

MOLECULAR, CELLULAR, AND DEVELOPMENTAL BIOLOGY

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The science of biology is extremely broad, ranging across the domains of molecules, cells, tissues and organs, organisms, and ecosystems. Moreover, biology explores questions of evolutionary history and the processes of evolutionary change, as well as the mechanisms by which cells, organisms, and ecosystems function. Students majoring in Molecular, Cellular, and Developmental Biology receive a thorough yet varied liberal education and preparation for professional careers in a diverse array of fields. Practical applications of biology include the development of biologicals and pharmaceuticals, the practice of medicine, and the pursuit of the scientific bases for understanding the development and function of biological systems.

Molecular, Cellular, and Developmental Biology (MCDB) offers programs for students wishing to concentrate on molecular and cellular biology and genetics, with applications to problems in cell and developmental biology, neurobiology, and various aspects of quantitative biology. Interdisciplinary opportunities are available within the major in the Biotechnology, Neurobiology, and Quantitative Biology concentrations (previously tracks).

The MCDB major offers many opportunities for independent laboratory research. With approval, research can be conducted under the supervision of faculty members in any Yale department.

PREREQUISITES

Most but not all of the MCDB courses require prior preparation in biological science. First years should take BIOL 101, 102, 103, and 104 or contact the director of undergraduate studies (DUS) for more information. All majors must also complete a course in mathematics numbered MATH 115 or higher or a statistics course (S&DS 100, S&DS 101-109, or S&DS 238), and other statistic courses taken at Yale with approval from the DUS.

For the B.A. degree, students must take a two-term lecture sequence in chemistry, usually in their first year, and a term course in physics numbered PHYS 170 or higher usually in their junior year.

For the B.S. degree, students must take a two-term lecture sequence in chemistry, with associated laboratories usually in their first year; a term course in organic chemistry with its associated laboratory usually in their sophomore year; and two term courses in physics numbered PHYS 170 or higher usually in their junior year.

PLACEMENT PROCEDURES

Placement in MCDB courses is determined by examinations administered at Yale or by permission of the DUS. A student may place out of one or more courses in the BIOL 101-104 sequence. One or more of these foundational biology courses (or equivalent

performance on the corresponding biological sciences placement examination) may be explicitly required as prerequisites for upper-level MCDB courses. Students that place out of two BIOL modules will be required to take an additional credit in MCDB's core courses.

Placement in chemistry courses is arranged by the Department of Chemistry. Because required chemistry courses are prerequisite to several MCDB courses, students are strongly encouraged to take general and organic chemistry in the first and/or sophomore years. Students who place out of general chemistry may want to consider taking organic chemistry during the first year. Finishing the prerequisites early allows for a more flexible program in later years.

Acceleration credit awarded in chemistry, mathematics, or physics, or completion of advanced courses in those subjects, is accepted in place of the corresponding prerequisites for the MCDB major. Students who have mathematics preparation equivalent to MATH 115 or higher are encouraged to take additional mathematics courses, such as MATH 120, 121, 222, or 225, or ENAS 151 or 194. Students in the B.A. degree program who have satisfied one or more prerequisites with advanced placement must still complete three term courses in chemistry and physics at Yale, including at least one from each department.

REQUIREMENTS OF THE MAJOR

B.A. degree program The B.A. degree requires a minimum of five and one-half course credits beyond the prerequisites, including five lecture or seminar courses and one laboratory, as follows:

1. Two core courses selected from MCDB 200, 202, 205, 210, 290, 300 (or MB&B 300)
2. Two general electives selected from MCDB courses numbered 250 or above, or two additional core courses from the list above. Two laboratory courses, either MCDB 342L and 343L or MCDB 344L and 345L, can be paired for a single elective credit. If used as an elective, these laboratories cannot also fulfill the laboratory requirement
3. One special elective selected from MCDB courses numbered 350 or higher
4. One laboratory from the biological sciences. Laboratories may be selected from MCDB, Molecular Biology and Biophysics, or Biomedical Engineering, or, with permission of the DUS, from Anthropology or Ecology & Evolutionary Biology
5. The senior requirement (senior essay option does not carry course credit)

B.S. degree program The B.S. degree requires a minimum of nine course credits beyond the prerequisites, including eight lecture or seminar courses and two laboratories, as follows:

1. Three core courses selected from MCDB 200, 202, 205, 210, 290, 300 (or MB&B 300)
2. Two general electives selected from MCDB courses numbered 250 or above. Additional core courses from the list above, a second term of organic chemistry, and a course in statistics may be used as general electives. Two laboratory courses, either MCDB 342L and 343L or MCDB 344L and 345L, can be paired for a single elective

credit. If used as an elective, these laboratories cannot also fulfill the laboratory requirement

3. One special elective from MCDB courses numbered 350 or higher
4. Two laboratories from MCDB
5. The senior requirement (2 course credits), described below

The B.S. degree program, intensive major Requirements for the B.S. degree program, intensive major, are the same as those for the B.S. degree except for the senior requirement (see below). This degree requires eleven course credits beyond the prerequisites, including 6 courses, 2 half-credit labs, and 2 senior research courses, each worth two credits.

Independent research courses before senior year The only independent research course available to students prior to the senior year is MCDB 474. This course is graded Pass/Fail and contributes to the thirty-six course credits required for the bachelor's degree, but it does not substitute for any MCDB major requirement, including the senior requirement. No independent research course satisfies a lab requirement for the MCDB major.

Independent research courses during senior year The research courses MCDB 475, 485, 486, and 495, 496 exist primarily to fulfill the senior requirement, and do not satisfy any other requirement for the major. Note that Yale College limits the number of independent study or independent research courses that students may take; see Academic Regulations, section C, Course Credits and Course Loads. Any independent study course, regardless of its number, is included in the total. No independent research course satisfies a lab requirement for the MCDB major.

Credit/D/Fail No course taken Credit/D/Fail may be counted toward the MCDB major, including prerequisites.

SENIOR REQUIREMENT

In addition to the course requirements described above, all students must satisfy a senior requirement undertaken during the senior year. A booklet listing the senior requirements of each concentration and degree is available in the office of the DUS (111 YSC). All students must fill out a checklist of requirements and go over it with the MCDB undergraduate registrar, (mcdb.ureg@yale.edu) by the spring term of the junior year.

B.A. degree program For the B.A. degree, the senior requirement can be met either by submitting a senior essay of 15–20 pages evaluating current research in a field of biology, or by successful completion of one term of individual research (MCDB 475). A student choosing to fulfill the requirement with a senior essay must consult with a faculty adviser on the scope and literature of the topic and submit the adviser's written approval to the DUS no later than the course selection period of the term in which the paper is due. The senior essay may be related to the subject matter of a course, but the essay is a separate departmental requirement in addition to any work done in a course and does not count toward the grade in any course. The senior essay must be completed and submitted to the office of the DUS by the last day of classes. Students electing this option should obtain an approval form from the office of the DUS. Students who select this option should be aware it carries no credit.

B.S. degree program For the B.S. degree, the senior requirement is usually fulfilled by completing a yearlong research course, MCDB 485, 486. The senior requirement must be completed during the senior year. Yale College does not grant academic credit for summer research unless the student is enrolled in an independent research course in Yale Summer Session. Seniors working toward the B.S. degree are expected to spend at least ten hours per week in the lab conducting individual research.

B.S. degree program, intensive major Requirements for the B.S. degree with an intensive major are the same as those for the B.S. degree except that students fulfill the senior requirement by taking MCDB 495, 496 for four course credits. Seniors in the intensive major are expected to spend at least twenty hours per week in the lab conducting individual research.

ADDITIONAL INFORMATION AND ADVISING

The prerequisites for the B.S. degree fulfill most of the usual premedical science requirements. Students who choose the B.A. degree can also prepare for medical school by taking additional premedical courses.

Selection of courses A relevant intermediate or advanced course from another department in science, engineering, mathematics, or statistics may be accepted as an elective with permission of the DUS. Many courses in other departments have prerequisites; such prerequisites can be substituted for an upper-level elective with permission of the DUS.

Residential College Seminars cannot be substituted for electives and do not count toward the requirements of the major. The MCDB major should not be taken as one of two majors with Molecular Biophysics and Biochemistry, Ecology and Evolutionary Biology, or Neuroscience.

Advising First-year students considering a major in Molecular, Cellular, and Developmental Biology are invited to consult with the DUS and/or a faculty member in MCDB who is a fellow of their residential college. MCDB majors are required to meet with the MCDB faculty adviser and the departmental undergraduate registrar (mcdb.ureg@yale.edu) once per term and prior to registration. For assistance in identifying a suitable adviser, students should contact the departmental undergraduate registrar. (mcdb.ureg@yale.edu) Students in the Biotechnology, Neurobiology, or Quantitative Biology concentrations should consult an adviser for their concentration (listed below). Students whose regular adviser is on leave can consult the office of the DUS to arrange for an alternate.

College faculty advisers available to first-year students are listed below.

BF	D. Kankel	MC	H. Keshishian
BK	V. Irish, J. Wolenski, S. Bahmanyar	MY	D. Clark, C. Crews
BR	I. Dawson, T. Emonet, S. Hatzios, J. van Wolfswinkel, D. Breslow	PC	J. Carlson, V. Horsley, N. Dimitrova, J. Yan
DC	P. Forscher, W. Zhong	SM	S. Dellaporta
ES	TBD	SY	S. Nachtergaele
GH	M. Mooseker, R. Wyman	TC	Y. Jacob, M. Moreno
JE	R. Breaker, F. Isaacs	TD	S. Holley

Simultaneous B.S./M.S. degree program Exceptionally able and well-prepared students may accelerate their professional education by completing a course of study leading to the simultaneous award of the B.S. and M.S. degrees after eight terms of enrollment. Students may not enroll in Yale College for more than eight terms in order to qualify for the simultaneous award of both degrees. It is possible to earn both degrees in fewer than eight terms, but not by the use of acceleration credits. The requirements are as follows:

1. Candidates must satisfy the Yale College requirements for the B.S. degree. Students in the program must complete the core courses for the major and choose their 4 electives from graduate-level courses. One of the electives must be a graduate seminar selected with the approval of the DUS. Grades below B- in graduate courses are not accepted.
2. In addition to the courses specified above, students must complete three terms of graduate research courses for six course credits: (1) MCDB 585, a two-credit course taken in the second term of the junior year. At the start of the course, each student forms a committee comprised of the faculty adviser and two faculty members that meets to discuss the research project. Two of the members of this committee must be members of the MCDB faculty. At the end of the course, the student completes a detailed prospectus describing the thesis project and the work completed to date. The committee evaluates an oral and written presentation of the prospectus and determines whether the student may continue in the combined program; (2) MCDB 595, 596, a four-credit, yearlong course that is similar to MCDB 495, 496 and is taken during the senior year. During the course, the student gives an oral presentation describing the work. At the end of the course, the student is expected to present his or her work to the department in the form of a poster presentation. In addition, the student is expected to give an oral thesis defense, followed by a comprehensive examination of the thesis conducted by the thesis committee. Upon successful completion of this examination, as well as all other requirements, the student is awarded the combined B.S./M.S. degree.

Students must also satisfy the requirements of Yale College for the simultaneous award of the bachelor's and master's degrees, including the following:

1. To be considered for admission to the program, by the end of their fifth term of enrollment students must have achieved at least two-thirds A or A- grades in all of their courses as well as in all of the courses directly relating to the major, including prerequisites.
2. Students must apply in writing to the DUS and obtain departmental approval no later than the last day of classes in their fifth term of enrollment in Yale College.
3. Students must have the approval of both the DUS and the director of graduate studies to receive graduate credit for the graduate courses they select.
4. Graduate work must not be entirely concentrated in the final two terms, and students in the program must take at least six term courses outside the department during their last four terms at Yale and at least two undergraduate courses during their last two terms.
5. Students must earn grades of A in at least two of their graduate-level term courses (or in one yearlong course) and have at least a B average in the remaining ones.

For more information, see Academic Regulations, section L, Special Academic Arrangements, “Simultaneous Award of the Bachelor's and Master's Degrees.”

STUDY ABROAD

Some programs for study abroad are available to MCDB majors. Approved programs can fulfill some of the requirements for the major. Interested students should consult the DUS and the Center for International and Professional Experience.

SUMMARY OF MAJOR REQUIREMENTS

Prerequisites *B.A.* — BIOL 101, 102, 103, 104; a two-term lecture sequence in chem; one term of PHYS 170 or above; MATH 115 or above or a Yale statistics course approved by the DUS; *B.S.* — same as for the *B.A.* degree, in addition to labs associated with a two-term lecture sequence in chem; 1 term of organic chem with lab; two terms of physics, PHYS 170 or above

Number of courses *B.A.* — 5 courses and 1 lab, totaling at least 5½ course credits beyond the prereqs; *B.S.* — 8 courses and 2 labs, totaling at least 9 course credits beyond the prereqs; *B.S., intensive* — 8 courses and 2 labs, totaling at least 11 course credits beyond prereqs

Specific courses required *Neurobiology concentration* — MCDB 320; *Biotechnology concentration* — MCDB 370; *Quantitative Biology concentration* — MCDB 330

Distribution of courses *B.A.* — 2 core courses from MCDB 200, 202, 205, 210, 290, 300 (or MB&B 300); 2 electives numbered MCDB 250 or above (or 2 addtl core courses); 1 elective numbered MCDB 350 or above; 1 biology lab; *B.S. and B.S. intensive* — 3 core courses from MCDB 200, 202, 205, 210, 290, 300 (or MB&B 300); 2 electives numbered MCDB 250 or above (or 2 addtl core courses); 1 elective numbered MCDB 350 or above; 2 MCDB labs; *Biotechnology, Neurobiology, and Quantitative Biology concentrations* — same as *B.A.* and *B.S.* degree programs, with a specific req (MCDB 320, 330, or 370) and 1 addtl concentration-related elective in place of 2 general electives

Senior requirement *B.A.* — MCDB 475 taken in senior year, or senior essay; *B.S.* — 2 consecutive terms of independent research in senior year, MCDB 485, 486; *B.S., intensive major* — MCDB 495, 496 in senior year (each course is worth 2 credits)

Prerequisites for the B.S. Degree and B.S. Intensive Degree

- BIOL 101
- BIOL 102
- BIOL 103
- BIOL 104
- 2-term lecture sequence in chemistry with associated labs
- 1 organic chemistry course with associated lab
- 2 physics courses, PHYS 170 or above
- MATH 115 or above or a Yale statistics course approved by the DUS

Prerequisites for the B.A. Degree

- BIOL 101
- BIOL 102

- BIOL 103
- BIOL 104
- 2-term lecture sequence in chemistry
- PHYS 170 or above
- MATH 115 or above or a Yale statistics course approved by the DUS

Note: If pursuing a concentration the following course is required for all degrees. One additional elective is required - See Concentrations.

- *Neurobiology concentration*—MCDB 320
- *Biotechnology concentration*—MCDB 370
- *Quantitative Biology concentration*—MCDB 330

Requirements for the B.S. Degree

6 courses, 2 half-credit labs, 2 senior requirement research courses (9 credits), beyond prereqs

- 3 core courses from MCDB 200, MCDB 202, MCDB 205, MCDB 210, MCDB 290, MCDB 300 (or MB&B 300)
- 2 electives numbered MCDB 250 or above (or 2 additional core courses from the list above or MCDB 342L and 343L or MCDB 344L and 345L, which can be paired for a single elective credit)
- 1 elective numbered MCDB 350 or above
- 2 MCDB half-credit labs
- 2 independent research courses in senior year, MCDB 485 and MCDB 486

Requirements for the B.S. Intensive Degree

6 courses, 2 half-credit labs, and 2 senior requirement research courses for 2 credits each (11 credits), beyond prereqs

- 3 core courses from MCDB 200, MCDB 202, MCDB 205, MCDB 210, MCDB 290, MCDB 300 (or MB&B 300)
- 2 electives numbered MCDB 250 or above (or 2 additional core courses from the list above or MCDB 342L and MCDB 343L or MCDB 344L and MCDB 345L, which can be paired for a single elective credit)
- 1 elective numbered MCDB 350 or above
- 2 MCDB half-credit labs
- MCDB 495 (2 credits)
- MCDB 496 (2 credits)

Requirements for the B.A. Degree

5 courses and 1 lab (5.5 credits), does not include the senior requirement or the prerequisites

- 2 core courses selected from MCDB 200, MCDB 202, MCDB 205, MCDB 210, MCDB 290, MCDB 300 (or MB&B 300)

- 2 electives numbered 250 or higher (or 2 additional core courses from the list above or MCDB 342L and MCDB 343L or MCDB 344L and MCDB 345L, which can be paired for a single elective credit)
- 1 lab from the biological sciences
- 1 MCDB elective numbered 350 or higher
- MCDB 475, or a senior essay that does not carry course credit

CONCENTRATIONS

In addition to the requirements for the B.A. degree or the B.S. degree programs, students interested in pursuing a concentration (previously referred to as a track) within the MCDB major must complete one required course and one elective from the list of approved courses as indicated. The difference between the standard major and the concentrations is that the two required general electives are more specific for the various concentrations. The laboratory requirement, special elective (MCDB 350 and above) and the senior requirement are the same as those for the B.A. degree or the B.S. degree programs. No substitutions are provided for the concentrations.

NEUROBIOLOGY CONCENTRATION

The Neurobiology concentration requires MCDB 320 and one elective course from BENG 410, CPSC 475, MCDB 250, 310, 315, 361, 415, 425, 430, 440, PSYC 376, or S&DS 101. Students should note that PSYC 110 is a prerequisite for many psychology courses but does not substitute as an elective in the Neurobiology track. Students interested in the Neurobiology concentration should consult an adviser for the track.

Neurobiology concentration advisers

J. Carlson, 206 YSB (432-3541)
 D. Clark, C148 YSB (432-0750)
 T. Emonet, C169 YSB (432-3516)
 P. Forscher, 120 YSB (432-6344)
 H. Keshishian, 228 YSB (432-3478)
 M. O'Donnell, 110 YSB (436-1934)
 W. Zhong, 225 YSB (432-9233)

BIOTECHNOLOGY CONCENTRATION

The Biotechnology concentration requires MCDB 370 and one elective course from MB&B 420, 421, 443, BENG 351, 352, 410, 435, 457, 463, 464, CENG 210, 411, 412L, CPSC 437, 445, 470, or 475. Students interested in the Biotechnology concentration should consult an adviser for the track.

Biotechnology concentration advisers

R. Breaker, 311 YSB (432-9389)
 C. Crews, 250 YSB (432-9364)
 F. Isaacs, 141 YSB (432-3783)
 K. Nelson, 137 YSB (432-5013)
 J. Wolenski, C112 YSB (432-6912)

QUANTITATIVE BIOLOGY CONCENTRATION

The Quantitative Biology concentration requires MCDB 330 and one elective course from MCDB 320, 361, 461, BENG 463, 467, CPSC 440, 475, MB&B 302, 435, 452, 523,

PHYS 402, MATH 246, 251, or CPSC 475, 440. Students interested in the Quantitative Biology concentration should consult an adviser for the track.

Quantitative Biology concentration advisers

D. Clark, C148 YSB (432-0750)

T. Emonet, C169 YSB (432-3516)

D. Kankel, 111 YSB (432-3532)

For a summary of the requirements, see the Overview page.

The major in Molecular, Cellular, and Developmental Biology (MCDB) offers programs for students interested in molecular biology; neurobiology; cell biology, genetics, and their applications to problems in cell and developmental biology; and various aspects of computational biology. Concentrations in biotechnology, neurobiology, and quantitative biology offer interdisciplinary opportunities.

Students have the opportunity to carry out independent research, which may consist of laboratory or field work. Those who are particularly interested in research can elect either a standard B.S. degree or a B.S. degree with an intensive major, in which research occupies up to half of the senior year. Programs to study abroad that fulfill some MCDB requirements are available. The MCDB major provides excellent preparation for medical school and the health professions as well as for a wide range of professional careers in the biological sciences, biotechnology, law, conservation, and science writing.

Prospective majors and other students who have not had biology courses in high school should take the foundational sequence BIOL 101–104, which provides a solid grounding in modern biological science. If students have background in biology, they can place out of individual modules of BIOL 101–104 with a placement examination given in the summer or by permission of the MCDB DUS. Students that place out of two BIOL modules will be required to take an additional credit in MCDB's core courses.

These courses are prerequisite to all majors in the biological sciences. Students who take them along with chemistry courses during the first year will have more flexible programs in later years. The sequence consists of the following half-term, half-credit courses:

- BIOL 101, Biochemistry and Biophysics
- BIOL 102, Principles of Cell Biology
- BIOL 103, Genetics and Development
- BIOL 104, Principles of Ecology and Evolutionary Biology

The department also offers courses with no college-level prerequisites that are intended for non-science majors:

- MCDB 040, The Science and Politics of Cancer
- MCDB 050, Immunity and Microbes
- MCDB 065, The Science and Politics of HIV/AIDS
- MCDB 070, Human Biology
- MCDB 103, Cancer
- MCDB 105, Biology, the World, and Us
- MCDB 106, Biology of Malaria, Lyme, and Other Vector-Borne Diseases

- MCDB 109, Immunity and Contagion
- MCDB 175L, Exploring the Microbial World

Students in the first year should consult with their faculty adviser or a faculty member in the Molecular, Cellular, and Developmental Biology department for advice on which courses to take. For additional information, visit the department website, or contact Douglas Kankel (douglas.kankel@yale.edu) the Director of Undergraduate Studies, or Andrea Chamba the MCDB undergraduate registrar. (mcdm.ureg@yale.edu)

FACULTY OF THE DEPARTMENT OF MOLECULAR, CELLULAR, AND DEVELOPMENTAL BIOLOGY

Professors Ronald Breaker, John Carlson, †Lynn Cooley, Craig Crews, Stephen Dellaporta, Thierry Emonet, Paul Forscher, †Mark Hochstrasser, Scott Holley, Vivian Irish, †Akiko Iwasaki, Douglas Kankel, †Paula Kavathas, Haig Keshishian, Mark Mooseker, Thomas Pollard, Anna Pyle, Joel Rosenbaum, †Hugh Taylor

Associate Professors Damon Clark, Joshua Gendron, Valerie Horsley, Farren Isaacs, †Megan King, †Kathryn Miller-Jensen, Weimin Zhong

Assistant Professors Shirin Bahmanyar, David Breslow, Nadya Dimitrova, Stavroula Hatzios, Yannick Jacob, Binyam Mogessie, Sigrid Nachtergaele, Michael O'Donnell, Josien van Wolfswinkel, Jing Yan

Professor Adjunct Robert Bazell

Lecturers †Meghan Bathgate, †Alexia Belperron, Francine Carland, †Surjit Chandhoke, Iain Dawson, †Seth Guller, Amaleah Hartman, Ronit Kaufman, Rebecca LaCroix, Thomas Loreng, †Elizabeth Luoma, Maria Moreno, Kenneth Nelson, †Aruna Pawashe, Joseph Wolenski

†A secondary appointment with primary affiliation in another department or school.

See visual roadmap of the requirements.

View Courses