Computational Biology Program

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Bachelor of Science in Computational Biology

Success in computational biology requires significant technical knowledge of fundamental computer science as well as a broad biological intuition and general understanding of experimental biology. However, most importantly, it requires students who can integrate their knowledge by making connections between the two fields.

There is significant industry demand for excellent computational biology students, in biotech, pharmaceuticals, and biomedical research. Both established companies and startups struggle to find employees with the correct skillset, and our students will be able to take advantage of the fact that an undergraduate computational biology major has the rigorous training required to handle the challenges of modern research that is not provided by any of our peer institutions.

Students in the B.S. program in Computational Biology are expected to acquire the following skills upon graduation:

- Understand the fundamentals of single and multi-variable calculus, as used to construct models of biological systems.
- Construct their own logical mathematical proofs and later apply these proof techniques to theorems in algorithms and theoretical computer science.
- Obtain a firm grounding in probability and statistics necessary for interpretation of biomedical research results.
- Apply the fundamentals of modern chemistry and physics to biological molecules.
- Learn the principles of organization of biological systems on the cellular and molecular level.
- Interpret the connection of the principles of inheritance to the molecular level.
- Understand the relationship between macro and micro in terms of biological structure and function and the connection to metabolic pathways.
- Produce sound, stable, well-organized computer programs that scale well on large datasets.
- Understand the theoretical basis of modern computer science and integrate the inherent limitations of any computing system.
- Design algorithms based on efficient data structures to a variety of computational contexts to meet specified goals.
- Apply machine learning methods by which computers can “learn” from experience and apply these methods to genomic and biomedical data.
- Become familiar with structured biological databases and computational tools for operating on these databases.
- Construct mathematical/computational models of biological systems at differing scales and analyze the strengths and weaknesses of these models.
- Learn the fundamental laboratory techniques used in modern cell and molecular biology as well as the influence of computational methods on experimental design.
- Acquire a skillset of canonical algorithms applied in modern biological research and understand how these algorithms are applied to solve biological problems.
- Gain fluency in contemporary biomedical research topics and be able to interpret primary research results in computational biology.
- Understand the role of computation in biotechnology, pharmaceutical development, and medicine.

Degree Requirements

(students entering Fall 2023)

Students completing the Bachelor of Science in Computational Biology follow certain policies that apply to all SCS students; please consult the SCS policies page (http://coursecatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#policiestext) for a complete listing of these expectations.

Students must complete a **minimum of 360 units** for the degree in computational biology.

Mathematics/Statistics Core

21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
15-151	Mathematical Foundations for Computer Science (or 21-127/21-128 if not offered)	12
36-218	Probability Theory for Computer Scientists (Students taking 15-259 should take 36-326 or 15-260 instead. 15-260 is only open to students who have taken 15-259.)	9
or 36-226	Introduction to Statistical Inference	
or 36-326	Mathematical Statistics (Honors)	
or 36-235	Probability and Statistical Inference I	
or 15-260	Statistics and Computing	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
Total Units		**51**

General Science Core

09-105	Introduction to Modern Chemistry I	10
or 09-107	Honors Chemistry: Fundamentals, Concepts and Applications	
33-121	Physics I for Science Students	12
or 33-141	Physics I for Engineering Students	
Total Units		**22**

Biological Core

03-151	Honors Modern Biology	10
or 03-121	Modern Biology	
03-221	Genomes, Evolution, and Disease: Introduction to Quantitative Genetic Analysis	9
03-232	Biochemistry I (Students taking 03-231, including pre-med students, will take organic chemistry as a prerequisite, which will satisfy a biology elective requirement.)	9
or 03-231	Honors Biochemistry	
03-320	Cell Biology	9
Total Units		**37**

Computer Science Core

07-128	First Year Immigration Course (This course may be replaced by 03-201 or 03-202 if and only if 07-128 is not offered)	1
15-122	Principles of Imperative Computation	12
15-251	Great Ideas in Theoretical Computer Science	12
15-451	Algorithm Design and Analysis	12
or 15-351	Algorithms and Advanced Data Structures	
10-315	Introduction to Machine Learning (SCS Majors)	12
Total Units		**49**

Computational Biology Core

02-251	Great Ideas in Computational Biology	12
02-261	Quantitative Cell and Molecular Biology Laboratory	12
or 02-262	Computation and Biology Integrated Research Lab	
02-402	Computational Biology Seminar	3
02-510	Computational Genomics	12
02-512	Computational Methods for Biological Modeling and Simulation	9
Total Units		**48**

Major Electives

02-3xx	Computational Biology Electives at 300 level or above	18-24
03-3xx	Biology Electives at 300 level or above (09-217 or 42-202 also count as biology electives)	9-12
xx-2xx	School of Computer Science Electives at 200 level or above, at least 9 units each. 15-150 is an acceptable 100-level course counting in this category, but the following exceptions are not allowed in this category: 02-201, 02-223, 02-250, 02-261, 02-262, 11-423, 15-351, 16-223, 17-200, 17-333, 17-562.	18-24
Total Units		**45-60**

Humanities & Arts

All candidates for the bachelor's degree in Computer Science must complete a minimum of 63 units offered by the College of Humanities & Social Sciences and/or the College of Fine Arts. These courses offer students breadth in their education and perspectives and provide students with a better appreciation of social, artistic, cultural, political and economic issues that can influence their effectiveness as computer scientists upon graduation.

Requirements for this component of the degree are listed under the SCS main page under General Education Requirements (http://coursecatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/#genedtext).

Computing @ Carnegie Mellon (1 course)

The following course is required of all students to familiarize them with the campus computing environment:

99-101	Computing @ Carnegie Mellon	3

Free Electives

A free elective is any Carnegie Mellon course. However, a maximum of nine (9) units of Physical Education and/or Military Science (ROTC) and/or Student-Led (StuCo) courses may be used toward fulfilling graduation requirements.

Summary of Degree Requirements

Area	
Math/Stats Core	39
General Science Core	22
Biological Core	36
Computer Science Core	47
Computational Biology Core	48
Major Electives	45-60
General Education (Humanities & Arts)	63
Computing at Carnegie Mellon	3
Remaining Units	42-57
Total Units	**360**

Sample Course Sequence

The following is an example four-year course sequence for computational biology majors, assuming the student has credit for one semester of calculus. Note that our suggested courses during the first year fall are aligned with the sample course sequence for Computer Science majors (https://www.csd.cs.cmu.edu/content/sample-undergraduate-course-sequence/). All students interested in computational biology should take 03-151 (Honors Modern Biology) in their first fall and 02-251 (http://cbd.cmu.edu/education/courses-offered/02-251-great-ideas-in-comp-bio.html) (Great Ideas in Computational Biology) in their first spring.

Some suggestions listed below are quite flexible. For example, physics and chemistry can be taken at any point in the student's first three semesters, and some of the computer science courses below can be replaced by other courses within the School of Computer Science, depending on a student's individual interests.

Other courses, such as cell biology, biochemistry, computational genomics, and biological modeling and simulation, are only offered in either the fall or the spring.

We discuss a tailored plan with our majors to ensure that courses are taken at the appropriate times, while affording each student the flexibility to explore their other interests at CMU.

Note: Before you arrive at CMU, you will take 99-101 Computing at Carnegie Mellon and 15-051, a Discrete Math primer, in your own time. These short courses are provided to incoming students for free.

First-Year		Second-Year	
Fall	**Spring**	**Fall**	**Spring**
07-128 First Year Immigration Course	02-251 Great Ideas in Computational Biology	02-261 Quantitative Cell and Molecular Biology Laboratory	02-xxx Computational Biology Elective
15-112 Fundamentals of Programming and Computer Science	15-122 Principles of Imperative Computation	21-241 Matrices and Linear Transformations	15-251 Great Ideas in Theoretical Computer Science
15-131 Great Practical Ideas for Computer Scientists	09-105 Introduction to Modern Chemistry I	33-121 Physics I for Science Students	03-232 Biochemistry I
15-151 Mathematical Foundations for Computer Science	21-259 Calculus in Three Dimensions	36-218 Probability Theory for Computer Scientists	03-221 Genomes, Evolution, and Disease: Introduction to Quantitative Genetic Analysis
03-151 Honors Modern Biology	76-101 Interpretation and Argument	15-150 Principles of Functional Programming	xx-xxx Humanities and Arts Elective
21-122 Integration and Approximation			

Third-Year		Fourth-Year	
Fall	**Spring**	**Fall**	**Spring**
02-512 Computational Methods for Biological Modeling and Simulation	02-402 Computational Biology Seminar	02-xxx Computational Biology Elective	xx-xxx Humanities and Arts Elective
03-320 Cell Biology	02-510 Computational Genomics	xx-xxx Humanities and Arts Elective	xx-xxx Free Elective
10-315 Introduction to Machine Learning (SCS Majors)	03-xxx Biology Elective	xx-xxx Free Elective	xx-xxx Free Elective
15-210 Parallel and Sequential Data Structures and Algorithms	15-451 Algorithm Design and Analysis	xx-xxx Free Elective	xx-xxx Free Elective
xx-xxx Humanities and Arts Elective	xx-xxx Humanities and Arts Elective		

Additional Major in Computational Biology

The Additional Major in Computational Biology is designed for undergraduate students wishing to study computational biology as a second field of study at Carnegie Mellon University in addition to their primary major.

The additional major is open to all students who complete the prerequisite coursework listed below, with the requirement that a student from outside SCS must have a 3.0 overall QPA when applying.

To prevent double-counting, students must complete at least seven courses of at least 9 units each as part of the additional major in computational biology (not including pre-requisites) that are unique to the additional major.

Students interested in the Additional Major in Computational Biology should contact the Computational Biology Undergrad Program Director.

Prerequisite Courses

02-250	Introduction to Computational Biology	12
or 02-251	Great Ideas in Computational Biology	
03-151	Honors Modern Biology	10
or 03-121	Modern Biology	
15-122	Principles of Imperative Computation	10
15-151	Mathematical Foundations for Computer Science	12
or 21-127	Concepts of Mathematics	
or 21-128	Mathematical Concepts and Proofs	
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
Total Units		**64**

Mathematics/Statistics Core

36-218	Probability Theory for Computer Scientists	9
or 36-226	Introduction to Statistical Inference	
or 36-326	Mathematical Statistics (Honors)	
or 36-235	Probability and Statistical Inference I	
or 15-260	Statistics and Computing	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
Total Units		**19**

General Science Core

09-105	Introduction to Modern Chemistry I	10
or 09-107	Honors Chemistry: Fundamentals, Concepts and Applications	
33-121	Physics I for Science Students	12
or 33-141	Physics I for Engineering Students	
Total Units		**22**

Biological Core

03-221	Genomes, Evolution, and Disease: Introduction to Quantitative Genetic Analysis	9
or 03-220	Genetics	
03-232	Biochemistry I (Students taking 03-231, including pre-med students, will take organic chemistry as a prerequisite, which will satisfy a biology elective requirement.)	9
or 03-231	Honors Biochemistry	
03-320	Cell Biology	9
Total Units		**27**

Computer Science Core

15-251	Great Ideas in Theoretical Computer Science	12
15-451	Algorithm Design and Analysis	12
or 15-351	Algorithms and Advanced Data Structures	
10-315	Introduction to Machine Learning (SCS Majors)	12
Total Units		**36**

Computational Biology Core

02-261	Quantitative Cell and Molecular Biology Laboratory	12
or 02-262	Computation and Biology Integrated Research Lab	
02-402	Computational Biology Seminar	3
02-510	Computational Genomics	12
02-512	Computational Methods for Biological Modeling and Simulation	9
Total Units		**36**

Major Electives

02-3xx	Computational Biology Electives at 300 level or above	18-24
03-3xx	Biology Electives at 300 level or above (09-217 or 42-202 also count as biology electives)	9-12
xx-2xx	School of Computer Science Electives at 200 level or above, at least 9 units each. 15-150 is an acceptable 100-level course counting in this category, but the following exceptions are not allowed in this category: 02-201, 02-223, 02-250, 02-261, 02-262, 11-423, 15-351, 16-223, 17-200, 17-333, 17-562.	18-24
Total Units		**45-60**

General Education (Humanities & Arts)

For specific courses that may be used to satisfy each elective, please consult the General Education Requirements for your primary major.

Computational Biology Minor

SCS Majors: Please see the Computational Biology Concentration **(**http://coursecatalog.web.cmu.edu/schools-colleges/schoolofcomputerscience/scsconcentrations/#computationalbiologytext**)**

Phillip Compeau, PhD, *Director*
Tara Seman, *Program Manager*

The computational biology minor is open to students in any major of any college at Carnegie Mellon outside the School of Computer Science. The curriculum and course requirements are designed to maximize the participation of students from diverse academic disciplines. The program seeks to produce students with both basic computational skills and knowledge in biological sciences that are central to computational biology.

Students are encouraged to declare the minor as early as possible in their undergraduate careers and in all cases before their final semester so that the minor advisor can provide advice on their curriculum.

Why Minor in Computational Biology?

Computational Biology is concerned with solving biological and biomedical problems using mathematical and computational methods. It is recognized as an essential element in modern biological and biomedical research. There have been fundamental changes in biology and medicine over the past two decades due to spectacular advances in high throughput data collection for genomics, proteomics and biomedical imaging. The resulting availability of unprecedented amounts of biological data demands the application of advanced computational tools to build integrated models of biological systems, and to use them to devise methods of prevent or treat disease. Computational Biologists inhabit and expand the interface of computation and biology, making them integral to the future of biology and medicine.

Policy on Double Counting

No more than two courses may be double counted with your major's core requirements. Courses in the minor may not be counted towards another SCS minor. Consult the minor advisor for more information.

Curriculum Overview

The minor in computational biology requires a total of five courses: 3 core courses, 1 biology elective, and 1 computational biology elective, for a **total of at least 45 units**.

Prerequisites

Students must take both of the following courses as prerequisites:		Units
03-151	Honors Modern Biology	10
or 03-121	Modern Biology	
15-112	Fundamentals of Programming and Computer Science	12

Core Classes

Students must take both of the following courses:		
02-250	Introduction to Computational Biology	12
or 02-251	Great Ideas in Computational Biology	
02-261	Quantitative Cell and Molecular Biology Laboratory (03-343 Experimental Techniques in Molecular Biology may be substituted for 02-261 with permission of the minor advisor; 03-116 may be used to replace 02-261 if and only if the latter is not offered)	9-12
or 02-262	Computation and Biology Integrated Research Lab	
Students must take one of the following courses:		
02-510	Computational Genomics	12
02-512	Computational Methods for Biological Modeling and Simulation	9

Biology Elective

Please select one of the following courses:		
03-220	Genetics	9
03-221	Genomes, Evolution, and Disease: Introduction to Quantitative Genetic Analysis	9
03-231	Honors Biochemistry	9
03-232	Biochemistry I	9
03-320	Cell Biology	9
03-327	Evolutionary Bioinformatics: Trees, Sequences and the Comparative Method	9
03-362	Cellular Neuroscience	9
03-363	Systems Neuroscience	9
03-439	Introduction to Biophysics	10
03-442	Molecular Biology	9
42-202	Physiology	9

Computational Biology Elective

Please select one of the following courses:		
02-xxx	Any 02-xxx listed course 02-300 or above	9-12