edu/catalog/courses/CHEM/5140)
  Advanced Analytical Chemistry
- CHEM.5260
  (https://www.uml.edu/catalog/courses/CHEM/5260)
  Chromatography
- CHEM.5130
  (https://www.uml.edu/catalog/courses/CHEM/5130)
  Spectroscopy
- CHEM.5800
  (https://stace.uml.edu/catalog/courses/CHEM/5800)
  Advanced Analytical Biochemistry

and two courses of the following:

- [CHEM.5230](https://www.uml.edu/catalog/courses/CHEM/5230)
  Organic Reaction Mechanism
- or CHEM.5680
  (https://www.uml.edu/catalog/courses/CHEM/5680)
  Structural Analysis
- CHEM.5320
  (https://www.uml.edu/catalog/courses/CHEM/5320)
  Advanced Physical Chemistry
- CHEM.5500
  (https://www.uml.edu/catalog/courses/CHEM/5500)
  Biochemistry I
- CHEM.5430
  (https://www.uml.edu/catalog/courses/CHEM/5430)
  Modern Inorganic Chemistry
- CHEM.5221
  (https://www.uml.edu/catalog/courses/CHEM/5221)
  Solid State Materials Chemistry
- CHEM.5660
  (https://www.uml.edu/catalog/courses/CHEM/5660)
  Nanomaterials and Nanostructures

For an MS with thesis, include 12 credits (4 courses) of laboratory research.

For an NTMS without thesis, choose any 4 graduate (5000 level or higher) chemistry courses (worth the final 12 credits to complete 30 credits)

Biochemistry Option:
Required:

- CHEM.5500
  (https://www.uml.edu/catalog/courses/CHEM/5500)
  Biochemistry
- CHEM.5510
  (https://www.uml.edu/catalog/courses/CHEM/5510)
  Biochemistry II
- CHEM.5600
  (https://www.uml.edu/catalog/courses/CHEM/5600)
  Advanced Physical Biochemistry
- CHEM.5670
  (https://www.uml.edu/catalog/courses/CHEM/5670)
  Computational Chemistry
- CHEM.5700
  (https://www.uml.edu/catalog/courses/CHEM/5700)
  Protein Biochemistry

and any three courses of the following:

- CHEM.5680
  (https://www.uml.edu/catalog/courses/CHEM/5680)
  Structural Analysis
- CHEM.5140
  (https://www.uml.edu/catalog/courses/CHEM/5140)
  Advanced Analytical Chemistry
- CHEM.5260
  (https://www.uml.edu/catalog/courses/CHEM/5260)
  Chromatography
- CHEM.5230
  (https://www.uml.edu/catalog/courses/CHEM/5230)
  Organic Reaction Mechanisms
- CHEM.5800
  (https://www.uml.edu/catalog/courses/CHEM/5800)
  Advanced Analytical Biochemistry
For an MS with thesis, include 12 credits (4 courses) of laboratory research. For an NTMS without thesis, choose any 4 graduate (5000 level or higher) chemistry courses (worth the final 12 credits to complete 30 credits)

Inorganic Chemistry Option

Required:

- CHEM.5430 (https://www.uml.edu/catalog/courses/CHEM/5430) Modern Inorganic Chemistry
- CHEM.5320 (https://www.uml.edu/catalog/courses/CHEM/5320) Advanced Physical Chemistry
- CHEM.5130 (https://www.uml.edu/catalog/courses/CHEM/5130) Spectroscopy
- CHEM.5221 (https://www.uml.edu/catalog/courses/CHEM/5221) Solid-State Materials Chemistry

and two courses of the following:

- CHEM.5140 (https://www.uml.edu/catalog/courses/CHEM/5140) Advanced Analytical Chemistry
- CHEM.5500 (https://www.uml.edu/catalog/courses/CHEM/5500) Biochemistry I
- CHEM.5510 (https://www.uml.edu/catalog/courses/CHEM/5510) Biochemistry II
For an MS with thesis, include 12 credits (4 courses) of laboratory research and choose any 1 graduate (5000-level or higher) chemistry course (worth the final 3 credits to complete 30 credits)

For an NTMS without thesis, choose any 4 graduate (5000 level or higher) chemistry courses (worth the final 15 credits to complete 30 credits)

Organic Chemistry Option:

Required:

- CHEM.5230 (Organic Reactions, Mechanisms)
- CHEM.5680 (Structural Analysis)
- CHEM.5850 (Modern Organic Chemistry)

and at least two courses from the following:

- CHEM.5240 (Organic Synthesis)
- CHEM.5320 (Advanced Physical Chemistry)
- CHEM.5500 (Biochemistry I)
- CHEM.5430 (Modern Inorganic Chemistry)
- CHEM.5660 (Nanomaterials and Nanostructures)

For an MS with thesis, include 12 credits (4 courses) of laboratory research and choose any 1 graduate (5000-level or higher) chemistry course (worth the final 3 credits to complete 30 credits)

For an NTMS without thesis, choose any 4 graduate (5000 level or higher) chemistry courses (worth the final 15 credits to complete 30 credits)

Physical Chemistry Option

Required:

- CHEM.5320 (Advanced Physical Chemistry)
- CHEM.5130 (Spectroscopy)
- CHEM.5340 (Quantum Chemistry)

and at least two courses from the following:

- CHEM.5360 (Advanced Materials Chemistry I)
- CHEM.5221 (Solid-State Materials Chemistry)
- CHEM.5660 (Nanomaterials and Nanostructures)
- CHEM.5950 (Supermolecular Chemistry)
- CHEM.5230
Advanced Physical Chemistry
- CHEM.5230
  (https://www.uml.edu/catalog/courses/CHEM/5230)
Organic Reaction Mechanisms
- CHEM.5430
  (https://www.uml.edu/catalog/courses/CHEM/5430)
Modern Inorganic Chemistry
- POLY.5040
  (https://stage.uml.edu/catalog/courses/POLY/5040) Advanced Polymer Science II

For an MS with thesis, include 12 credits (4 courses) of laboratory research and choose any 1 graduate (5000-level or higher) chemistry course (worth the final 3 credits to complete 30 credits)

For an NTMS without thesis, choose any 4 graduate (5000 level or higher) chemistry courses (worth the final 15 credits to complete 30 credits)

Polymer Science Option

Required:

- POLY.5030
  (https://www.uml.edu/catalog/courses/POLY/5030) Advanced Polymer Science I
- POLY.5040
  (https://www.uml.edu/catalog/courses/POLY/5040) Advanced Polymer Science II
- POLY.5050
  (https://www.uml.edu/catalog/courses/POLY/5050) Polymer Preparation and Characterization
- POLY.5110
  (https://stage.uml.edu/catalog/courses/POLY/5110) Biopolymers

and two courses of the following:

- CHEM.5680
  (https://www.uml.edu/catalog/courses/CHEM/5680) Structural Analysis
- CHEM.5320
  (https://www.uml.edu/catalog/courses/CHEM/5320)
- POLY.5030
  (https://www.uml.edu/catalog/courses/POLY/5030) Advanced Polymer Science I
- CHEM.5680
  (https://www.uml.edu/catalog/courses/CHEM/5680) Structural Analysis
- POLY.5110
  (https://stage.uml.edu/catalog/courses/POLY/5110) Biopolymers
- POLY.60
  (https://www.uml.edu/catalog/courses/POLY/6070)0/6020 - Polymer Science Seminar
- POLY.6030
  (https://www.uml.edu/catalog/courses/POLY/6030)/6040 - Polymer Science Colloquium
- POLY.7430/7460/7490

For an MS with thesis, include 12 credits (4 courses) of laboratory research.

For an NTMS without thesis, choose any 4 graduate (5000 level or higher) chemistry courses (worth the final 12 credits to complete 30 credits)

And Polymer Seminar:

Each semester the student is required to attend and participate in the chemistry seminar/colloquium program CHEM.6010, 6020, 6030 and 6040. In addition, a master’s candidate is required to present one seminar in 6020 - Polymer Science Seminar.

Although the design of the academic program is the responsibility of the student’s advisory committee, the following listing provides recommended courses for program development.

First Semester Subjects
Thesis Advisory Committee

An advisory committee should be selected jointly by the student and advisor at the earliest possible opportunity. A minimum of three (3) faculty members are required for the master’s thesis committee. The student’s advisor will serve as the chairperson of this advisory committee. The purpose of this committee is twofold. First, it will be responsible for ascertaining that the student’s research was conducted and presented in final form, in a professional and acceptable manner. Perhaps of more importance, the committee will serve in an advisory capacity during the course of the research project. In this spirit it is recommended that the student convene a meeting of the selected committee prior to starting his/her research. The purpose of this meeting is to informally present an outline of the proposed research project.

Non-Thesis Masters in Chemistry (NTMC)

This program provides opportunity for advanced study in chemistry that must include at least three of the following areas: analytical chemistry, biochemistry, inorganic chemistry, organic chemistry, physical chemistry, or polymer chemistry.

Credit Requirements

The NTMC degree requires 30 credits (10 courses). The following NTMC requirements must be met:

1. A total of 18 course credits (CHEM or POLY prefix) must be taken within the Chemistry Department at University of Massachusetts Lowell.

2. The remaining credits may be satisfied by either additional CHEM or POLY courses or by transfer of up to 12 credits from a closely related program at a domestic university, including University of Massachusetts Lowell.

Note: Students who wish to pursue the NTMC degree who currently hold a B.S. or B.A. degree in chemistry or a related science, but do not have previous laboratory experience, may be required to take up to three undergraduate chemistry laboratory courses to ensure that they have sufficient laboratory skills upon completion of their NTMC degree.
CHEM.5130 Spectroscopy (Formerly 84.513) - Credits: 3
This course covers both basic theory and practical applications of modern photon, electron, and X-ray spectroscopies. The techniques covered will include infrared, Raman, visible, circular dichroism, UV, X-ray photoelectron, and X-ray absorption spectroscopies. Qualitative and quantitative applications of these methods to chemistry (organic and inorganic), materials, catalysis, and biochemistry will be discussed.

CHEM.5140 Advanced Analytical Chemistry (Formerly 84.514) - Credits: 3
Designed to provide graduate students and senior undergraduate students with an understanding of the principles and the theory of analytical measurements and instrumentation. The course is divided into three sections consisting of a) analytical measurements including potentiometry and voltammetry, b) spectrophotometric measurements (i.e. molecular spectrometry), and c) ionic equilibria and statistics. This course is required for graduate programs in Analytical Chemistry and Environmental Studies (Ph.D.) and is recommended for students in other graduate programs such as Biology, Biochemistry and Environmental Studies (MS) and other areas of chemistry.

CHEM.5190 Environmental Chemistry (Formerly 84.519) - Credits: 3
Covers chemical processes and measurements in marine and estuarine systems. Emphasis is placed on water column processes; however, air-water and sediment-water interface phenomena are covered as well. Topics include but are not limited to: ionic equilibria, trace metal complexation, redox processes, mathematical modeling applied to chemical systems, and oceanographic sampling.

CHEM.5220L Organic Synthesis and Characterization Laboratory - Credits: 3
An advanced project-based organic chemistry laboratory course. Students will separate mixtures of compounds by chromatographic methods, elucidate structures using spectroscopic techniques and consult the chemical literature to design and execute a multi-step synthesis. Students will also propose a multi-step synthesis of a compound of interest. Emphasis on laboratory work with a discussion of theoretical background.

CHEM.5210 Solid-State Materials Chemistry - Credits: 3
This course is an introductory course to materials and solid-state chemistry for graduate students. Topics covered include the electronic and optical properties of solids, the properties of metals and semiconductors, optical properties of materials and their physical origins, and special topics in nanomaterials and materials science. Qualitative and quantitative applications of these materials will be included for energy, electronics, batteries, lighting, catalysis, and coatings.

CHEM.5230 Organic Reaction Mechanisms (Formerly 84.523) - Credits: 3
The course is designed to provide an advanced understanding of the principles controlling structure/reactivity and the experimental techniques used to elucidate the mechanisms of modern organic reactions. The material covered includes: molecular orbital theory applied to bonding and reactivity, stereoelectronic and conformational effects, intermolecular interactions, potential energy surfaces, reaction kinetics, reaction mechanisms, catalytic methods, pericyclic reactions, and photochemistry. Introductory applications of computational chemistry are covered. The course is open to undergraduate students (with permission) interested in a stronger foundation in organic reactions.

CHEM.5240 Organic Synthesis (Formerly 84.524) - Credits: 3
Mechanism, scope and limitations of important selected types of reactions and design of synthetic sequences. Emphasis is placed on methodology of synthesis and current literature.

CHEM.5260 Chromatography (Formerly 84.526) - Credits: 3
Coverage includes the components, theory and performance of chromatographic separations including packed and capillary gas chromatography (GC) and high performance liquid chromatography (HPLC). Modern injectors, detectors, pumping systems, and other hardware used in chromatography are also discussed in detail.

CHEM.5320 Advanced Physical Chemistry (Formerly 84.532) - Credits: 3
Extension of introductory physical chemistry. Open to undergraduates and graduate students in chemistry and related fields. Emphasis is placed on classical and statistical thermodynamics; surface and colloid chemistry; and electronic and vibration-rotation spectra.

CHEM.5340 Quantum Chemistry - Credits: 3
This course will start with the basics of Quantum Mechanics.
and Quantum Chemistry followed by use of the molecular modeling software GAUSSIAN. Topics to be covered include: Schrödinger equation and wave functions; Particle in a box; Particle in a ring; Heisenberg uncertainty principle; QM operators, Eigenvalue problem; Eigenvectors Eigenvectors; Hermitian operators and commutators; Harmonic oscillator & IR spectroscopy; Rigid Rotator & Rotational Spectroscopy; H-atom, H2+ion; using Mathematics to solve QM problems (e.g. atomic/molecular orbitals visualization), He-atom and variational method; Electron spin and Pauli exclusion principle; EPR/NMR; Semiempirical methods; Many-electron systems; Slater Determinants, Hartree and Hartree-Fock methods; Diatomic molecules; Born-Oppenheimer approx.

CHEM.5360 Advanced Materials Chemistry I - Credits: 3

This course covers the concepts, principles, and applications of physical properties of organics- and polymer-based materials. In a broad sense, organic electronics and photonics, as a modern research and technology field, encompass both molecular organics and polymers in design, synthesis, and fabrication processes in the light of device application. For the practical purpose, this course discusses a collection of technologies that include conducting organics and polymers, organic light emitting diodes (OLED), organic photovoltaics (OP), dye sensitized solar cells (DSSC), nonlinear optical (NLO) two-photon absorption (2PA) chromophores, electro-optical (EO) polymers, and photodynamic therapeutic (PDT) and antibacterial inactivation (aPDI) drugs.

CHEM.5380 Biochemical Mechanisms (Formerly 84.538) - Credits: 3

Discussion of various biochemical reactions from the point of view of organic reaction mechanisms. Kinetics, coenzymes and methods of the study of enzyme and catalysis and mechanisms are emphasized.

CHEM.5430 Modern Inorganic Chemistry (Formerly 84.543) - Credits: 3

A theoretical treatment of atomic structure and chemical bonds, included are such topics as Russell Saunders’ coupling, molecular orbital theory, ligand field theory, and descriptive coordination chemistry.

CHEM.5500 Biochemistry I (Formerly 84.550) - Credits: 3

An advanced study of the structure and properties of proteins, nucleic acids, carbohydrates and lipids, including kinetics and mechanisms of enzyme action and detailed description of metabolic pathways of carbohydrates and lipids.

CHEM.5510 Biochemistry II (Formerly 84.551) - Credits: 3

A continuation of 84.550 with emphasis on metabolic pathways of amino acids and nucleic acid, biosynthesis of proteins and selected topics in molecular biology and various areas of biochemistry.

CHEM.5550L Laboratory in Modern Biochemistry and Biophysics - Credits: 2

This is a laboratory course designed to teach basic biochemical techniques using a series of well-characterized proteins in a research-like setting. The course will meet twice a week throughout the semester. The first half of the semester will be focused on teaching specific biochemical techniques. In the second half of the semester, students will develop an independent research question using protein(s) from a list using the techniques that were learned in the first half of the semester. Students will produce a report using an ACS Journal style based on their results and they will also present their results to the class at the end of the semester. Students will also prepare a review on the protein that they are using for their independent project.

CHEM.5600 Advanced Physical Biochemistry (Formerly 84.560) - Credits: 3

Physical chemistry encompasses a group of principles and methods helpful in solving many different types of problems. This course will present selected principles of thermodynamics, kinetics, statistical thermodynamics and quantum mechanics as they are applied to biochemical systems. Various experimental techniques will be strongly emphasized in view of their importance in biochemical research.

CHEM.5620 Biopharmaceutical Development (Formerly 84.562) - Credits: 3

Pharmaceutical Biochemistry examines the biochemical and molecular mechanisms of drug interaction. Topics include basic aspects of molecular complementarity (molecular recognition), specificity and stability of ligand binding (energetic), as well as crystallographic and computational approaches.

CHEM.5630 Chemistry Of Natural Products (Formerly 84.563) - Credits: 3

Covers the proof of structure of various types of natural products, approaches to the total synthesis of these products and the biosynthetic pathways.

CHEM.5660 Nanomaterials and Nanostructures
(Formerly 84.566) - Credits: 3
Nanoscience and nanotechnology focus on the understanding and control of matter at the dimension of 1-100 nanometers, i.e., the nanoscale. Nanoscale structures, materials and devices have unique properties and functions solely because of their sizes. Research and technology development in nanoscience and nanotechnology aim at understanding the fundamental nanoscale phenomena, synthesizing, fabricating and imaging nanomaterials and nanostructures, and constructing nanoscale systems that offer unprecedented properties and functions. In this course, we will discuss the fundamental nanoscale phenomena. We will learn variety of nanomaterial characterization techniques including scanning probe, electron probe, absorption and particle spectroscopies. Fabrication processes of top-down and bottom-up approaches will be discussed, including molecular and material self-assembly. We will study surface phenomena and surface energy that are of critical importance for nanomaterials and nanostructures. We will also learn various ways to control the structures and properties of nanomaterials and surfaces. A variety of nanomaterials and nanostructures will be discussed, including metal, semiconductor, organic and inorganic nanoparticles, carbon nanomaterials, and various natural and synthetic nanostructured surfaces. Applications of these nanomaterials in nanomedicine and theranostics will also be discussed.

CHEM.5670 Computational Biochemistry (Formerly 84.567) - Credits: 3
This course will provide and introductory survey of the basis of theory/simulations of biomolecules. It is accessible to anyone who has completed two semesters of undergraduate chemistry and who has some background in physical chemistry. Topics/examples will be borrowed from modern biological chemistry and biophysics of single biomolecules. The course will be useful for senior undergraduates and beginning graduate students. Chem/Bioinformatics 84.567 will attempt to cultivate computational skills, which on needs to tackle current scientific problems of biology and biophysics.

CHEM.5680 Structural Analysis (Formerly 84.568) - Credits: 3
Practical applications of instrumental data in the determination of the structure of organic compounds and polymers. Includes mass spectrometry, ultra-violet spectroscopy, infrared spectroscopy and nuclear magnetic resonance spectroscopy. Open to undergraduate students with permission.

CHEM.5700 Protein Chemistry (Formerly 84.570) - Credits: 3
This course outlines the assembly process, structural and functional attributes of protein. Special attention will be given to three-dimensional structures, folding, post translational modifications, misfolding and degradations, as well as biochemical and biophysical techniques used to elucidate protein structure and function.

CHEM.5800 Bioanalytical Chemistry (Formerly 84.580) - Credits: 3
Analytical biochemistry involves the separation, detection, and analysis of biological molecules. This course addresses advanced theory and applications of contemporary biochemical techniques and instrumentation. Topics covered include chromatographic and electrophoretic separation techniques, detection of biomolecules by spectroscopy and radiochemical methods, biological preparations, and structural analysis of proteins, nucleic acids, polysaccharides and lipids.

CHEM.5850 Modern Organic Chemistry - Credits: 3
This course aims to provide deepened and widened knowledge of concepts, reactivity, and synthesis in modern organic chemistry. It encompasses: main group chemistry, carbonyl/enol/enolate chemistry, heterocyclic compounds, fragmentations, rearrangements, frontier molecular orbital theory, pericyclic reactions, reactive intermediates, organometallic chemistry, selective synthesis, stereochemistry, catalysis, asymmetric synthesis, and multi-step synthesis.

CHEM.5950 Supramolecular Chemistry - Credits: 3
Supramolecular Chemistry is a rapidly growing area at the interfaces between chemistry, biology, physics, and engineering. It can be described as Chemistry Beyond the Molecule and the chemistry of molecular assemblies. Inspired by Nature, it involves the study of complex structures held together by reversible, mostly non-covalent interactions, and encompasses the design and development of functional systems based on multiple chemical components. This course will provide detailed understanding of the general principles and concepts of the field, including host-guest chemistry, molecular recognition, and self-assembly, as well as highlight a wide variety of examples and applications of supramolecular systems in chemistry, biology, nanotechnology, and materials science.

CHEM.6010 Chemistry Seminar (Formerly 84.601) - Credits: 0-2
Required of all graduate students. Presentation of current topics by graduate students. "Variable credit course, student chooses appropriate amount of credits when registering."

CHEM.6020 Chemistry Seminar (Formerly 84.602) - Credits: 0-2
Required of all graduate students. Presentation of current
topics by graduate students. "Variable credit course, student chooses appropriate amount of credits when registering."

CHEM.6030 Chemistry Colloquium (Formerly 84.603) - Credits: 0-1

Required of all graduate students. Presentation of current topics by visiting scientists and staff. "Variable credit course, student chooses appropriate amount of credits when registering."

CHEM.6040 Chemistry Colloquium (Formerly 84.604) - Credits: 1

Required of all graduate students. Presentation of current topics by visiting scientists and staff.

CHEM.6310 Principles of Medicinal Chemistry I (Formerly 84.631) - Credits: 3

This course teaches fundamental principles of drug development, including small organic compounds and biologics. Key aspects of their synthesis, physical characteristics, and pharmaceutical properties are discussed. Topics covered include discovery strategies, statistic-based modeling (e.g., QSAR), structure-based and mechanism-based design methods, and combinatorial techniques.

CHEM.6410 Co-Op Internship (Formerly 84.641) - Credits: 0-1

Practical training for International Students in a Co-operative agreement with Industry or a Government Laboratory for 1 semester. "Variable credit course, student chooses appropriate amount of credits when registering."

CHEM.6510 Selected Topics: Chemistry (Formerly 84.651) - Credits: 3

Advanced topics in various fields of chemistry. Content may vary from year to year so that students may, by repeated enrollment, acquire a broad knowledge of contemporary chemistry.

CHEM.6530 Chemical Oceanography (Formerly 84.653) - Credits: 3
CHEM.6720 Surface and Colloid Chemistry (Formerly 84.672) - Credits: 3

Surface and colloid chemistry describes the nanoscopic and mesoscopic regimes that connect molecular and macroscopic length scales. The course focuses on how phenomena at macroscopic surfaces and interfaces arise from molecular interactions. Intermolecular and surface forces discussed in detail include van der Waals and electrostatic forces, and how these together with steric interactions give rise to different molecular aggregates (self-assembled structures of surface active molecules and polymers) in bulk solution and in the vicinity of solid surfaces. Examples of modern experimental techniques for measurements of surface forces and for characterization of surfaces and aggregates are discussed and demonstrated.

CHEM.7050 Supervised Teaching Ch & Ps (Formerly 84.705) - Credits: 0
CHEM.7310 Graduate Project in Chemistry (Formerly 84.731) - Credits: 1

Continued research project supplementing the research credits for a doctoral student. This course will require special permission from the Graduate Coordinator.

CHEM.7330L Graduate Project - Chemistry (Formerly 84.733) - Credits: 3
CHEM.7410 Master's Thesis - Chemistry (Formerly 84.741) - Credits: 1

Master's Thesis - Chemistry

CHEM.7430 Master's Thesis - Chemistry (Formerly 84.743) - Credits: 3
CHEM.7460 Master's Thesis - Chemistry (Formerly 84.746) - Credits: 6
CHEM.7490 Master's Thesis - Chemistry (Formerly 84.749) - Credits: 0-9

CHEM.7510 Graduate Doctoral Research Credit (Formerly 84.751) - Credits: 1
CHEM.7530 Doctoral Dissertation/Chemistry (Formerly 84.753) - Credits: 3
CHEM.7560 Doctoral Dissertation/Chemistry (Formerly 84.756) - Credits: 6
CHEM.7590 Doctoral Dissertation /Chemistry (Formerly 84.759) - Credits: 0-9
CHEM.7630 Continued Graduate Research (Formerly 84.763) - Credits: 3
CHEM.7690 Continued Graduate Research (Formerly 84.769) - Credits: 0-9
POLY.5030 Polymer Science I (Formerly 97.503) - Credits: 3
A study of the principles of condensation, free radical, ionic, coordination and ring opening polymerization. The topics include the effect of polymerization techniques on reaction kinetics and molecular weight, and the evaluation of reactivity ratios in copolymerization reactions.

POLY.5040 Polymer Science II (Formerly 97.504) - Credits: 3
Introduction to chain statistics and thermodynamics of macromolecular solutions, methods of study of molecular weight and chain conformation, and the properties of polymers in bulk including viscoelasticity and crystallinity.

POLY.5050 Polymer Preparation Characterization I - Credits: 3
In this graduate-level laboratory class, the students will learn a variety of valuable techniques for the syntheses and characterization of high molecular weight polymers. This course offers a combination of traditional/historical polymer synthesis (i.e. Urea/Formaldehyde thermoset formation, interfacial polymerization of Nylon, determination of reactivity ratios for copolymerizations) and modern polymerization techniques (i.e. RAFT, ATRP, Living ROP) along with relevant polymer characterization techniques used in today's synthetic polymer landscape (i.e. GPC, MALDI, light scattering, NMR, TGA, DSC, etc.).

POLY.5110 Biopolymers (Formerly 97.511) - Credits: 3
Topics include conformation and configuration of vinyl polymers and polypeptides, energetics of chain folding and examination of the forces dictating ordered structures, helix to coil transitions in biopolymers with emphasis on polypeptide structures, instrumental analysis of biopolymer conformation, synthesis of biopolymers including polypeptides, polysaccharides and polynucleotides, and examination of relationships between synthetic polymers and naturally occurring polymers.

POLY.5530 Macromolecules Organic Chemistry (Formerly 97.553) - Credits: 3
An advanced study in polymer science concerned with the synthesis of macromolecules and their mechanisms of formation.

POLY.6010 Polymer Science Seminar (Formerly 97.601) - Credits: 0-2
Required of all Polymer Science graduate students. Presentation of current topics in polymer science by graduate students. "Variable credit course, student chooses appropriate amount of credits when registering."

POLY.6020 Seminar in Polymer Science (Formerly 97.602) - Credits: 0-2
Required of all Polymer Science graduate students. Presentation of current topics in polymer science by graduate students. "Variable credit course, student chooses appropriate amount of credits when registering."

POLY.6030 Polymer Science Colloquium (Formerly 97.603) - Credits: 0-1
Required of all Polymer Science graduate students. Presentation of current topics in polymer science by visiting scientists and staff.

POLY.6040 Polymer Science Colloquium (Formerly 97.604) - Credits: 0-1
Required of all Polymer Science graduate students. Presentation of current topics in polymer science by visiting scientists and staff.

POLY.6490 Introduction to Conjugated Polymers (Formerly 97.649) - Credits: 3
This course is an introduction to the fundamental science and potential applications of conjugated polymers in optical and electronic technologies. The topics covered include history, synthesis and molecular structure, including solid state polymerization; crystallinity and morphology, including assembly methods; electronic structure including energy bands, conjugation defects and photoelectron spectroscopy; properties of the insulating forms including light absorption and emission, thermochromism, carrier transport, electroluminescence and nonlinear optical properties; properties of the conducting forms, including "doping"; some specific devices.

POLY.7050 Supervised Teaching in Polymer Science (Formerly 97.705) - Credits: 0
POLY.7430 Master's Thesis in Polymer Science (Formerly 97.743) - Credits: 3
POLY.7460 Master's Thesis in Polymer Science (Formerly 97.746) - Credits: 6
POLY.7490 Master's Thesis in Polymer Science (Formerly 97.749) - Credits: 9
POLY.7510 Thesis Review (Formerly 97.751) -
Credits: 1
This is a one credit thesis review course.

POLY.7530 Doctoral Dissertation in Polymer Science
(Formerly 97.753) - Credits: 3
POLY.7560 Doctoral Dissertation in Polymer Science
(Formerly 97.756) - Credits: 6
POLY.7590 Doctoral Dissertation in Polymer Science
(Formerly 97.759) - Credits: 0-9
POLY.7690 Continued Graduate Research (Formerly
97.769) - Credits: 9
Department of Computer Science

The UMass Lowell Computer Science graduate program provides computer scientists with an education of sufficient breadth and depth to prepare them for leadership positions in both industrial and academic environments. It is distinguished by a balanced mixing of the practical, engineering aspects of computer science, with substantial exposure to the theoretical foundations of the field. This mission is supported by departmental and university research labs and Centers. Our graduate program is intended primarily for students with undergraduate degrees in computer science, or for those who have completed a degree in a related area (Engineering, Mathematics, Physics, etc.) and who possess a substantial background in computer science.

Programs

- Doctor of Philosophy
- Master of Science
- Graduate Certificate

(https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Resources

The Computer Science Department has strong industrial ties through its faculty members, its participation in the research activity in various University Centers, its internal laboratories and institutes, its continuing relationships with many local computer and software manufacturers, and its industrial advisory committee. These relationships provide sources of short and long range research projects, hardware donations and student funding, while also providing insight to and understanding of the short and long term directions of local industry. To support instructional and research activities, the Department of Computer Science maintains a large heterogeneous network, including PCs, workstations, and a collection of more specialized equipment. All systems and servers are connected to /accessible via the University's network.

Financial Support

The Department has a limited number of teaching assistantships available to qualified graduate students. These assistantships can be renewed for up to four semesters. Other support is available through funded research programs in the departmental laboratories and, possibly, through support from other university departments.

Master of Science Degree in Computer Science

The Master of Science degree program in Computer Science serves several audiences, from the professional with extensive industrial experience to the recent graduate aiming ultimately for an advanced research degree. In all cases, a major objective is to prepare the student for a professional work environment in which continued growth is the norm.

- Admission Requirements
- Master of Science
- Master of Science, Bioinformatics Option (we are no longer accepting applications for this program)
- Master of Science, Cybersecurity Option
- Master of Science, Information Technology MSIT (Online Program)
- Bachelor’s-Master’s Program

Admission Requirements

In order to be fully matriculated into the MS program, students must demonstrate competency in the following six knowledge areas:

- Data Structures and Programming in C, C++, or Java
- Operating Systems
- Analysis of Algorithms
- Calculus
- Discrete Mathematics
- Probability and Statistics

Competency is typically demonstrated by producing a transcript of previous academic experience which contains passing grades in courses related to these six areas, or by earning a B or better in the courses below. Knowledge in areas that have not been satisfied at the time of entrance into the M.S. program become conditions on full matriculation. It is the student’s responsibility to fulfill his/her conditions at the earliest possible time. The following is the list of courses which satisfy each of the six knowledge areas.

Data Structures and Programming in C, C++ or Java:

- COMP.1020

(https://www.uml.edu/catalog/courses/COMP/1020) Computing II

Operating Systems:

- COMP.3080

(https://www.uml.edu/catalog/courses/COMP/3080) Intr
Introduction to Operating Systems

Algorithms:

Calculus:

Discrete Math:

Probability and Statistics:

Master of Science, General Option

Each degree candidate will be required to pass, with an average of B or better, and not more than two grades below B, the following minimum number of credits, distributed to include core courses and electives.

- 30 Courses Credits (10 courses)
- Four graduate level core courses in Computer Science and six graduate level courses selected from five categories
  (see the degree pathway)

Degree Pathway for the Master of Computer Science, General Option (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Master’s Thesis:

An optional master’s thesis can be substituted for at most six credits, and can be used to substitute for two elective courses. Students who wish to do a thesis must file a

Proposed Thesis Committee

form with the Graduate Coordinator prior to begin working on the thesis.

Master of Science, Bioinformatics Option

We are no longer accepting applications for this option.

Course Requirements:
- 30 Courses Credits (10 courses)
- Eight Graduate level courses in Computer Science and two graduate level courses in Biology, under the direction of the Graduate Coordinator, from an approved list of courses.

Degree Pathway for the Master of Science, Bioinformatics Option

Master of Science, Cybersecurity Option

Course Requirements:
- 30 Courses Credits (10 courses)
- Four graduate level core courses in Computer Science and six graduate level courses selected from five categories
  (Foundations, Systems & Networks, Human-Computer Interaction, Visualization, Robotics & AI, Information Management & Analysis, Interdisciplinary and Other Approved Electives)

An optional Master’s thesis can be substituted for two elective courses (a maximum of six credits). Students who wish to do a thesis must file a Proposed Thesis Committee form with the Graduate Coordinator prior to beginning work on the thesis.

Degree Pathway for the Master of Science, Cybersecurity Option (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Master of Science, Information Technology (Online Program)

The program is offered fully online, providing a pathway for students who have completed a Bachelor’s in Information Technology degree and for working professionals who want to pursue advanced graduate studies in information technology.
The online delivery framework provides an accessible format for students juggling work and family responsibilities.

Students may also count course from two graduate IT certificate programs in Systems Models and Management and Network Security towards the Master's Degree in Information Technology.

The 10-course master's degree program is designed to provide both a principled and applied exposure toward designing, managing and deploying networked systems of computers. The program places emphasis on practical skills based on Linus/Unix, Windows and Apple platforms, but also teaches general principles along with their technical and ethical foundations.

**Admissions Requirements:**

1. Completion of an undergraduate BS or BA degree from an accredited institution.
2. Mathematical Maturity: Students should have completed a minimum of one semester of precalculus mathematics, one semester of discrete mathematics and one semester of statics as part of their undergraduate studies, or possess the equivalent experience.
3. C Programming proficiency, to include a minimum of one semester of C Programming an one semester of Data Structures, or the equivalent experience.

**Note:** Students who do not meet the above requirements, may need to take additional undergraduate courses in order to meet the requirements.

**Course Requirements:**

30 Course Credits (10 Courses)

**System Infrastructures Courses:**(Choose 2 of the following)

- MSIT.5110 [Network and Systems Administration](https://www.uml.edu/catalog/courses/MSIT/5110) (3 credits)
- MSIT.5170 [Operating Systems Foundations](https://www.uml.edu/catalog/courses/MSIT/5170) (3 credits)
- MSIT.5190 [Virtual Systems](https://www.uml.edu/catalog/courses/MSIT/5190) (3 credits)
- MSIT.5140 [Systems Security and Auditing](https://www.uml.edu/catalog/courses/MSIT/5140) (3 credits)

**Network Infrastructure Courses:**(Choose 2 of the following)

- MSIT.5600 [Network Infrastructures](https://www.uml.edu/catalog/courses/MSIT/5600) (3 credits)
- MSIT.5610 [Computer Network Security](https://www.uml.edu/catalog/courses/MSIT/5610) (3 credits)
- MSIT.5620 [Digital Forensics](https://www.uml.edu/catalog/courses/MSIT/5620) (3 credits)
- MSIT.5630 [Secure Mobile Networks](https://www.uml.edu/catalog/courses/MSIT/5630) (3 credits)
- MSIT.5650 [Cloud Computing](https://www.uml.edu/catalog/courses/MSIT/5650) (3 credits)

**Software Management Courses:**(Choose 2 of the following)

- MSIT.5180 [Large Scale Application Deployment](https://www.uml.edu/catalog/courses/MSIT/5180) (3 credits)
- MSIT.5310 [Project Management](https://www.uml.edu/catalog/courses/MSIT/5310) (3 credits)
- MSIT.5320 [Managing Large Data](https://www.uml.edu/catalog/courses/MSIT/5320) (3 credits)

**Program Electives:**(Choose 4 additional MSIT.xxxx courses from this Program Electives or from any of the first three categories above, as long as you have not already taken the course to fulfill the above category requirements).

- MSIT.5350 [Agile and Iterative Project Management](https://www.uml.edu/catalog/courses/MSIT/5350) (3 credits)
- MSIT.5360
Data Mining (3 credits)
- MSIT.5360

Information Security, Privacy and Regulatory Compliance (3 credits)
- MSIT.5410

Intrusion Detection Systems (3 credits)
- MSIT.5430

Designing and Building a Cybersecurity Program (3 credits)
- MSIT.5450

Advanced Cloud Computing (3 credits)
- MSIT.5460

Bachelor's-Master's Program

The Computer Science Department offers to outstanding undergraduates a Bachelor's-Master's (BS/MS) program. The major advantage of this program is that it allows students to integrate their undergraduate and graduate education, possibly reducing the amount of time required for completion and reducing the administrative overhead for the student.

To be accepted into the BS/MS program, students are expected to have at least a B (3.0) grade point average, both overall and in Computer Science, and to apply during their junior year. The rules governing eligibility for the program appear in the current UMass Lowell online Graduate Catalog.

Doctor of Philosophy Degree

The Doctor of Philosophy degree program aims to provide a student, whether planning on an industrial or academic career, with a challenging research environment and the opportunity to tackle theoretical or applied projects of major scope, depth, and originality.

- Admission Requirements
- Candidacy Requirements

Admission Requirements

Admission into the Doctor of Philosophy degree program requires a Masters degree in Computer Science. If the student does not already have an MS in CS, they may be admitted into the MS/Ph.D. program; in this program, students must complete the required coursework for the MS in CS as well as degree requirements for the Ph.D. in CS.

Candidacy Requirements

Despite acceptance into the program, in order to be admitted to candidacy, student must:

- Complete the degree requirements for the MS in CS (unless he or she possesses an MS in CS or a closely related engineering, scientific, or mathematical discipline)
- Pass the departmental qualifying examinations.

Course Requirements:

- 6 courses (18 credits) from the Masters course group list (http://www.cs.uml.edu/%7Egcoord/MS_Degree_Course_Requirements.pdf) (pdf), with at most 4 courses from a single Masters course group (pdf). No course applied towards an MS degree can be used to satisfy course distribution requirements for the Doctoral degree.
- Thesis Credits: 24 Credits
- Total: 42 credits

Additional Requirements

- submission and defense at an oral examination of a thesis proposal
- completion of the thesis
- final defense of the thesis during another oral examination
- acceptance of two papers for publication in a peer-reviewed (refereed) journal or conference approved by the thesis advisor. At least one of these publications must be
in the thesis area. This rule applies to students whose thesis proposals were defended on or after July, 2007.

- Students are required to report completion of each of these milestones according to the Procedures for Student Progress Through the Ph.D. Program (https://www.uml.edu/Sciences/computer-science/Programs/Masters/Doctorate/Checklist.aspx).

**Computational Mathematics Option**

Requirements: (beyond a master's degree)

- 18 Course Credits (6 courses)
- Four Graduate level courses in Computer Science and two graduate level courses in Mathematics, under the direction of an advisor, from an approved list of courses
- 24 Dissertation Credits
- Supervised by faculty from the Mathematics and Computer Science Departments
- Any student interested in this program should contact the Chair of the CS Department and/or the Chair of the Mathematics Department.

**M.S. in Computer Science Bio/Cheminformatics Option**

- Admissions Criteria and Requirements
- Core Courses
- Course Pairs
- Electives

**Admissions Criteria and Requirements**

Applicants for admission to the Master of Science Program with a Bio/Cheminformatics option typically have an undergraduate degree in computer science or a related discipline such as mathematics, physics, biochemistry or engineering. Students wishing to enroll in the Master's program in Computer Science with Bio/Cheminformatics option must demonstrate competency in the knowledge areas listed below. Competency in these areas is usually demonstrated by producing a transcript of previous academic experience which contains related courses passed with a B or better, or by earning a B or better in the courses listed below. Competency in the biology and chemistry area may be demonstrated by successfully passing a CLEP exam. Additional information regarding these exams may be obtained at the CollegeBoard website. The following are the knowledge areas in which competency must be demonstrated:

- Biology BIOL.1110 Principles of Biology I
- Chemistry CHEM.1210 Chemistry I and CHEM.1220 Chemistry II
- Discrete Mathematics MATH.3210 Discrete Structures I and MATH.3220 Discrete Structures II
- C or C++ through Data Structures
- COMP.2500 Accelerated C with Data Structures or
- COMP.1010 Computing I and
- COMP.1020 Computing II
- Programming Languages
- COMP.3010 Organization of Programming Languages
- Computer Architecture
- COMP.3050 Computer Architecture
- Operating Systems
- COMP.3080 Introduction to Operating Systems
- Analysis of Algorithms
- COMP.4040 Analysis of Algorithms
- Calculus MATH.1250 Calculus A and MATH.1260 Calculus B or MATH.1310 Calculus I and MATH.1320 Calculus II

**Core courses:** Total 9 credits

- COMP.5020 Foundations of CS
- COMP.5030 Algorithms
- COMP.5310 Design of Programming Languages

**Course Pairs:**

The following course pairs are selected from the approved list of Computer Science pairs, these courses have been chosen because they complement the goals of the bio/cheminformatics option.

Total 12 Credits (Two pairs of courses from the approved list of CS pairs.)

- COMP.5030 Algorithms I
- COMP.5460 Graphics I
Electives - Total 9 credits

Three additional courses will be taken from the list of approved bio/cheminformatics approved courses. The list below is for example only and it includes the current approved courses. This list will be updated as new courses are added to the program.

- BIOL.5050* (3 credits) Bioinformatics
- BIOL.5070* (1 credit) Bioinformatics Laboratory (coreq. BIOL.4050)
- BIOL.5190 (3 credits) Biochemistry I
- BIOL.5200 (3 credits) Biochemistry II
- BIOL.5010 (3 credits) Selected Topics I
- BIOL.5020 (3 credits) Selected Topics II
- BIOL.5670 Recombinant DNA Techniques
- CHEM.6510 Selected Topics in Chemistry: Protein and Chemical Informatics
- CHEM.5500 (3 credits) Biochemistry I
- CHEM.5510 (3 credits) Biochemistry II
- CHEM.5670 (3 credits) Biocheminformatics
- CHEM.5680 (3 credits) Computational Chemistry
- CHEM.5700 (3 credits) Advanced Protein Chemistry
- CHEM.5800 Advanced Analytical Biochemistry
- MATH.5930 (3 credits) Experimental Design (Mathematics Department)

Although Organic Chemistry is not required as a prerequisite, some of the courses offered as part of this degree rely on knowledge of this subject.

Students should be aware that the above courses may only be used toward the Bio/Cheminformatics option. If the entire requirements of the option are not completed then these courses cannot be applied in isolation toward the M.S. in Computer Science.

Program Total: 30 credits (assuming prerequisites have been filled)

An optional master’s thesis can be substituted for at most 6 credits, and may be used to substitute for one pair of related courses.
COMP.5020 Foundations of Computer Science (Formerly 91.502) - Credits: 3
An advanced introduction to theoretical computer science. This course will cover the fundamentals of automata, formal languages, and computability theory.

COMP.5030 Algorithms (Formerly 91.503) - Credits: 3
Advanced algorithms and complexity analysis. Dynamic programming; greedy algorithms; amortized analysis; shortest path and network flow graph algorithms; NP-completeness; approximation algorithms; number-theoretic algorithms; string matching; computational geometry. Additional topics may include linear programming, parallel algorithms, fast Fourier transforms, polynomial, integer, and matrix algorithms. Readings may include conference and journal papers from the algorithms literature. Abstract types, lists, trees, graphs, sets; relevant algorithms and their worst and average case analyses; fast transforms; polynomial, integer, and matrix algorithms; NP-completeness.

COMP.5040 Advanced Algorithms: Computational Geometry (Formerly 91.504) - Credits: 3
Advanced algorithms topics, such as design and analysis of geometric and combinatorial algorithms, computability and complexity.

COMP.5100 Computational Complexity Theory (Formerly 91.510) - Credits: 3
This course covers polynomial-time hierarchy and polynomial space, circuit complexity, structure of NP, probabilistic machines and complexity classes, complexity of counting, interactive proof systems, probabilistically checkable proofs, complexity of approximation problems, and average-case NP-completeness.

COMP.5130 Internet And Web Systems I (Formerly 91.513) - Credits: 3
This course is a survey of Web programming technologies. It begins with a discussion of what Web servers and clients are, how they interact, and how one sets them up. We then explore a wide variety of Web technologies including HTML, JavaScript, JavaServer Pages, Java Servlets, and XML and its many related technologies. Our goal in this course is to provide the basic understanding and knowledge of how the Internet and World Wide Web operate and the technical knowledge required to establish and maintain an Internet/Web site and to develop and introduce new capabilities and features on such sites.

COMP.5140 Internet & Web Systems II (Formerly 91.514) - Credits: 3
A continuation of 91.513 with a focus on current topics and topics of special interest. Examples of recent topics include: The semantic Web and ontologies, Web services, Peer-to-peer networks, Information Search and Retrieval, Autonomous intelligent agents and Multi-modal presentations.

COMP.5150 Operating Systems I (Formerly 91.515) - Credits: 3
This course provides insight into multiprocess operating systems including processor memory, peripheral, and file systems management in batch, timesharing, real time, and distributed systems targeted for various hardware. Particular emphasis will be placed on techniques of virtual memory as well as the problems of concurrency in both centralized and distributed systems. An OS simulation is a required programming project. Some topics to be covered are process synchronization; high-Level mechanisms for concurrency; processor scheduling and system analysis; deadlock; virtual memory; distributed systems; computer security.

COMP.5160 Operating Systems II (Formerly 91.516) - Credits: 3
The design and implementation of an interactive multiprocess operating system to run on a bare hardware system. Separate teams manage the major subsystems with in-class design reviews to coordinate system integration. A functioning system is a class requirement.

COMP.5230 Computer Vision I (Formerly 91.423 & 91.523) - Credits: 3
Computer vision has seen remarkable progress in the last decade, fueled by the ready availability of large online image collections, rapid growth of computational power, and advances in representations and algorithms. Applications range from 3-D scene reconstruction, to visual Simultaneous Localization and Mapping (SLAM) for robotics, to real-time human body pose estimation. This introductory computer vision course explores various fundamental topics in the area, including the principles of image formation, local feature analysis, segmentation, multi-view geometry, image warping and stitching, structure from motion, and object recognition.

COMP.5270 Human Computer Interaction (Formerly 91.527) - Credits: 3
The purpose of this class is to ground students in the basics of how humans interact with technology, and make students aware of the breadth of topic areas related to human-computer interactions.
interaction (HCI). This course emphasizes theoretical constructs such as the Model-Human Processor, and includes seminal readings by the original researchers. Further, the course emphasizes techniques for understanding users’ tasks, formulating users’ requirements, and assessing proposed designs using heuristic evaluation. As part of understanding users’ needs, students will consider social, organizational, and ethical perspectives on information technology. Students are also exposed to specialty topics in human-computer interaction such as multi-user computing, universal access to computer applications, and internationalizing interfaces. This course includes a project to design, develop, document, and orally present a prototype interface. At the end of the course students will be able to cite basic principles of human interaction and devise and carry out a usability engineering plan to aid in developing new human interfaces.

COMP.5280 Evaluation of Human-Computer Interaction (Formerly 91.528) - Credits: 3

This course is an introduction to methods used to evaluate the design of human-computer interaction (HCI). Students will apply examples of all three of the major types of HCI evaluation techniques: inspection, analytical, and empirical techniques. The course also covers HCI experiment design and data analysis, including threats to experimental validity. The course project consists of a formal usability test. This project requires students to learn principles of ethical treatment of human subjects, complete the University’s Institutional Review Board applications and training for human-subject testing, conduct testing sessions, analyze data, recommend design changes, and document results in a professional manner. At course completion, students will have demonstrated skills for assessing the effectiveness of interface designs and will understand how evaluation fits into computer products’ lifecycles.

COMP.5300 Special Topics (Formerly 91.530) - Credits: 0-3

Topics of mutual interest to the instructor and student(s). "Variable credit course, student chooses appropriate amount of credits when registering."

COMP.5310 Design of Program Languages (Formerly 91.531) - Credits: 3

A one-semester course designed to provide students with hands-on understanding of the underlying concepts of programming languages, the principles of their design, and the fundamental methods for their implementation. An executable metalanguage such as Scheme or SML is used throughout the course, facilitating the design of high-level, concise interpreters that are easy to comprehend. The approach is analytical because the salient features of the imperative, functional, object-oriented, and logic programming paradigms are described in the executable meta-language.

COMP.5340 Compiler Construction I (Formerly 91.534) - Credits: 3

This course implements a compiler for a complete language. Topics include grammars, syntax, elements of parsing and recursive descent, semantics, basic code generation, fast compilation runtime support. Programming project required.

COMP.5400 Visual Analytics (Formerly 91.540) - Credits: 3

This course covers the basic topics for the interdisciplinary field of visual analytics. This course is not just for computer science students but also for analysts and scientists in different disciplines. The topics include visual analytics science and technology, perception, cognitive processes and human tasks and reasoning, data and knowledge representation, visualization and interaction, statistical and analytic methods, data mining and knowledge discovery, and evaluation and usability. Numerous examples of systems, tools and applications will be presented.

COMP.5411 Data Visualization (Formerly 91.541) - Credits: 3

This course looks at classical and novel methodologies for the visualization of large and complex data sets. The course covers both scientific and information visualization starting with data modeling, human perception and cognition, basic and advanced techniques, interaction, formal models, real time systems, and frameworks for integrated analysis and visualization. Examples used come from numerous areas including the biomedical literature and security.

COMP.5420 Natural Language Processing (Formerly 91.542) - Credits: 3

This course introduces principles and techniques behind natural language processing (NLP), and covers a large selection of important automatic text processing tasks. Selected topics include n-gram language models, part-of-speech tagging, statistical parsing, word sense disambiguation, discourse segmentation, information extraction, sentiment analysis, machine translation. Quantitative techniques are emphasized, with a focus on applying statistical models to large collections of text. The course provides students with a hands-on experience in building a substantial NLP application of their choice.

COMP.5430 Artificial Intelligence (Formerly 91.543) - Credits: 3
Search and games, knowledge representation paradigms, natural language understanding, planning, perception. Use of the LISP language for one or more programming projects.

COMP.5435 Reinforcement Learning - Credits: 3

This course provides a solid introduction to the field of Reinforcement Learning (RL) and Decision Making. The students will learn about the basic blocks, main approaches, and core challenges of Reinforcement Learning including tabular methods, Finite Markov Decision Processes, Dynamic Programming, Monte Carlo methods, Temporal-Difference learning, policy search, function approximation, exploration, and generalization. Through a combination of lectures, and written and coding assignments, students will become well versed in key ideas and techniques for RL. Assignments will include the basics of reinforcement learning. In addition, students will advance their understanding and the field of RL through a final project.

COMP.5440 Data Mining (Formerly 91.544) - Credits: 3

This introductory data mining course will give an overview of the models and algorithms used in data mining, including association rules, classification, clustering, etc. The course will teach the theory of these algorithms and students will learn how and why the algorithms work through computer labs.

COMP.5450 Machine Learning (91.545) - Credits: 3

This introductory course gives an overview of machine learning techniques used in data mining and pattern recognition applications. Topics include: foundations of machine learning, including statistical and structural methods; feature discovery and selection; parametric and non-parametric classification; supervised and unsupervised learning; use of contextual evidence; clustering, recognition with strings; small sample-size problems and applications to large datasets.

COMP.5455 Graph Machine Learning - Credits: 3

This course focuses on computational and modeling challenges in real world graphs (networks), with a particular emphasis on key advancements in graph representation and its applications. At the end of this course, students should have good understanding of computational techniques that can be applied to a variety of networks, as well as hands-on experience on a range of tasks from identifying important nodes to detection communities to tracing information diffusion in networks. Guest lectures by distinguished researchers and course assignments emphasize the subtleties of translating these techniques into practical applications that reveal insights on a variety of networks. Students should have a strong interest in conducting (or learning how to conduct) research to succeed in this course.

COMP.5460 Computer Graphics I (Formerly 91.546) - Credits: 3

Introduction to the hardware, software and mathematics of 2- and 3-dimensional interactive computer graphics systems, including standards, modeling, transformations, hidden-surface removal, shading, and realism.

COMP.5470 Computer Graphics II (Formerly 91.547) - Credits: 3

Lighting models, photo-realism, animation, constructive solid geometry, and distributed graphics.

COMP.5480 Robot Design (Formerly 91.548) - Credits: 3

A broad interpretation of robotics to mean systems that interact with people, each other, and the world around them, using sensors, actuators, communications, and a control program. Project- and lab-based course that involves electronics, embedded coding, mechanical design, and research.

COMP.5490 Mobile Robots (Formerly 91.549) - Credits: 3

This course will focus on the artificial intelligence side of robotics in a project- and lab-based course. Topics to be covered include robot architectures, mapping and localization, learning, vision, multi-agent systems and current research areas.

COMP.5495 Robot Learning - Credits: 3

This course will cover a variety of machine learning approaches that allow robots to learn manipulation tasks from their own actions and experiences, as well as through interaction with humans. Topics will include methods from a) imitation learning, b) learning from demonstration, and c) Reinforcement Learning. We will discuss methods including, but not limited to, data gathering and pre-processing, skill encoding, reproduction, and generalization, skill refinement, obstacle avoidance, symbol grounding, symbolic planning, feature selection and segmentation, and active learning. The course includes student presentations and a final project where students develop an existing approach and extend it further by applying and implementing their own ideas. There are no formal pre-requisites however, this course covers material that utilize a good deal of machine learning and there will be no time to cover all the background material. Therefore, I strongly recommend having a graduate-level machine learning course (COMP.5450), equivalent research experience, or the willingness to do significant studying outside of class. Students are also expected to have fair knowledge of (a) Linear algebra,
(b) calculus, and (c) statistics.

**COMP.5500 Topics (Formerly 91.550) - Credits: 3**
Topics of mutual interest to the instructor and student(s).

**COMP.5510 Bioinformatics for CS - Credits: 3**
Complete genomic sequences of human, other mammals, and numerous other organisms are known for some time. From early on, comparisons or analyses of genomic sequences require aids on computer programming. After brief introductions to molecular biology for Computer Science students, the course will examine computer algorithms used in bioinformatics problems including sequence alignment, phylogeny, DNA sequencing, and data analyses.

**COMP.5520 Foundations in Digital Health - Credits: 3**
Digital health is concerned about utilizing computational technologies to develop health systems, in order to improve healthcare quality. These technologies include various software and hardware solutions such as web apps and wearable devices. This will introduce the foundations and methods in digital health and hand on lab sections to both undergraduate and graduate students, which include the scientific problems, challenges, and application tools of the domain, the tasks we need to handle with, and the applications of various methods such as statistics, machine learning and deep learning. After taking this course, students will obtain a clear concept about what is digital health and knowledge of a wide range of resources and tools to solve the problems and tasks in this domain.

**COMP.5530 Deep Learning - Credits: 3**
This course focuses on the deep learning theory, algorithms, systems, and applications. Topics to be covered in this course include math and machine learning basics for Deep Learning, foundations of Deep Learning, Convolutional neural networks, Recurrent neural networks, Deep reinforcement learning, and practical methodology.

**COMP.5610 Computer & Network Security I (Formerly 91.561) - Credits: 3**
Basic concepts and techniques of computer network security; data encryption algorithms; public-key cryptography and key management; data authentication; network security protocols in practice; wireless network security; network perimeter security; the art of anti malicious software; the art of intrusion detection. Students will implement encryption and authentication algorithms as network applications.

**COMP.5620 Computer Security II (Formerly 91.562) - Credits: 3**
Applied computer security topics such as a computer and network forensics, virtual private networks, denial of service, viruses and worms, intrusion detection systems, smart cards, biometrics, programming language security, web security and privacy, e-commerce; case studies of deployed systems; policy and legal considerations.

**COMP.5630 Data Communications I (Formerly 91.563) - Credits: 3**
Resource sharing; computer traffic characterizations; multiplexing; network structure; packet switching and other switching techniques; design and optimization; protocols; routing and flow control; simulation and measurement; communications processors.

**COMP.5640 Data Communications II (Formerly 91.564) - Credits: 3**
Continuation of 91.563

**COMP.5660 Malware Analysis - Credits: 3-33**
This class covers both introductory and advanced topics on binary reverse engineering techniques including virtual machines as sandboxes, basic and advanced dynamic analysis, a crash course on assembly language, reverse engineering tools, shellcode analysis and anti-reverse engineering techniques.

**COMP.5670 IoT Security and Privacy - Credits: 3**
The key objectives of this class include: understand IoT frameworks, applications and security and privacy concerns; be familiar with IoT hardware security; master IoT systems security; master IoT software security; master IoT network security; understand the IoT data security and privacy.

**COMP.5690 Computer and Network Forensics - Credits: 3**
This class introduces students to computer forensics and network forensics. Computer forensics tackles forensic investigation of stand-alone computers while network forensics deals with forensic investigation of networked computers and networks. The class will cover topics such as laws and legal compliance, forensic imaging and analysis, log-file analysis, network traffic analysis and case study.

**COMP.5700 Topics (Formerly 91.570) - Credits: 3**
Topics of mutual interest to the instructor and student(s).
COMP.5730 Data Base I (Formerly 91.573) - Credits: 3
Study of various database models including hierarchical, network, relational, entity-relationship, and object-oriented models. This course also covers data design, integrity, security, concurrency, recovery, query processing, and distribution.

COMP.5740 Data Base II (Formerly 91.574) - Credits: 3
Continuation of Data Base I. Various issues in the implementation of database systems will be covered.

COMP.5800 Topics in Computer Science (Formerly 91.580) - Credits: 3
Topics of mutual interest to the instructor and student(s).

COMP.5870 Computer Science Education in Secondary School (Formerly 91.587) - Credits: 3
COMP.5901 Directed Study in Computer Science - Credits: 3
Directed Study in Computer Science

COMP.5920 Special Topics: Computer Science (Formerly 91.592) - Credits: 3
COMP.5930 Cooperative Education (Formerly 91.593) - Credits: 0-1
"Variable credit course, student chooses appropriate amount of credits when registering."

COMP.6040 Network Optimization (Formerly 91.604) - Credits: 3
This course covers advanced topics in network optimization on continuous and discrete models, including the max-flow problem, the min-cost flow problem, simplex methods for min-cost flow, dual ascent methods for min-cost flow, auction algorithms for min-cost flow, nonlinear network optimization, convex separable network problems, and network problems with integer constraints.

COMP.6130 Advanced Topics in Information Retrieval and Mining (Formerly 91.613) - Credits: 3
This is a proposed new 600-level course. The topics are advanced topics in Information Retrieval and Mining, including (but not limited to) Search and Information Retrieval, Visual Text Mining, Document Retrieval and Analysis, Non-textual Retrieval (including Image-, Sound, Video-Retrieval). The course’s format is a seminar: (advanced, doctoral) students will be reading and presenting the current state-of-the-art literature. Course requirements include weekly bibliography reports (at least 2 new entries each week) class presentations, two term papers, and a term project.

COMP.6410 Advanced Topics in Visualization (Formerly 91.641) - Credits: 3
This course covers advanced topics in data visualization. Coverage will be topical and may include advanced graph & text visualization, modern coordinated visualizations, collaborative visualization knowledge visualizations, security visualization, web-based visualization, and high-performance visualization. Theory will also be covered.

COMP.6440 Topics in Data Mining (Formerly 91.644) - Credits: 3
This course continues with 91.421/91.544 Data Mining and explores the state of the art research advances in mining large amount of data especially algorithms in association classification, clustering, and applications such as web mining and spatio-temporal data mining.

COMP.6610 Advanced Topics in Network Security (Formerly 91.661) - Credits: 3
This is a topic course, with a subtitle to be determined by the instructor. It covers advanced topics in network security of mutual interests to the faculty and students.

COMP.6730 Advanced Database Systems (Formerly 91.673) - Credits: 3
This course covers advanced topics in database management systems, including query processing and optimization, indexing, transaction management, data warehousing, data mining, etc. It also covers spatio-temporal databases, search engines, stream and sensor databases, and open problems for research.

COMP.7010 Computer Science Research (Formerly 91.701) - Credits: 1
COMP.7020 Computer Science Research (Formerly 91.702) - Credits: 6
COMP.7030 Computer Science Research (Formerly 91.703) - Credits: 3
COMP.7060 Directed Research (Formerly 91.706) - Credits: 6
COMP.7100 Approximation Algorithms (Formerly 91.710) - Credits: 3

This course covers advanced topics in approximation algorithms for NP-hard problems, including combinatorial algorithms and LP-based algorithms for set cover, k-cut, k-center, feedback vertex set, shortest superstring, knapsack, bin packing, maximum satisfiability, scheduling, Steiner tree, Steiner Forest, Steiner network, facility location, k-median, semidefinite programming. It also covers counting problems, shortest vector, hardness of approximation, and open problems for research.

COMP.7410 Thesis Review (Formerly 91.741) - Credits: 1
COMP.7430 Master's Thesis - Computer Science (Formerly 91.743) - Credits: 3
COMP.7460 Master's Thesis - Computer Science (Formerly 91.746) - Credits: 6
COMP.7490 Master's Thesis - Computer Science (Formerly 91.749) - Credits: 9
COMP.7510 Doctoral Thesis Research (Formerly 91.751) - Credits: 1-3
COMP.7530 Doctoral Dissertation/Computer Science (Formerly 91.753) - Credits: 3
COMP.7560 Doctoral Dissertation/Computer Science (Formerly 91.756) - Credits: 6
COMP.7590 Doctoral Dissertation/Computer Science (Formerly 91.759) - Credits: 9
COMP.7690L Continued Graduate Research (Formerly 91.769) - Credits: 9
MSIT.5110 Network and Systems Administration (Formerly 94.511) - Credits: 3
MSIT.5140 Systems Security and Auditing (Formerly 94.514) - Credits: 3
MSIT.5170 Operating Systems Foundations (Formerly 94.517) - Credits: 3
MSIT.5180 Large Scale Application Deployment (Formerly 94.518) - Credits: 3
MSIT.5190 Virtual Systems (Formerly 94.519) - Credits: 3
demonstrate the configuration and management of such systems. Para-virtualized software components will be analyzed and their pros and cons discussed. Processor and peripheral support for virtualization will also be examined, with a focus on emerging hardware features and the future of virtualization.

MSIT.5200 Digital Storage Architectures (Formerly 91.520 and COMP.5200) - Credits: 3

This course will focus on existing and proposed technologies for storing digital information. Both hardware and software issues will be examined, beginning with device and controller organization and proceeding through aggregation techniques, interconnect architectures and host consideration. At each level, specific components will be evaluated with respect to critical storage criteria, such as bandwidth and latency, fault tolerance, infrastructure requirements and cost. Students must already have completed a bachelor’s degree in a related discipline and must meet all undergraduate prerequisite requirements specified for graduate IT programs to enroll in this course and in a graduate career.

MSIT.5310 Project Management (Formerly 94.531) - Credits: 3

This course explores the application of knowledge, skills, tools, and techniques that project managers use when managing information technology projects as well as the current IT factors that affect IT project management decision making. Special emphasis will be placed on learning the best practices currently used by organizations and practitioners to ensure the best chance for project success by learning and applying the concepts of managing scope, risk, budget, time, expectations, quality, people, communications, procurement, and externally provided services. Students will be expected to perform research in the above areas as well as using tools such as Microsoft Project to solve project management related problems. Special attention will also be placed on the issues affecting project managers today such as PMOs, virtualization, green IT, and net sourcing. Practical examples will be used to demonstrate the concepts and techniques, plus you will receive hands on experience by working on a case study.

MSIT.5320 Managing Large Data Sets (Formerly 94.532) - Credits: 3

The amount of data generated by businesses, science, Web, and social networks is growing at a very fast rate. This course will cover the algorithms and database techniques required to extract useful information from this flood of data. Data mining, which is the automatic discovery of interesting patterns and relationships in data, is a central focus of the course. Topics covered in data mining include association discovery, clustering, classification, and anomaly detection. Special emphasis will be given to techniques for data warehousing where extremely large datasets (e.g., many terabytes) are processed. The course also covers Web mining. Topics covered include analysis of Web pages and links (like Google) and analysis of large social networks (like Facebook).

MSIT.5330 Developer Operations (DevOps) - Credits: 3

"DevOps" is a set of practices to support software development and business operations in live production environments. By using agile practices and automation, these practices enable software to be developed and deployed to users quickly and with high quality. In this course you will learn DevOps tools and techniques. Tools include microservices, continuous integration and deployments, monitoring, and infrastructure-as-code. Techniques include oh DevOps engineers blur traditional roles of IT, development, release engineering, and quality assurance. Case studies in DevOps from companies such Amazon and Facebook will be studied. For experimentation purposes, Linux will be used on AWS together with open source tools such as Jenkins, Ansible, and Kubernetes. Students must already have completed a bachelor’s degree in a related discipline and must meet all undergraduate prerequisite requirements specified for graduate IT programs to enroll in this course and in a graduate career.

MSIT.5350 Agile and Iterative Project Management (Formerly 94.535) - Credits: 3

This course explores the differences between the Traditional Project management and the Agile management approaches, introduces the principles of Agile Development through applications within each major Project Management process: Project Initiation, Project Planning, Project Execution, and Project Closing. The project will be developed in a timely manner, using Agile techniques that encourage frequent adaptation, self-organization, accountability and with a focus towards rapid delivery. Upon completion, students will understand how to apply Agile principles and practices, recognize ways to increase team performance through better communication and close involvement of stake holders, and recognize the key success criteria for implementing Agile Projects.

MSIT.5360 Data Mining (Formerly 94.536) - Credits: 3

Today, we are surrounded by big data applications. Smartphone and sensor data, medical and scientific data, financial data, web and text data, and social network data are just a few examples. As a result, mining useful information and discovering knowledge from the big data are increasingly important. It is fair to say that, without data mining, we would not be able to make good use of this large amount of data. In this course, we learn the state-of-the-art techniques in data
mining and analysis. Topics include types and properties of data, exploring data, classification, association analysis, cluster analysis, and anomaly detection.

**MSIT.5430 Intrusion Detection Systems (Formerly 94.543) - Credits: 3**

Intrusion Detection Systems is a survey of the hardware and software techniques that are applied to the detection, identification, classification and remediation of compromised information systems. From this introduction to intrusion detection systems, students will develop a solid foundation for understanding IDS and how they function. This course will give students a background in the technology of detection network attacks. It will introduce all the concepts and procedures used for IDS (intrusion Detection Systems) and IPS (intrusion Prevention Systems). Students will have hands-on experience with implementing and configuring software and hardware based IDS in a network infrastructure. This course is designed with a network administrator in mind.

**MSIT.5450 Designing and Building a Cybersecurity Program (Formerly 94.545) - Credits: 3**

This course focuses on best practices for designing and building a comprehensive Cybersecurity Program based on the NIST Framework for Improving Critical Infrastructure Cybersecurity ("The Framework"). The Framework was issued on February 12, 2014, as directed by President Obama in Executive Order 13636. This framework provides guidance for reducing cybersecurity risk for organizations, and this course will examine its basic tenets of: "Cybersecurity Fundamentals", techniques applied to "Building a Controls Factory", "Cybersecurity Programs" "Establishing Cybersecurity Centers of Expertise" and "The Cybersecurity Program Implementation Roadmap".

**MSIT.5600 Network Infrastructures (Formerly 94.560) - Credits: 3**

This course provides an introduction to the fundamental concepts in the design and implementation of computer communication networks, their protocols, and applications. Topics to be covered include: an overview of network architectures, applications, network programming interfaces (e.g. sockets), transport, congestion, routing, and data link protocols, addressing, local area networks, network management, and emerging network technologies. Cannot be used toward MS or D.Sc. in Computer Science.

**MSIT.5610 Computer Network Security (Formerly 94.561) - Credits: 3**

This course is aimed to provide students with a solid understanding of key concepts of computer network security and practical solutions to network security threats. Topics to be covered include common network security attacks, basic security models, data encryption algorithms, public-key cryptography and key management, data authentication, network security protocols in practice, wireless network security, network perimeter security and firewall technology, the art of anti-malicious software, and the art of intrusion detection. Pre-Req: BS in IT or Equivalent. Cannot be used toward MS or D.Sc. in Computer Science.

**MSIT.5620 Digital Forensics (Formerly 94.562) - Credits: 3**

Identifying, preserving and extracting electronic evidence. Students learn how to examine and recover data from operating systems, core forensic procedures for any operating or file system, understanding technical issues in acquiring computer evidence and how to conduct forensically sound examinations to preserve evidence for admission and use in legal proceedings.

**MSIT.5630 Secure Mobile Networks (Formerly 94.563) - Credits: 3**

This course covers principles and practices of wireless networks, including cellular networks, wireless LANs, ad hoc mesh networks, and sensor networks. The potential attacks against these wireless networks and the security mechanisms to defend these networks will be discussed. Topics to be covered include cellular network architecture, wide-area mobile services, wireless LANs and MACs, introduction to emerging wireless networks, survey of malicious behaviors in wireless networks, securing wireless WANs and LANs, securing wireless routing, securing mobile applications, wireless intrusion detection and prevention, challenges in securing next-generation wireless networks, and privacy issues in wireless networks.

**MSIT.5650 Cloud Computing (Formerly 94.565) - Credits: 3**

This course starts with an overview of modern distributed models, exposing the design principles, systems architecture, and innovative applications of parallel, distributed, and cloud computing systems. The course will focus on the creation and maintenance of high-performance, scalable, reliable systems, providing comprehensive coverage of distributed and cloud computing, including: Facilitating management, debugging, migration, and disaster recovery through virtualization. Clustered systems for research or ecommerce applications. Designing systems as web services. Principles of cloud computing using examples from open-source and commercial applications.
MSIT.5660 Advanced Cloud Computing (Formerly 94.566) - Credits: 3

This course is a continuation of the 94.565 Cloud Computing course and will cover in further detail such topics as Cloud Based Storage, Virtualization, Service Oriented Architecture (SOA), High Availability, Scaling, and Mobile Devices. The course will also study the role of Open Source cloud software such as Hadoop, OpenStack and others. Similar to the first course where hands-on projects included the use of Cloud Services such as Amazon Web Services (AWS), Google Apps and App Engine, and Windows Azure, this course will continue with those services and add others such as Rackspace and VMware. Current articles and publications in this fast moving field of Cloud Computing will also be followed.
Program Options

Doctoral Program in Earth System Science

- Ph.D. in Earth System Science
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Master's of Science in Environmental Studies

- Atmospheric Science Option
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Environmental Geoscience Option
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Professional Science Masters Environmental Geoscience Option
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Professional Science Master's Atmospheric Science Option
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)

Graduate Certificate Programs

- Certificate in Environmental Geoscience
  (https://www.uml.edu/resources/catalog-archive/current/Graduate.pdf)
- Certificate in Environmental Atmospheric Science

Professional Internship and Seminar

This professional internship is required for students in this program and is expected to represent a minimum of 350 hours and will have a 3-6 month duration. The internship is designed to provide students with an opportunity to obtain real-world experience in business, government agencies, non-profit organizations or research institutes. To be eligible for the internship students will be expected to have completed half of their STEM courses, two business/communication courses, attained a minimum GPA of 3.0 and received departmental permission. Through this experience the student engages in real-world work situations involving technical problems, teamwork, communication skills and decision-making. Students who are employed full-time in a pertinent field may fulfill the internship requirement by completing an approved project, which adds to the students current set of skills. All students will be required to submit a final written report and give an oral presentation on their work at a seminar. All post-internship students will participate in this seminar. All Professional Internships require supervision by program faculty.

Graduate Certificate in Environmental Atmospheric Science

- Admission Requirements
- Certificate Pathway
- Curriculum

This certificate is designed for students who have an interest in the environmental aspects of the Atmospheric Sciences. The intended audience is practitioners in the environmental field who want to broaden their expertise. The target audience would encompass individuals with engineering or science degrees. There are two suggested concentrations (see below) one addressing the needs of individuals interested in air quality the other energy.

Students who successfully complete the Graduate Certificate in Environmental Atmospheric Science at UMass Lowell with a GPA of 3.5 or higher may waive the GRE requirement if applying to the MS Environmental Studies-Atmospheric Science (option) program.

Admission Requirements:

- Baccalaureate degree in science, engineering or similar area from an accredited institution with a minimum GPA of 3.0. This requirement may be waived if the applicant has significant professional experience or submits other evidence supporting the likelihood of academic success.
- Graduate Certificate Application Form.
- Application Fee.
- Official transcript from the baccalaureate (undergraduate) institution.
- Citizens of non-English speaking countries who have never earned an academic degree in the United States must submit TOEFL scores.

Certificate Pathway:

Four courses (minimum of 12 credits) are required for an
Environmental Atmospheric Science Certificate. Required course from Area I and three courses from Area II. For an Air Quality Focus or an Energy Focus, select Area II courses from the appropriate Focus course listing.

Curriculum

**Area I. Foundation Course (3 cr)**
- ATMO.5010
  (https://www.uml.edu/catalog/courses/ATMO/5010) Boundary Layer Meteorology (3 cr)

**Area II. Environmental and Energy Courses (Elect 3) (9 cr)**
- ATMO.5080
  (https://www.uml.edu/catalog/courses/ATMO/5080) The Climate System (3 cr)
- ATMO.5100
  (https://www.uml.edu/catalog/courses/ATMO/5100) Regional Climate and Weather Modeling (3 cr)
- ATMO.5230
  (https://www.uml.edu/catalog/courses/ATMO/5230) Air Pollution Control (3 cr)
- ATMO.5710
  (https://www.uml.edu/catalog/courses/ATMO/5710) Air Pollution
- ATMO.6740
  (https://www.uml.edu/catalog/courses/ATMO/6740) Air Quality Modeling (3 cr)
- ENVI.5720
  (https://www.uml.edu/catalog/courses/ENVI/5720) Energy and Environment (3 cr)
- PUBH.6190
  (https://www.uml.edu/catalog/courses/PUBH/6190) Measurement of Chemical Exposures (3 cr)
- MECH.5210
  (https://www.uml.edu/catalog/courses/MECH/5210) Solar Fundamentals (3 cr)
- MECH.5810
  (https://www.uml.edu/catalog/courses/MECH/5810) Advanced Fluid Mechanics (3 cr)

**Total Credits (12 credits)**

**Air Quality Focus:**
For Area II, select three courses from the suggested courses listed below:
- ATMO.5100
  (https://www.uml.edu/catalog/courses/ATMO/5100)
- ATMO.5230
  (https://www.uml.edu/catalog/courses/ATMO/5230)
- ATMO.5710
  (https://www.uml.edu/catalog/courses/ATMO/5710)
- ATMO.6740
  (https://www.uml.edu/catalog/courses/ATMO/6740)
- PUBH.6190
  (https://www.uml.edu/catalog/courses/PUBH/6190)

**Energy Focus:**
For Area II, select three courses from the suggested courses listed below:
- ATMO.5080
  (https://www.uml.edu/catalog/courses/ATMO/5080)
- ATMO.5100
  (https://www.uml.edu/catalog/courses/ATMO/5100)
- ENVI.5720
  (https://www.uml.edu/catalog/courses/ENVI/5720)
- MECH.5210
  (https://www.uml.edu/catalog/courses/MECH/5210)
- MECH.5810
  (https://www.uml.edu/catalog/courses/MECH/5810)
ATMO.5010 Boundary Layer Meteorology (Formerly 85.501) - Credits: 3

This course draws upon the equations of motion in the atmosphere to develop a theoretical understanding of the atmospheric boundary layer. This understanding is compared with real observations taken with the Department's rawinsonde equipment, as well as published data. The emphasis is on blending theory and practice to enhance the student's understanding of the behavior of the atmosphere.

ATMO.5020 Advanced Synoptic Meteorology (Formerly 85.502) - Credits: 3

This course is designed for graduate students who have a strong background in mathematics and physics, but whose meteorology preparation is weak. The basic concepts of weather forecasting and analysis on synoptic scales are covered theoretically as well as in application to case studies and current weather. The coursework encourages the development of three-dimensional visualization techniques and an appreciation of the physics which controls weather systems.

ATMO.5030 Remote Sensing (Formerly 85.503) - Credits: 3

This course is a survey of ground based, balloon, rocket probe, radar and satellite remote sensing techniques. Optical and radio frequency remote sensing techniques are surveyed. The focus is on the determination of physical, chemical and dynamical quantities by remote sensing measurements. The theory is presented used to interpret data obtained by remote sensing techniques. Various inversion methods are discussed used to obtain spatial discrete quantities from line-of-sight observations. Modeling and simulation techniques are described and practiced.

ATMO.5050 Atmospheric Measurements and Data Analysis - Credits: 3

Against the backdrop of unprecedented global environmental change, meteorological and climatological observations have been thrust into the scientific and public spotlight. ATMO.5050 explores the range of instrumentation, measurement principles, and data analysis techniques used to monitor Earth's ever-changing weather and climate. From hands-on work with state-of-the-art field instruments, to computational data processing and visualization, students will gain a broad set of skills that will position them to succeed in both the observational and computational atmospheric science sub-fields.

ATMO.5080 The Climate System (Formerly 85.508) - Credits: 3

The main elements of the Climate System are the atmosphere, ocean, biosphere, land surface, and the cryosphere; the primary input of energy is from the Sun. This course examines these elements, the ways in which they interact and how they can be modeled. The Global Energy Budget is examined and both natural and human-caused climate change are considered.

ATMO.5100 Regional Weather and Climate Modeling (Formerly 85.510) - Credits: 3

Mesoscale atmospheric dynamics and regional climate dynamics. Application of regional weather and climate model to regional weather, climate modeling and forecast problems. Multi-scale physical processes, such as mesoscale and convective-scale phenomena, low-level jets, mountain waves and orographic precipitation, land/sea breezes, cyclones etc., will be discussed in order to understand the linkage between regional weather and climate.

ATMO.5130 Physical Meteorology (Formerly 85.513) - Credits: 3

This course explores the essentials of cloud physics, beginning with the basic laws of thermodynamics of both dry and moist atmospheres. Condensation, nucleation, and drop growth are studied in detail at an advanced level.

ATMO.5150 Atmospheric Structure and Dynamics (Formerly 85.515) - Credits: 3

The temperature, pressure and density structure of the atmosphere are reviewed, as well as the chemical composition. Topics include atmospheric and solar radiation, atmospheric heat budget and the hypsometric equation. Dynamics of the atmosphere explores the behavior of fluids on a rotating earth, global circulation, synoptic scale motions, perturbation theory of wave motions. Elements of climatic change and the effects of anthropogenic emissions on climate and weather will also be discussed.

ATMO.5160 Mesoscale Atmospheric Dynamics (Formerly 85.516) - Credits: 3

This course is designed for students to apply atmospheric dynamics and physical analysis techniques to mesoscale and convective-scale phenomena, including mesoscale convective systems, severe thunderstorms, tornadoes, dry lines, low-level jets, mountain waves and orographic precipitation, land/sea breezes, boundary layer rolls, and hurricanes. Emphasis will be given to the physical understanding of these processes instead of forecasting.
ATMO.5180 Forecasting and Synoptic Techniques I  
(Formerly 85.518) - Credits: 3

This is the first of a two-course sequence that provides graduate students a combined theoretical and applied understanding of synoptic-scale meteorology, with an emphasis on forecasting applications. The first course introduces the concepts of vorticity advection and the quasi-geostrophic approximation, and applies them synoptic-scale cyclones, including nor’easters. The graduate students will learn to use Gempak graphics and will be introduced to the National Weather Service Weather Event Simulator, a combined hardware and software package that simulates the NWS forecast environment.

ATMO.5230 Air Pollution Control (Formerly 85.523)  
- Credits: 3

This course describes air pollutants, their characterization, ambient concentrations, effects on human health and the ecology, and the environmental laws and regulations that set standards on emission rates and ambient concentrations. The basics of air pollutant dispersion and transport are also covered. The main focus of the course is on emission control technologies for particulate matter, carbon monoxide, sulfur oxides, nitrogen oxides, organic and inorganic toxic pollutants. The following technologies are discussed: cyclones, scrubbers, electrostatic precipitators, baghouses, adsorption, absorption and incineration. The automobile and its emission control are reviewed. Alternative methods are also discussed, such as fuel substitution, conservation and efficiency improvement.

ATMO.5240 Simple Atmospheric Models (Formerly 85.524)  
- Credits: 3

The basic wave types and fundamental dynamics of atmospheric motion are considered through analytical and numerical modeling of the main simplifications (models) of the full equations of motion for the atmosphere. These models are derived by making assumptions that greatly simplify the full equations and which isolate individual wave types and specific physical mechanisms. Together, these models describe the basic aspects of atmospheric motion: the maintenance and structure of the jet stream, the genesis and propagation of synoptic storms, and the forced and internal contributions to seasonal patterns of midlatitude climate variability.

ATMO.5290 Advanced Forecasting (Formerly 85.529)  
- Credits: 3

This course builds on the student’s basic understanding of storm systems and extends their theoretical knowledge to particular weather patterns. Topics include nowcasting, long-range forecasting, snow squalls, sea breeze, and especially deep convection. Particular attention is paid to the structure and development of supercells. Students will also be required to write a special report on a topic assigned by the professor, and present this in class as a special lecture.

ATMO.5400 Tropical Meteorology (Formerly 85.540)  
- Credits: 3

An introduction to the tropical atmosphere, including tropical climatology, structure and dynamics of easterly waves, tropical cyclones and monsoon circulation’s.

ATMO.5500 Satellite and Rad Meteorology  
(Formerly 85.550) - Credits: 3

ATMO.5710 Air Pollution Phenomenology (Formerly 85.571)  
- Credits: 3

The course centers on transport, dispersion and transformation of air pollutants in the atmosphere. Atmospheric structure and dynamics are reviewed. The atmospheric dispersion equation is developed for instantaneous and steady-state releases of pollutants, including the Gaussian Plume Equation for point, line and area sources. The sources and transport of particulate matter are discussed, including haze and visibility impairment. Other topics are photooxidants (ozone), acid deposition, stratospheric ozone depletion and the greenhouse effect.

ATMO.5810 Meteorology for Teachers (Formerly 85.581)  
- Credits: 3

The purpose of this course is to provide the middle school teacher with: a thorough understanding of several key concepts and processes of meteorology; the ability to effectively present meteorology topics that are appropriate for the middle school science classroom; the tools necessary to develop inquiry based lessons for the classroom.

ATMO.5910 Directed Study (Formerly 85.591)  
- Credits: 1-3

ATMO.5950 Professional Experience Atmospheric  
Science (Formerly 85.595) - Credits: 1-3

Professional experience with a private or public employer. Written report and supervisor evaluation required.

ATMO.6410 Special Topics in Meteorology (Formerly 85.641)  
- Credits: 3

ATMO.6420 Special Topics in Meteorology  
(Formerly 85.642) - Credits: 3

ATMO.7010 Graduate Research Seminar (Formerly
85.701) - Credits: 1
ATMO.7310 Master’s Research (Formerly 85.731) - Credits: 1-6
ATMO.7320 Graduate Research (Formerly 85.732) - Credits: 2
ATMO.7330 Master’s Research in Atmospheric Sciences (Formerly 85.733) - Credits: 1-6
ATMO.7430 Master's Thesis in Atmospheric Sciences (Formerly 85.743) - Credits: 1-6
ATMO.7530 Doctoral Dissertation in Atmospheric Sciences (Formerly 85.753) - Credits: 3-8
ATMO.7600 Continuing Graduate Research (PhD) (Formerly 85.760) - Credits: 1-9
Continuing Graduate Research at the PhD level. May be taken for variable credit.

ATMO.7630 PhD Research in Atmospheric Sciences (Formerly 85.763) - Credits: 2
ATMO.7650 Doctoral Dissertation (Formerly 85.765) - Credits: 1-9
ATMO.7680 Doctoral Dissertation (Formerly 85.768) - Credits: 9
ENVI.5000 Graduate Seminar in Environmental Sciences - Credits: 1
The Graduate Seminar in Environmental Sciences includes speaker presentations by invited external and internal faculty, as well as student presentations. Graduate seminar students will also be expected to evaluate professional papers and complete several writing assignments specific to presentations and/or research papers. The class includes interdisciplinary topics in Atmospheric Sciences, Geosciences, and Environmental Sciences. The goals are to improve oral and written communication skills and expand knowledge of state-of-the-art research approaches and research themes.

ENVI.5020 Freshwater Ecology - Credits: 3
Freshwater Ecology is a 3-credit lecture course that covers the basic concepts regarding the physical structure, water quality, and ecological communities of freshwater lake and pond as influenced by the environment. Physical and chemical concepts (e.g., lake circulation patterns, thermal stratification, nutrient budgets, etc.) are incorporated with the lake biota (e.g., phytoplankton, zooplankton, and fish) and synthesized to provide perspective on ecosystem function. Within this scientific framework, we will also study the application of practical lake management using current lake and watershed-based management tools and options.

ENVI.5040 Geographic Information Systems (Formerly 85.504) - Credits: 3
This course will cover most of the elements of a geographic information system commonly found in basic and mid-level GIS applications. Topics will include file organization, data entry including digitizing and image registration, geocoding, thematic mapping, Structured Query Language (SQL) applications, map algebra, raster operations, interpolative methods, distance mapping, density mapping, cost surfaces, and an introduction to modeling. This course will use the Arcview GIS platform.

ENVI.5100 Environmental Pollution - Credits: 3
This class is designed for graduate students in Environmental, Earth and Atmospheric Sciences, Environmental Engineering, Environmental Chemistry and Biology. The class describes the origin, transport, and transformation of pollutants in the environmental behavior and biological impacts of contaminants. Students also will learn about national and international regulations regards pollutant emissions and technology for control and remediation.

ENVI.5160 Climate Change: Science, Communication, and Solutions (Formerly 81.516/BIOL.5160) - Credits: 3
Like many of the 'grand challenges' currently facing society, climate change is a complex problem that cuts across academic disciplines, including the physical sciences, biology, engineering, economics, political sciences, and behavioral psychology. In this course, we integrate recent research from many of these disciplines to explore the scientific basis of climate change, its impacts on the natural world and human society, and societal responses to it. Through interactive simulations, class discussions, lectures, current scientific literature, and student-led projects, the goal of this course is to empower students to come to their own decisions about how society can address the climate change challenge. Students taking this course at the graduate level will lead group projects.

ENVI.5170L Climate Change: Science, Communication, Solutions Recitation Lab - Credits: 1
This course is designed to integrate closely with the lecture course, Climate Change: Science, Communication, and Solutions. Students will use interactive simulations, build models, and create media projects that explore climate change and sustainability. Topics include the physical climate system
and carbon cycle, human energy systems, and climate policy and economics. Students take this course at the graduate level will lead group projects.

**ENVI.5200 Methods in Environmental Impact Assessment and Analysis (Formerly 87.520) - Credits: 3**

This course describes, and illustrates with case studies, environmental evaluation required to implement projects and policies potentially affecting the environment. Methods available to integrate technical impact predictions, prepare Environmental Statements, and make informed decisions regarding environmental effects will be covered. Incorporation of sustainability and permitting with environmental analyses will also be examined.

**ENVI.5500 Earth System Science - Credits: 3**

ENVI.5500 explores a broad range of Earth science disciplines, with a focus on active research areas in each field. Core concepts and research tools from atmospheric science, hydrology, ecology, and geochemistry are reviewed and discussed within the context of major research thrusts. Emphasis will be placed on Earth system changes occurring since the start of the Anthropocene, including those related to climate change, nutrient cycling, land use change, and coastal processes.

**ENVI.5720 Energy and Environment (Formerly 87.572) - Credits: 3**

This course discusses the world and U.S. primary energy resources and consumption, including fossil, nuclear and renewable energy sources. Principles of thermodynamics are reviewed, especially in regard to energy usage efficiency improvement. A significant part of the course is devoted to electricity production, including site visits to fossil and nuclear power plants. The environmental effects are discussed of energy extraction and consumption, such as SOx, NOx and particulate matter emissions, acid deposition, the greenhouse effect, radioactive waste disposal. Also the risks of accidents are discussed in fossil and nuclear fuel usage.

**ENVI.5850 Climate Change in the Classroom (Formerly 87.585) - Credits: 3**

The course is designed to help teachers from all levels improve their ability to foster student learning about the earth’s changing climate. The course addresses the scientific, sociological, and pedagogical dimensions associated with climate change science. How to incorporate climate change into existing curriculum across disciplines is considered.

**GEOL.5010 Paleoclimatology (Formerly 89.501) - Credits: 3**

This course provides students with an overview of paleoclimatology by examining the use of proxy records, such as marine and lake sediment sequences, ice cores, tree rings, corals and historical data to reconstruct past climatic conditions. Dating methods will be introduced. Throughout, we will critically analyze our understanding of past climates and environments and identify directions for future research. Topics include: abrupt climate change, human evolution and climate, biosphere-climate interactions and paleoclimate modeling.

**GEOL.5020 Quantitative Gemorphology (Formerly 89.502) - Credits: 3**

This course follows the path of material as it is weathered form bedrock, moved down hillslopes and transported via glaciers and rivers. Emphasis is on 1) quantifying erosion and sediment transport, 2) applying computer-based models and conservation of mass equations to earth surface processes and 3) understanding long-term landform evolution.

**GEOL.5100 Geology of New England (Formerly 89.510) - Credits: 3**

New England has an ancient and diverse geologic history. This course covers the tectonic and sedimentary processes that formed the bedrock of New England and New York, the Pleistocene history of ice sheet erosion and deposition, and the most recent period of human interactions with the landscape.

**GEOL.5130 Exploring the Solar System - Credits: 3**

We live in a remarkable era of robotic space exploration. In this course, we will walk through the formation of the Solar System and the comparative evolutions of the planets, moons, and other objects form a geological perspective, with special attention paid to the latest research and missions. We will also consider the prospects for life on other planetary bodies in our Solar System and in extrasolar planetary systems.

**GEOL.5150 Topics in Environmental Geochemistry (Formerly 89.515) - Credits: 3**

Case-based course dealing with the application of thermodynamics and kinetics, acid-base equilibria, oxidation-reduction reactions, radioactive and stable isotopes, and mineral chemistry to the understanding and solution of environmental problems. Other topics will be considered based on student interest.

**GEOL.5200 Structural Geology (Formerly 89.520) -**
Credits: 3
An analysis of crustal deformation through detailed study of geologic structures with emphasis upon the response of geologic materials to stress and strain. Field techniques, tectonic principles, and geometrical analysis are employed.

GEOL.5240 Regional Hydrogeology (Formerly 89.524) - Credits: 3
Concentrating on the storage and steady state flow of ground water at a basin-wide scale, the course studies flow nets, fluid potential, and numerical modeling of flow controlled by basingeometry and geology; water movement in the zone of aeration, the interaction of groundwater with surface water, the transport and dispersion of contaminants, and the use of modeling for groundwater management.

GEOL.5250 Groundwater Modeling - Credits: 3
This course covers the concepts and practice of mathematical and numerical modeling of saturated groundwater flow and solute transport. Students will use industry-standard groundwater modeling software, including MODFLOW, MODPATH, MT3DMS, SEAWAT, and PHT3D for single- and variable-density flow, particle tracking, and solute and reactive transport. Emphasis will be on formulating mathematical representations of flow, use of groundwater models with graphical user interfaces, and post-processing and analysis of model results.

GEOL.5310 Isotopes in Environmental and Geosciences (Formerly 89.531) - Credits: 3
The course will show how radioactive and stable isotopes can be used to understand environmental and geological systems. Topics to be covered include radiometric dating using short and long half-life isotopes, radiogenic isotopic tracers, and stable isotopes.

GEOL.5560 Applied Geophysics (Formerly 89.556) - Credits: 3
Application of geophysics to problems in geology and environmental science. Principles and techniques of gravity, magnetic, electrical, and seismic methods. Field projects and surveys.

GEOL.5850 Oceanography for Teachers (Formerly 89.585) - Credits: 3
This course will introduce students to basic oceanographic principles and processes. Content will be linked to National and State Science Standards. Students will create a number of oceanography-based lessons linked to the standards. Pedagogy will be modeled in relation to teacher instruction and student learning.

GEOL.5930 Special Topics: Environmental Geoscience (Formerly 89.593) - Credits: 3
Student/Instructor selected in-depth study of a specific topic(s) within the Environmental Geosciences of a closely related field.

GEOL.7310 Master’s Research in Environmental Geoscience (Formerly 89.731) - Credits: 1-6
GEOL.7410 Master’s Thesis in Environmental Geoscience (Formerly 89.741) - Credits: 1-9
ENVS.5010 Wetlands Ecology (Formerly 18.501) -
Credits: 3
Types, characteristics and definitions, functions and values, regulation and management of wetlands; with due regard given to geology, soils and hydrology, and biological/ecosystem interactions.

ENVS.5810 Understanding Massachusetts Contingency Plan (Formerly 18.581) - Credits: 3
The Massachusetts Contingency Plan (MCP) is a body of regulations designed to streamline and accelerate the assessment and cleanup of releases of oil and hazardous materials to the environment. This course serves as an introduction to the MCP and will explore the intent and use of key aspects of this working document. Though primarily a regulatory course, some topics to be covered are technical by nature. Prerequisites: None. Though not required, some familiarity with relevant environmental science and/or engineering principles is desirable.
IM.769 Continuing Graduate Research (Formerly IM.769) - Credits: 9
Graduate Research.

MARI.6300 Biological Oceanography (Formerly IM.630) - Credits: 3
MARI.6500 Physical Oceanography (Formerly IM.650) - Credits: 3
MARI.7430 Master’s Thesis (Formerly IM.743) - Credits: 3
MARI.7460 Master’s Thesis (Formerly IM.746) - Credits: 6
MARI.7490 Master’s Thesis (Formerly IM.749) - Credits: 9
MARI.7510 Doctoral Dissertation (Formerly IM.751) - Credits: 1-9
Doctoral Dissertation Research

MARI.7530 Doctoral Dissertation (Formerly IM.753) - Credits: 3
Doctoral Dissertation Research

MARI.7550 Doctoral Dissertation (Formerly IM.755) - Credits: 5
Doctoral Dissertation Research

MARI.7560 Doctoral Dissertation (Formerly as IM.756) - Credits: 6
Doctoral Dissertation Research

MARI.7590 Doctoral Dissertation (Formerly IM.759) - Credits: 9
Doctoral Dissertation Research

MARI.7690 Continuing Graduate Research (Formerly IM.769) - Credits: 9
Graduate Research.
MATH.5000 Discrete Structures (Formerly 92.500) - Credits: 3
An introduction to discrete mathematics, including combinatorics and graph theory. The necessary background tools in set theory, logic, recursion, relations, and functions are also included. Masters degree credit for Teacher Option Only.

MATH.5010 Real Analysis (Formerly 92.501) - Credits: 3
The class is aimed to give rigorous foundations to the basic concepts of Calculus such as limits of sequences and functions, continuity, Riemann integration. The main focus is given to rigorous proofs rather than computations. Tentative topics are: Real numbers (algebraic, order and distance structures); Archimedean property; Sequences and their limits. Bolzano-Weierstrass theorem; Cauchy sequences and completeness; Limit of a function; Continuity of a function at a point and on a set; Uniform continuity; Open and closed sets, idea of compactness, compactness of a closed interval; Sequences of functions, uniform convergence; Riemann integration. Prerequisites: Calculus I-III or equivalent.

MATH.5070 Applied Functional Analysis I (Formerly 92.507) - Credits: 3

MATH.5090 Probability and Mathematical Statistics (Formerly 92.509) - Credits: 3
This course provides a solid basis for further study in statistics and data analysis or in pattern recognition and operations research. It is especially appropriate for students with an undergraduate science or engineering major who have not had a rigorous calculus-based probability and statistics course. The course covers the topics in probability models, random variables, expected values, important discrete and continuous distributions, limit theorems, and basic problems of statistical inference: estimation and testing.

MATH.5100 Computers and Calculators in Classroom (Formerly 92.510) - Credits: 3
Explores the roles of computers and calculators in instruction, examines some of the available software, and considers their use in a variety of areas of school mathematics, such as algebra, geometry (Euclidean and analytic) probability and statistics, and introductory calculus. Mathematics Masters degree credit for Teacher Option Only.

MATH.5130 Number Theory (Formerly 92.513) - Credits: 3
Study of primes, congruences, number-theoretic functions, Diophantine approximation, quadratic forms and quadratic number fields. Additional topics as time permits.

MATH.5230 Linear Algebra (Formerly 92.523) - Credits: 3
Sets and maps; vector spaces and linear maps, matrix of linear maps, solving systems of equations, scalar products and orthogonality, eigenvalues and applications. Masters degree credit for Teachers Option Only.

MATH.5260 Topology (Formerly 92.426/526) - Credits: 3
Metric spaces, topological spaces, connectedness, compactness, the fundamental group, classifications of surfaces, Brouwer's fixed point theorem.

MATH.5300 Applied Mathematics I (Formerly 92.530) - Credits: 3
Infinite Series, Complex Algebra, Ordinary Differential Equations, Special Functions, Fourier Series, Vector Spaces, Operators and Matrices.

MATH.5310 Applied Mathematics II (Formerly 92.531) - Credits: 3

MATH.5430 Ordinary Differential Equations (Formerly 92.543) - Credits: 3

MATH.5450 Partial Diff Equations (Formerly 92.545) - Credits: 3
Linear and quasilinear first order PDE. The method of

MATH.5500 Mathematical Modeling (Formerly 92.550) - Credits: 3
Applications of mathematics to real life problems. Topics include dimensional analysis, population dynamics wave and heat propagation, traffic flow. Pre-requisite: 92.132 Calculus II.

MATH.5510 Calculus of Variations (Formerly 92.551) - Credits: 3
The first variational problem, necessary conditions. Euler’s equation. Generalization to dependent and independent variables. Constraints and Lagrange multipliers. Application to dynamics and elasticity. Direct methods.

MATH.5550 Applied Math for Life Scientists (Formerly 92.555) - Credits: 3
The objective of this course is to give students an opportunity to learn how to use a computer algebra system in the context of reviewing some of the key mathematical topics that are used in the life sciences. The first half of the course includes a review of mathematical topics ranging from trigonometry through differential equations. A parallel introduction to a computer algebra system is also included in the first half. In the second half, students will study a mathematical topic such as pattern recognition or models for growth and complete a project using the computer algebra system. (UMassOnline).

MATH.5630 Computational Mathematics (Formerly 92.563) - Credits: 3

MATH.5640 Applied Linear Algebra (Formerly 92.564) - Credits: 3
Use of iterative algorithms to find exact or approximate constrained solutions to large, and often spares, systems of linear equations, and on applications, such as medical imaging, in which such problems arise. Maximization of likelihood and entropy. Emphasis on exploiting sparseness, accelerating convergence, and stabilizing calculations in the presence of noise. Block-iterative methods and bounds for singular values will be included. Basic results in matrix theory presented as needed.

MATH.5650 Special Functions (Formerly 92.565) - Credits: 3
Introduction to functions beyond those studied in calculus and which arise in applied mathematics, including gamma, beta, elliptic, Bessel, orthogonal polynomials ... Asymptotic approximation will be introduced.

MATH.5680 Approximation Theory (Formerly 92.568) - Credits: 3
MATH.5720 Optimization (Formerly 92.572) - Credits: 3
Optimization without calculus; geometric programming; convex sets and convex functions; review of linear algebra; linear programming and the simplex method; convex programming; iterative barrier-function methods; iterative penalty-function methods; iterative least-squares algorithms; iterative methods with positivity constraints; calculus of variations; applications to signal processing, medical imaging, game theory.

MATH.5750 Applied Statistics with R (Formerly 92.575) - Credits: 3
This is a methods course focusing on the applications of statistics using R programming language. Topics include: Study designs, review of inference and regression, categorical data, logistic regression, rates and proportions, and nonparametric methods. Additional topics may be considered if time permits. Only one of 92.575(R) and 92.576(SAS) may be applied toward a Masters degree in Mathematics.

MATH.5760 Statistical Programming using SAS (Formerly 92.576) - Credits: 3
An introduction to creation and manipulation of databases and statistical analysis using SAS software. SAS is widely used in the pharmaceutical industry, medical research and other areas. Cannot be used as a Math Elective.

MATH.5780 Statistical Inference and Data Mining (Formerly 92.578) - Credits: 3
Topics in nonasymptotic direct computational methods for statistical inference in data mining. Background in probability and statistics required.
MATH.5840 Stochastic Process (Formerly 92.584) - Credits: 3
Markov chains and processes, random walks, stationary, independent increments, and Poisson processes. Ergodicity. Examples (e.g., diffusion, queuing theory, etc.).

MATH.5870 Measure and Probability Theory (Formerly 92.587) - Credits: 3
This course presents the mathematical foundations of Probability Theory, including the concepts of Probability Space and random variable. Various types of convergence of sequences and measurable functions will be introduced, and precise statements and proofs of the probability limit theorems (Law of Large Numbers, Central Limit Theorems, etc.) will be given. Theory of measure and Lebesgue integration will be introduced. If time permits, conditional probabilities will be discussed.

MATH.5880 Mathematical Statistics (Formerly 92.588) - Credits: 3
Random variables, densities, joint and conditional distributions, expectations, variance, estimation, sufficiency and completeness, hypothesis testing, limiting distributions.

MATH.5900 Statistical Quality Control (Formerly 92.590) - Credits: 3
Overview of quality and managing quality, Define Measure Analyze Improve Control (DMAIC), the six sigma approach to quality, visual representation of data, Pareto charts, histograms, process capability vs specification (process) limits, t-tests, ANOVA, and other statistical hypothesis testing in quality, normal probability plots, control charts, measurement system analysis, application of regression analysis to manufacturing and/or design, Minitab.

MATH.5910 Linear Statistics Modeling and Regression (Formerly 92.591) - Credits: 3

MATH.5920 Multivariate Statistics (Formerly 92.592) - Credits: 3
Nonlinear model building via the method of least squares. Discriminant and factor analysis, principal components, profile analysis, canonical correlation, cluster analysis. Experience on real data sets.

MATH.5930 Experimental Design (Formerly 92.593) - Credits: 3
How to design, carry out, and analyze experiments. Randomized block designs, randomization, blocking, matching, analysis of variance and covariance, control of extraneous variables.

MATH.6510 Selected Topics in Mathematics (Formerly 92.651) - Credits: 3
Intended to satisfy individual student needs. Topics include various fields of mathematics.

MATH.6530 Selected Topics (Formerly 92.653) - Credits: 3
Advanced topics in various fields of mathematics and related fields. Since topical coverage varies from term to term, a student may be allowed to receive credit more than once for this course.

MATH.7060 Directed Research - Credits: 1-6
Direct supervision with a dissertation advisor.

MATH.7420 Thesis Review (Formerly 92.472) - Credits: 1
MATH.7430 Master's Thesis in Mathematical Sciences (Formerly 92.743) - Credits: 3
Master's Thesis Research.
PHYS.4780 Integrated Optics: Wave Guides and Lasers (Formerly 95.478/578) - Credits: 3

This course is a continuation of 95.477 and serves as an introduction to solid state electronic and optoelectronic devices. The course will cover bipolar junction transistors, field effect transistors, integrated circuits, lasers, switching devices, and negative conductance microwave devices. Three or four practical demonstrations will also be performed with the analysis of the generated data assigned as homework. (offered as 95.548 for graduate credit)

PHYS.5010 Energy, Force and Motion (Formerly 95.501) - Credits: 3

An introduction to the most fundamental area of physics: the nature of motion, what affects it, and how it is measured. We examine Newton’s laws, including the law of gravity, and how forces produce acceleration The course also examines the nature of energy - potential and kinetic - and how it relates to motion and forces. We will concentrate on how to analyze physical situations and solve the basic equations of motion. This course is intended to help teachers develop their understanding of the physics of motion.

PHYS.5170 Space Science Mission Design (Formerly 95.417/517) - Credits: 3

This one-semester, 3-credit course intended for junior level science and engineering majors, is centered around the conceptual design of a spaceflight mission. In this project-based and team-based class, students will apply their science and technical knowledge to develop a spacecraft and mission concept tailored to answer a specific science question. Students will perform quantitative trade studies consistent with real-life constraints such as cost, schedule, manufacturability, team-expertise, operational environment, mission lifetime, etc. Students will 1) learn the fundamentals of key subsystems involved in a space flight mission and 2) apply their skills of inquiry, research, critical thinking to design a complete space science mission to solve a real-world problem while working within a multidisciplinary team.

PHYS.5210 Statistical Thermodynamics (Formerly 95.421/517) - Credits: 3

An integrated study of the thermodynamics and statistical mechanics, review of the experimental foundations and historical development of classical thermodynamics; probability and statistical methods of studying macroscopic systems; atomic basis of the laws of thermodynamics and microscopic definitions of thermodynamics quantities using the method of ensembles; entropy and related quantities; TdS equations, Maxwell relations, equation of state, and applications: canonical and grand canonical ensembles; phase transitions; quantum statistics; application to radiation, magnetism, specific heats. (offered as 95.521 for graduate credit)

PHYS.5360 Introductory Quantum Mechanics II (Formerly 95.536) - Credits: 3

The three dimensional Schroedinger equation, the deuteron nucleus, angular momentum, spin, the hydrogen atom, spin-orbit interaction, Zeeman effect, Pauli exclusion principle, atomic structure, multi-electron atoms, the Fermi gas, X-rays.

PHYS.5370 Geometric Optics - Credits: 3

This course will cover the use of lenses, mirrors, and other optics to construct optical systems. Topics will include paraxial optics, aberrations, two element systems (such as telescopes), and dispersive optics (such as diffraction gratings and binary optics). We will discuss transfer functions, zernike polynomials, ray tracing procedures, and other analysis techniques in order to understand the performance of systems and their aberrations. As time allows we will discuss wave effects including diffraction, interferometry, and other physical effects.

PHYS.5380 Physical Optics and Waves (Formerly 95.538) - Credits: 3

Wave nature of light, mathematics of wave motion, electromagnetic theory of light propagation, reflection and refraction, Fresnel coefficients, polarization, interference, Young’s experiment, fringe visibility and coherence, various interferometers, Newton’s rings and applications, Fraunhofer diffraction by single and multiple apertures and diffraction gratings, Fresnel diffraction.

PHYS.5390 Electro-Optics (Formerly 95.439/539) - Credits: 3

Optical properties of materials, including dispersion, absorption, reflection and refraction at the boundary of two media. Crystal optics and induced birefringence and optical activity. Polarization states and Jones matrices. Applications to electro-optic devices. Experiments and projects involving the study of optical sources and detectors, spectroscopy, polarization, birefringence, pockels’ effect, optical fibers, and optical communication. (offered as 95.539 for graduate credit)

PHYS.5450L Characterization of Materials (Formerly 96.445/545) - Credits: 2

A one-semester course designed to teach the student several of the important techniques for characterizing the structural, optical, and electronic properties of materials. Experiments will
include x-ray diffractometry, hardness measurements, ellipsometry, visible and near infrared spectroscopy, far infrared spectroscopy, and raman spectroscopy.

PHYS.5550 Introduction to Space Physics (Formerly 95.555) - Credits: 3

The course introduces the present knowledge of space phenomena and the physical understanding of the plasma environment from the sun to the earth’s ionosphere and in the heliosphere. Regions in space to be discussed include the solar surface, solar wind, bow shock, magnetosheath, magnetosphere, magnetotail, radiation belts, ring currents, and the ionosphere. Among space plasma physic theories, single particle theory, kinetic theory, and magnetohydrodynamics, which describe charged particle motion in electromagnetic fields and its consequences, are introduced and applied to the space environment.

PHYS.5560 Radiative Processes in Astrophysics (Formerly 95.456/556) - Credits: 3

Our knowledge of the universe beyond the Solar System is derived almost entirely from our interpretation of the radiation we receive from the universe; Our knowledge of the Earth’s upper atmosphere and the atmospheres of other solar system objects is heavily dependent on observations of electromagnetic radiation. To understand the atmospheres of Earth and other planets, stars, galaxies and the universe, we need to understand the processes which produce electromagnetic radiation, and how radiation interacts with matter and propagates through space. This course describes the basic processes which create and alter such electromagnetic radiation before it’s detected here in the Solar System. The course will consist of a combination of lectures, problem sets and class discussion sessions. The lectures will be expanded from the material in the text and will include additional material on the astrophysical and planetary context of radiative processes, drawn primarily from the following list of references. The discussion sessions will often be based on recent problem sets - regular participation of students in class discussions is expected.

PHYS.5630 Computational Methods in Physics - Credits: 3

The course aims to provide an overview of the main and common computational methods currently used in physics research. The course will cover the topics of basic concepts of computational physics, first and second order methods of integration of advection equations, kinetic methods and N-body methods, Monte Carlo and Particle in Cell (PIC) methods, finite elements, finite volume and Computational Fluid Dynamics (CFD), spectral methods, girding methods and Adaptive Mesh Refinement (AMR), and introduction to parallel computing.

PHYS.5640 Particle Astrophysics (Formerly 95.464/564) - Credits: 3


PHYS.5670L Automation Techniques (Formerly 96.567) - Credits: 3

PHYS.5690 Plasma Physics - Credits: 3

The course aims to provide upper level undergraduate and graduate students from Physics and Engineering background in plasma physics, focusing on the fundamental physics principles, not any specific application or field of research. The course will cover the topics of basic plasma concepts, single-particle motion in an electromagnetic field, magnetohydrodynamics, plasma waves, plasma instabilities, plasma kinetics, and some advanced topics in plasma physics.

PHYS.5830 Astronomy and Astrophysics I (Formerly 95.583) - Credits: 3

Physics based introduction to modern Astronomy and Astrophysics. Aimed at students who have already studied E&M Modern Physics, and Calculus. Focus on fundamentals of Stellar Astrophysics and Galactic Astronomy.

PHYS.5870 Cloud Physics (Formerly 95.587) - Credits: 3

This course explores the essentials of cloud physics, beginning with the basic laws of thermodynamics of both dry and moist
atmospheres. Condensation, nucleation, and drop growth are studied in detail at an advanced level.

PHYS.5930L Graduate Physics Laboratory (Formerly 96.593) - Credits: 2

Experiments in various branches of physics including optics, atomic physics, solid state physics and nuclear physics.

PHYS.6050 Mathematical Methods of Physics I
(Formerly 95.605) - Credits: 3

Vector analysis; matrices and determinants; theory of analytical functions; differential equations, Fourier series, Laplace transforms, distributions, Fourier transforms. Students taking PHYS.6050/6060 cannot get credit for PHYS.6070.

PHYS.6060 Mathematical Methods of Physics II
(Formerly 95.606) - Credits: 3

Partial differential equations, boundary value problems, and special functions; linear vector spaces; Green’s functions; selected additional topics; numerical analysis. Students taking PHYS.6050/6060 cannot get credit for PHYS.6070.

PHYS.6070 Mathematical Methods of Physics - Credits: 3

Vector and tensor analysis; Linear spaces; Special functions; Fourier transforms; Theory of complex variables. Students taking PHYS.6070 cannot get credit for PHYS.6050/6060.

PHYS.6110 Classical Mechanics (Formerly 95.611) - Credits: 3


PHYS.6150 Quantum Mechanics I (formerly 95.615) - Credits: 3


PHYS.6160 Quantum Mechanics II (formerly 95.616) - Credits: 3


PHYS.6165 Graduate Quantum Mechanics - Credits: 3

This single-semester course assumes prior exposure to quantum mechanics and is designed to train students in more complex concepts and tools of quantum mechanics. The topics include mathematical framework of complex vector spaces, exactly solvable systems such as harmonic oscillator and spin-half, path integral formalism, continuous and discrete symmetries, gauge invariance and quantum Hall effect, time-independent and time-dependent perturbation theory, second quantization of many-body quantum systems. The aim of the course is to provide foundational conceptual and technical background requisite for advanced elective courses, such as quantum Information, quantum optics, quantum field theory, and/or quantum many-body physics. Students can get credit for either PHYS.6165 or for PHYS.6150/PHYS.6160 Sequence.

PHYS.6170 Advanced Quantum Mechanics I
(formerly 95.617) - Credits: 3

Dirac equation as a single particle wave equation, free particle spinors and plane waves, matrices and relativistic covariance, nonrelativistic approximation and the fine-structure of the H atom. Quantization of the e.m. field in the coulomb gauge; interaction of an atom with the quantized radiation field; radiative transitions in atoms; Thomson scattering; classical and quantized Lagrangian field theory; symmetries and conservation laws: quantization of the real and complex Klein-
Gordon field; Dirac Field and the covariant quantization of the e.m. field; Feynman propagators; the interaction picture and the S-matrix expansion in perturbation theory and the Wick's Rule. Feynman diagrams and rules for calculating S-matrix elements in QED; formulas for cross-section and spin and photon polarization sums; calculation of cross-sections for (1) e++e- l++ l - (2) e++e- e++e- (3) Compton scattering and (4) scattering of electrons by an external e.m. field.

**PHYS.6190 Physics of Quantum Information** - Credits: 3

Introduction of physical concepts behind quantum information processing; Quantum description of physical systems, such as a harmonic oscillator and a single qubit, from an information processing point of view; More complex systems composed of entangled qubits; General tools, rooted in density-matrix formalism, used to describe entanglement and decoherence; Quantum error correction and how it can correct for qubit decoherence to realize fault tolerant computation; Recent advances in engineering quantum information processing platforms, teleportation, and quantum annealing.

**PHYS.6310 Nonlinear Optics (formerly 95.631)** - Credits: 3

Wave propagation in a linear anisotropic medium; Wave propagation in a nonlinear optical medium. Classical model for the origin of nonlinear optical effects; Second order nonlinear optical effects - second harmonic generation, sum and difference frequency generation, linear electro-optical effect; Third order nonlinear optical effects, Kerr effect and intensity dependent nonlinear index of refraction, stimulated Raman and Brillouin scattering; Photorefraction; Nonlinear optical devices.

**PHYS.6570 Electromagnetic Theory I (formerly 95.657)** - Credits: 3

Electrostatics and magnetostatics with special attention to boundary value problems. Quasistatic fields and displacement currents. Maxwell's equations, special relativity, wave-guides, scattering, radiation from accelerated charges, propagation in material media and plasmas, Kramers-Kronig relations.

**PHYS.6580 Electromagnetic Theory II (formerly 95.658)** - Credits: 3

Electrostatics and magnetostatics with special attention to boundary value problems. Quasistatic fields and displacement currents. Maxwell's equations, special relativity, waveguides, scattering, radiation from accelerated charges; propagation in material media and plasmas, Kramers-Kronig relations.

**PHYS.6620 Nuclear Physics II (Formerly 95.662)** - Credits: 3

The nucleon-nucleon force; nuclear models; nuclear reaction theory and partial wave analysis of scattering; fast neutron physics.

**PHYS.6650 Space Physics (Formerly 95.665)** - Credits: 3

This course provides in depth knowledge of space phenomena and physical understanding of the plasma environment form the sun to the earth’s ionosphere and in the heliosphere. Regions in space include solar surface, solar wind, bow shock, magnetosheath, magnetosphere, magnetotail, radiation belts, ring currents, and upper ionosphere. Among space plasma physics theories, single particle theory and magnetohydrodynamics are discussed in depth.

**PHYS.6830 General Relativity** - Credits: 3

Special relativity and Lorentz transformations; Scalar and electromagnetic fields; Curved spacetime and the metric tensor; The equivalence principle; Geodesics, covariant derivatives, and Killing vectors; Einstein’s field equations; The energy conditions; Relativistic cosmology and the expanding Universe; (Special topics: Schwarzschild solution and black holes; Penrose-Carter diagrams; Quantum gravity)

**PHYS.6840 Theoretical Cosmology** - Credits: 3

Geometry, kinematics, and dynamics in an expanding Universe; Thermal history; Generation of standard model particles; Phase transitions; Inflation; quantum origin of primordial inhomogeneities; Scalar, vector, and tensor perturbations; Gravitational instability; Choice of gauge; Matter distribution; Galaxy bias; Redshift space distortions; Cosmic microwave background anisotropies; Baryon acoustic oscillations; Polarization.

**PHYS.7010 Physics Colloquium (Formerly 95.701)** - Credits: 0-1

A series of invited lectures on current research topics in Physics. "Variable credit course, student chooses appropriate amount of credits when registering."

**PHYS.7020 Physics Colloquium (Formerly 95.702)** - Credits: 0-1

A series of invited lectures on current research topics in Physics. "Variable credit course, student chooses appropriate amount of credits when registering."
PHYS.7040 Seminar in Nuclear Physics (Formerly 95.704) - Credits: 0-1

involve presentations by students, faculty members, and visiting scientists of advanced topics, original research or journal articles. "Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7050 Seminar in Solid State/Optics (Formerly 95.705) - Credits: 0-1

involve presentations by students, faculty members, and visiting scientists of advanced topics, original research or journal articles. "Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7051 Supervised Teaching - Physics (Formerly 96.705) - Credits: 0

PHYS.7060 Seminar in Solid State/Optics (Formerly 95.706) - Credits: 0-1

involve presentations by students, faculty members, and visiting scientists of advanced topics, original research or journal articles. "Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7090 Seminar in Accelerator Physics (Formerly 95.709) - Credits: 0-1

A weekly series of presentations and discussions by students and faculty concerning research in progress and planned research at the 5.5 MV Van de Graaff Accelerator. Enrollment in the course is limited to students whose research projects involve the Van de Graaff accelerator. "Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7100 Seminar in Experimental Optics (Formerly 95.710) - Credits: 0-1

A weekly series of presentations and discussions concerning experimental optics research in the University of Massachusetts Lowell Department of Physics and Applied Physics. "Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7110 Graduate Seminar in Physics (Formerly 95.711) - Credits: 0-1

Presentations by students of progress in their research projects. "Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7120 Graduate Seminar in Physics (Formerly 95.712) - Credits: 0-1

Presentations by students of progress in their research projects. "Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7130 Seminar in Theoretical Research (Formerly 95.713) - Credits: 0-1

"Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7140 Seminar in Experimental Research (Formerly 95.714) - Credits: 0-1

"Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7150 Seminar in Terahertz Technology (Formerly 95.715) - Credits: 0-1

Course involves presentations by students, faculty members, and visiting scientists of advanced topics, original research or journal articles relevant to technologies at terahertz frequencies. "Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7160 Seminar in Biomedical Optics (Formerly 95.716) - Credits: 0-1

Seminar in Biomedical Optics, offered at the Advanced Biophotonics Laboratory by Dr. Anna N. Yaroslavsky, covers topics related to recent advances in biomedical optics. Examples include, but are not limited to, the development of individualized, image-based methods of light dosimetry and planning for cancer treatments, concepts and implementation of full inverse Monte Carlo technique for reconstruction of tissue optical properties, investigations of light scattering by complex biological structures and live tissues, development of steady-state and time-resolved polarization, fluorescence and elastic scattering methods for diagnostics and treatment of pathology. "Variable credit course, student chooses appropriate amount of credits when registering."

PHYS.7160L Special Problems In Physics (Formerly 96.716) - Credits: 1-9

Reading in preparation for research, or research not for thesis. If results of the research are to be subsequently incorporated into a thesis, credits earned in this course may be used to satisfy thesis credit requirements in M.S. or Ph.D. Thesis Research with the written permission of the thesis supervisor,
provided such permission is granted at the time of registration for this course. If the results are incorporated in an M.S. project, not more than 3 credits are allowed.

**PHYS.7170 Seminar in Heavy Ion Physics (Formerly 95.717) - Credits: 0-1**

Involves presentations by students, faculty members, and research scientists on advanced topics in heavy-ion spectroscopy, including both original research and journal articles. "Variable credit course, student chooses appropriate amount of credits when registering."

**PHYS.7180 Seminar in Space Physics (Formerly 95.718) - Credits: 0-1**

This course is a weekly seminar covering the areas of conventional "space physics" and extending to "astrophysics" and 'Upper atmospheric physics". Each seminar is focused on a topic that is currently at the cutting edge in these fields while an extended introduction will be given based on diverse background knowledge at graduate level in physics and engineering. "Variable credit course, student chooses appropriate amount of credits when registering."

**PHYS.7190 Seminar in Nanoscale Physics and Technology (Formerly 95.719) - Credits: 0-1**

Students will study the scientific literature on topics and concepts in nanoscale physics and technology, including nanoscale thermal properties, micro-and nano-fluidity, nano-optics, quantum confinement to electronic states, and other phenomena. Students will make presentations and lead discussions on these studies at the frontiers of the field. The presentations will help them to generate new ideas for their own graduate research. Every student will have the opportunity to lead more than one discussion session. "Variable credit course, student chooses appropriate amount of credits when registering."

**PHYS.7200 Medical Physics Seminar - Credits: 0-1**

Current research topics in medical physics, discussed by faculty, students and invited speakers. "Variable credit course, student chooses appropriate amount of credits when registering."

**PHYS.7210 Selected Topics in Physics (Formerly 95.721) - Credits: 3**

Selected topics courses cover recent advances and more advanced topics, not covered in the regular courses in these areas. Subject matter varies, depending on the interests of the instructor and the needs of the students. Subject matter varies sufficiently that these courses may be taken more than once for credit without repeating topics.

**PHYS.7230 Selected Topics in Nuclear Physics (formerly 95.723) - Credits: 3**

Selected topics courses cover recent advances and more advanced topics, not covered in the regular courses in these areas. Subject matter varies, depending on the interests of the instructor and the needs of the students. Subject matter varies sufficiently that these courses may be taken more than once for credit without repeating topics.

**PHYS.7250 Selected Topics in Solid State (formerly 95.725) - Credits: 3**

Selected topics courses cover recent advances and more advanced topics, not covered in the regular courses in these areas. Subject matter varies, depending on the interests of the instructor and the needs of the students. Subject matter varies sufficiently that these courses may be taken more than once for credit without repeating topics.

**PHYS.7270 Selected Topics in Theoretical Physics (formerly 95.727) - Credits: 3**

Selected topics courses cover recent advances and more advanced topics, not covered in the regular courses in these areas. Subject matter varies, depending on the interests of the instructor and the needs of the students. Subject matter varies sufficiently that these courses may be taken more than once for credit without repeating topics.

**PHYS.7310 Advanced Projects In Physics I (formerly 96.731) - Credits: 3**

Research project leading to the Graduate Research Admission Examination (for Ph.D. candidates only.)

**PHYS.7320 Advanced Projects In Physics II (formerly 96.732) - Credits: 3**

Research project leading to the Graduate Research Admission Examination (for Ph.D. candidates only.)

**PHYS.7330 Graduate Project - Physics (formerly 96.733) - Credits: 3**

**PHYS.7460 Master’s Thesis Research Physics (formerly 96.746) - Credits: 0-9**

"Variable credit course, student chooses appropriate amount of credits when registering."
PHYS.7560 Doctoral Dissertation/Physics (formerly 96.756) - Credits: 1-9

Note: Courses with 98 prefix are described in the Radiological Sciences and Protection section of this catalog.

PHYS.7610 Continued Grad Research (formerly 96.761) - Credits: 1

Continued Grad Research

PHYS.7710 Physics Systems Analysis I (formerly 95.771) - Credits: 3

PHYS.7720 Physics Systems Analysis II (formerly 95.772) - Credits: 3

PHYS.7730 Physics Systems Analysis III (formerly 95.773) - Credits: 3

PHYS.8000 Cooperative Education in Physics (formerly 96.800) - Credits: 0-1

Cooperative Education in Physics. "Variable credit course, student chooses appropriate amount of credits when registering."
PSMA.5000 Professional Science Master's (PSM)  
Professional Development (Formerly PSM 500) - Credits: 0

Professional Science Master's students who are preparing to participate in an internship enroll in this Professional Development Seminar prior to the semester of their work period. This seminar will provide them with resources and skills to manage an internship search, secure a position and work successfully in a professional environment.

PSMA.5010 Professional Science Master's (PSM)  
Reflective Seminar. (Formerly PSM 501) - Credits: 1

Reflective seminar following the internship which will enable Professional Science Master's (PSM) students to share and learn from the experiences of colleagues in other settings. The seminar is be conducted on campus and will include writing and oral presentation of experience.

PSMA.5100 Professional Science Master's (PSM)  
Internship (Formerly PSM 510) - Credits: 0

The internship component is expected to be 350 hour minimum and 3-6 month duration. The student will work within a business, government agency or research institute directly related to their area of study. Through this experience the student engages in real world work situations involving technical problems, teamwork, communication skills and decision-making. A student must have completed a minimum of 18 credit hours before commencing the internship. This course records the internship experience and carries zero credits.

PSMA.5350 Project Management for Scientists  
(Formerly PSM 535) - Credits: 3

This course is designed to provide skills to prepare students to take on the role of project manager. The necessity for project Management is now realized by most companies where the entire business including most of the routine activities can be regarded as a series of projects. Project Management principles provide a systematic approach to running a business; both large and small businesses as well as a scientific laboratory.

PSMA.5550 Professional Leadership in Science and Engineering (PSM 555) - Credits: 3

This course is designed to provide awareness and skills to prepare students to take on the role of leader. Part of a technically competent professional’s responsibilities or opportunities for advancement may include leading small projects or work groups. This course will be organized around thematic video interviews with industry leaders to impart knowledge of and experience in leadership topics that support professional development.
RADI.5010L Radiation Safety and Control I (Formerly 98.501) - Credits: 3-4

This course provides a theoretical basis for radiological sciences and protection, with a rigorous review of the fundamentals of radiation physics including nuclear reactions, radioactivity and the kinetics of radioactive decay, natural and man-made radiation sources, the characteristics of ionizing radiation, radioactivity analysis, radiation dose quantities and measurement, external and internal radiation dosimetry, and radiation protection techniques.

RADI.5020L Radiation Safety and Control II (Formerly 95.420/98.502) - Credits: 3-4

This course provides a continuation of the theoretical and practical aspects of radiation protection provided in Radiation Safety and Control I (98.501). Topics include the statistical analyses and data reduction techniques that are used to analyze radiation measurements pertaining to the field of radiation protection. Laboratory sessions on alpha and gamma radiation measurements and air sampling will reinforce class lectures. Students also will experience applied radiation protection and dose assessment through a contamination control exercise that involves the use of protective clothing and respiratory protection.

RADI.5060 Nuclear Instrumentation (Formerly 98.506) - Credits: 3

This course provides the operating principles and applications of nuclear radiation detection systems, including detector theory, electronic signal processing, and measurement and data reduction techniques. The systems covered include gas-filled detectors (ion chambers, proportional counters, and Geiger-Mueller counters), inorganic and organic scintillators, and high-purity germanium detectors, for the detection of alpha, beta, gamma, and neutron radiation. This course also covers hypothesis testing, detection limits, and detector dead time.

RADI.5090 Nuclear Instrumentation (Formerly 96.409) - Credits: 3

This course provides the operating principles and applications of nuclear radiation detection systems, including detector theory, electronic signal processing, and measurement and data reduction techniques. The systems covered include gas-filled detectors (ion chambers, proportional counters, and Geiger-Mueller counters), inorganic and organic scintillators, and high-purity germanium detectors, for the detection of alpha, beta, gamma, and neutron radiation. This course also covers hypothesis testing, detection limits, and detector dead time. This course is adapted for Nuclear Engineering and Medical Physics majors. (offered as 98.509 for graduate credit).

RADI.5240 Environmental Health Physics (Formerly 98.524 & 94.424) - Credits: 3

Natural and man-made sources of environmental radioactivity and radiation; environmental transport in air, water, and soil; exposure pathways; environmental standards and regulations; environmental monitoring and surveys (MARSSIM); contaminated site characterization, and site remediation; environmental radiological impact of industry, accidents, and natural and man-made disasters.

RADI.5330 External Dosimetry and Shielding (Formerly 98.533) - Credits: 3

This course provides the theory and application of dosimetry and shielding for ionizing radiation sources outside the human body. Differential cross-sections, energy transfer and absorption coefficients, kerma, attenuation, and buildup are discussed for photons. Cross-sections, kerma factors, removal coefficients, diffusion, and point-source dose functions for fissioning sources are discussed for neutrons. Beta dosimetry concepts include stopping power, point-source dose functions, and the effects of attenuating materials. Heat generation and temperature profiles are discussed for irradiated materials and radioactive substances. Dosimetry concepts and barrier requirements also are described for particle accelerators, radiotherapy facilities, and medical x-ray imaging facilities.

RADI.5340 Internal Dosimetry and Bioassay (Formerly 98.534) - Credits: 3

RADI.5410 Radiochemistry (Formerly 98.541) - Credits: 3

This course provides the theory and application of several analytical techniques, including precipitation, solvent extraction, ion exchange chromatography, and electrodeposition, to the separation and analysis of radioactive substances in various samples. This course also covers some common radiation detection systems, measurement and data reduction techniques, radiotracer and isotope dilution techniques, neutron activation analysis, and radioimmunoassay.

RADI.5620 Radiation Biology (Formerly 98.562) - Credits: 3

Effects of ionizing radiation on cellular, molecular and organ systems levels of biological organization; Study of x-rays, gamma rays, accelerator beams, and neutrons in interaction with living systems; Cohesive treatment of radiation biophysics with applications in health physics and radiation oncology.
RADI.5650 Introduction to Radiation Therapy Physics
(Formerly 98.565) - Credits: 3
Introduction to the fundamental physics of radiation therapy,
with emphasis on external beam photon and electron therapy
and on brachytherapy. For these modalities, the basic
operation of delivery equipment, treatment planning principles,
methods of dose calculations, determination of time of
irradiation from dose prescription, dose measurements, and
quality assurance will be studied. This knowledge will prepare
the student for an introduction to the practice of clinical
physics in radiation therapy, for advanced radiation therapy
physics, and research in radiation therapy physics.

RADI.5750 Certification Preparation in Radiological
Sciences (Formerly 98.575) - Credits: 3
Advanced problem solving in radiological sciences including
strategies for preparing for and taking professional certification
examinations.

RADI.5820 Numerical Methods In Radiological
Sciences (Formerly 98.582) - Credits: 3
This course provides a more advanced mathematical treatment
of the topics covered in 98.481, with extensive application of
computer techniques to numerical problem solving that is
applicable to radiological sciences and protection.

RADI.5980 Medical Imaging I (Formerly 98.598) -
Credits: 3
Medical Imaging I is the first part of a two course sequence.
Medical Imaging I provides an overview of the medical imaging
modalities, teaches basic underlying physics and mathematics
of medical imaging, describes key modalities in radiographic
imaging, including general x-ray radiography, fluoroscopy, and
mammography.

RADI.6050 Radiation Interactions and Transport
(Formerly 98.605) - Credits: 3
Photon, neutron, and electron interactions and energy
deposition; the Boltzmann equation, elementary analytical
solutions; deterministic computational methods, including
spherical harmonics and discrete ordinates techniques;
continuous slowing down and Fokker Planck approximations.

RADI.6310L Professional Health Physics Internship
(Formerly 98.631) - Credits: 1-3
The student will be introduced to the physics of advanced
treatment techniques used in radiation therapy, which include
external beam electron, proton, and photon therapy and
internal brachytherapy. For these techniques, the principles of
the techniques such as clinical applications, radiation delivery
equipment, treatment planning methods, methods of dose
calculations, determination of time of irradiation from dose
prescription, dose measurements, and quality assurance will be
studied. This knowledge will prepare the student for an
introduction to the clinical practice of medical physics applied
to complex treatment techniques used in radiation therapy.
Also, this should help prepare the student for research in
radiation therapy physics.

RADI.6710L Graduate Accelerator HP Internship
(Formerly 98.671) - Credits: 3

RADI.6720 Graduate Reactor HP Internship (Formerly
98.672) - Credits: 1-3

RADI.6730L Graduate Reactor HP Internship
(Formerly 98.673) - Credits: 3

RADI.6750L Graduate Medical HP Internship
(Formerly 98.675) - Credits: 3

Clinical Rotation under the direction of clinical staff. This
course provides the student with exposure to medical physics
responsibilities in a radiation oncology department, including
simulation, treatment planning and preparation, monitor unit
calculations, dose measurements and calculations, treatment
delivery techniques, quality assurance, and radiation safety.

RADI.6770L Graduate Medical Physics Internship
(Formerly 98.677) - Credits: 3

RADI.6780L Graduate HP Internship (Formerly
98.678) - Credits: 1-3
Clinical Rotation under the direction of clinical staff. This course involves the student in one or more projects that require skill development, extended involvement, and project completion, which includes planning and delivery of advanced radiation therapy treatments.

RADI.6790L Graduate HP Internship (Formerly 98.679) - Credits: 1-3
RADI.6830L Graduate HP Internship (Formerly 98.683) - Credits: 3
RADI.6850L Advanced Medical HP Internship (Formerly 98.685) - Credits: 3
RADI.6860L Advanced Medical Physics Internship (Formerly 98.686) - Credits: 1-9

RADI.6870L Advanced Medical Physics Internship (Formerly 98.687) - Credits: 3
RADI.6890L Advanced Graduate HP Internship (Formerly 98.689) - Credits: 1
RADI.6900L Advanced Graduate HP Internship (Formerly 98.690) - Credits: 2
RADI.6910L Advanced Graduate HP Internship (Formerly 98.691) - Credits: 2
RADI.6920L Advanced Graduate HP Internship (Formerly 98.692) - Credits: 3
RADI.6930L Advanced Graduate HP Internship (Formerly 98.693) - Credits: 3
RADI.6980 Medical Imaging II (Formerly 98.599) - Credits: 3

RADI.6790L Graduate HP Internship (Formerly 98.679) - Credits: 1-3
RADI.6830L Graduate HP Internship (Formerly 98.683) - Credits: 3
RADI.6850L Advanced Medical HP Internship (Formerly 98.685) - Credits: 3
RADI.6860L Advanced Medical Physics Internship (Formerly 98.686) - Credits: 1-9

RADI.6870L Advanced Medical Physics Internship (Formerly 98.687) - Credits: 3
RADI.6890L Advanced Graduate HP Internship (Formerly 98.689) - Credits: 1
RADI.6900L Advanced Graduate HP Internship (Formerly 98.690) - Credits: 2
RADI.6910L Advanced Graduate HP Internship (Formerly 98.691) - Credits: 2
RADI.6920L Advanced Graduate HP Internship (Formerly 98.692) - Credits: 3
RADI.6930L Advanced Graduate HP Internship (Formerly 98.693) - Credits: 3
RADI.6980 Medical Imaging II (Formerly 98.599) - Credits: 3

RADI.6870L Advanced Medical Physics Internship (Formerly 98.687) - Credits: 3
RADI.6890L Advanced Graduate HP Internship (Formerly 98.689) - Credits: 1
RADI.6900L Advanced Graduate HP Internship (Formerly 98.690) - Credits: 2
RADI.6910L Advanced Graduate HP Internship (Formerly 98.691) - Credits: 2
RADI.6920L Advanced Graduate HP Internship (Formerly 98.692) - Credits: 3
RADI.6930L Advanced Graduate HP Internship (Formerly 98.693) - Credits: 3
RADI.6980 Medical Imaging II (Formerly 98.599) - Credits: 3

RADI.6890L Advanced Graduate Seminar in Radiological Sciences (Formerly 98.712) - Credits: 0-1
"Variable credit course, student chooses appropriate amount of credits when registering."

RADI.7120 Graduate Seminar in Radiological Sciences (Formerly 98.712) - Credits: 0-1
"Variable credit course, student chooses appropriate amount of credits when registering."

RADI.7310L Advanced Project in Radiological Sciences I (Formerly 98.731) - Credits: 3-6
RADI.7320L Advanced Project in Radiological Sciences II (Formerly 98.732) - Credits: 3
RADI.7330 Graduate Project in Radiological Sciences and Protection (Formerly 98.733) - Credits: 3-6
RADI.7430 Master's Thesis in Radiological Sciences and Protection (Formerly 98.743) - Credits: 3
RADI.7460 Master's Thesis in Radiological Sciences and Protection (Formerly 98.746) - Credits: 1-9
RADI.7490 Master's Thesis Research in Radiological Sciences (Formerly 98.749) - Credits: 9
RADI.7530L Doctoral Dissertation in Radiological Sciences and Protection (Formerly 98.753) - Credits: 3
RADI.7560 Doctoral Dissertation in Radiological Sciences and Protection (Formerly 98.756) - Credits: 1-9
RADI.7590L Doctoral Dissertation in Radiological Sciences and Protection (Formerly 98.759) - Credits: 9
RADI.7690 Continued Graduate Research (Formerly 98.769) - Credits: 9

RADI.7050 Supervised Teaching in Radiological Sciences (Formerly 98.705) - Credits: 0
RADI.7110 Graduate Seminar in Radiological Sciences (Formerly 98.711) - Credits: 0-1
"Variable credit course, student chooses appropriate amount of credits when registering."