Biomedical Engineering

This section presents the requirements for programs in:

- **M.A.Sc. Biomedical Engineering**
- **M.A.Sc. Biomedical Engineering with Collaborative Specialization in Accessibility**
- **M.A.Sc. Biomedical Engineering with Collaborative Specialization in Data Science**
- **M.A.Sc. Biomedical Engineering with Collaborative Specialization in Bioinformatics**
- **M.Eng. Biomedical Engineering**
- **M.Eng. Biomedical Engineering with Concentration in Clinical Engineering**
- **M.Eng. Biomedical Engineering with Collaborative Specialization in Accessibility**
- **M.Eng. Biomedical Engineering with Collaborative Specialization in Data Science**
- **Ph.D. Biomedical Engineering**

Program Requirements

All master's students must successfully complete a total of 5.0 credits, which includes a 2.5 credit master's thesis. Courses must be selected with the approval of the student's supervisor.

M.A.Sc. Biomedical Engineering (5.0 credits)

Requirements:

1.	**0.5 credit in:**		0.5
	BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2.	**1.0 credit in** BIOM (BMG) courses		1.0
3.	**1.0 credit in** elective courses at either Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director		1.0
4.	**2.5 credits in:**		2.5
	BIOM 5909 [2.5]	M.A.Sc. Thesis	
5.	**0.0 credit in:**		0.0
	BIOM 5800 [0.0]	Biomedical Engineering Seminar	
Total Credits			**5.0**

M.A.Sc. Biomedical Engineering with Collaborative Specialization in Accessibility (5.0 credits)

Requirements - Thesis pathway:

1.	**0.5 credit in:**		0.5
	BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2.	**1.0 credit in:**		1.0
	ACCS 5001 [0.5]	Critical Disability Studies	
	ACCS 5002 [0.5]	Accessibility and Inclusive Design Seminar	
3.	**1.0 credit in** BIOM(BMG) courses		1.0
4.	**2.5 credits in:**		2.5
	BIOM 5909 [2.5]	M.A.Sc. Thesis (in the specialization)	
5.	**0.0 credit in:**		
	BIOM 5800 [0.0]	Biomedical Engineering Seminar	
Total Credits			**5.0**

M.A.Sc. Biomedical Engineering with Collaborative Specialization in Data Science (5.0 credits)

Requirements:

1.	**0.5 credit in:**		0.5
	BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2.	**0.5 credit in:**		0.5
	DATA 5000 [0.5]	Data Science Seminar	
3.	**1.0 credit in** BIOM (BMG) courses		1.0
4.	**0.5 credit in** elective courses taken either at Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director		0.5
5.	**2.5 credits in:**		2.5
	BIOM 5909 [2.5]	M.A.Sc. Thesis (in the specialization)	
6.	**0.0 credit in:**		0.0
	BIOM 5800 [0.0]	Biomedical Engineering Seminar	
Total Credits			**5.0**

Note: for the course work **Item 3** and **Item 4** above, one 0.5 credit data science elective course must be taken (one of BIOM 5202, BIOM 5400, BIOM 5405, COMP 5100, COMP 5101, COMP 5107, COMP 5108, COMP 5111, COMP 5112, COMP 5204, COMP 5209, COMP 5305, COMP 5306, COMP 5307, COMP 5308, COMP 5401, COMP 5703, COMP 5704, PHYS 5002, SYSC 5001, SYSC 5003, SYSC 5004, SYSC 5007, SYSC 5101, SYSC 5102, SYSC 5103, SYSC 5108, SYSC 5201, SYSC 5207, SYSC 5300, SYSC 5303, SYSC 5306, SYSC 5401, SYSC 5404, SYSC 5405, SYSC 5407, SYSC 5500, SYSC 5703, SYSC 5706).

M.A.Sc. Biomedical Engineering with Collaborative Specialization in Bioinformatics (5.0 credits)

Consult the Bioinformatics section for details regarding admission requirements to this program.

Requirements - thesis pathway (5.0 credits)

1.	**0.5 credit in:**		0.5
	BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2.	**1.0 credit in:**		1.0
	BIOL 5515 [0.5]	Bioinformatics	
	BIOL 5517 [0.5]	Bioinformatics Seminar	
3.	**1.0 credit in** BIOM (BMG) courses		1.0
4.	**2.5 credits in:**		2.5
	BIOM 5909 [2.5]	M.A.Sc. Thesis (in the specialization)	
5.	**0.0 credit in:**		0.0
	BIOM 5800 [0.0]	Biomedical Engineering Seminar	
Total Credits			**5.0**

M.Eng. Biomedical Engineering (5.0 credits)

Requirements - by coursework

1.	**0.5 credit in:**		0.5

BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2. 2.0 credits in BIOM (BMG) courses		2.0
3. 2.5 credits in elective courses at either Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director		2.5
4. 0.0 credit in:		
BIOM 5800 [0.0]	Biomedical Engineering Seminar	
Total Credits		**5.0**

Requirements - by project

1. 0.5 credit in:		0.5
BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2. 1.5 credits in BIOM (BMG) courses		1.5
3. 1.5 credits in elective courses at either Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director		1.5
4. 0.0 credit in:		
BIOM 5800 [0.0]	Biomedical Engineering Seminar	
5. 1.5 credits in:		1.5
BIOM 5900 [1.5]	Biomedical Engineering Project	
Total Credits		**5.0**

M.Eng. Biomedical Engineering with Concentration in Clinical Engineering (5.0 credits)

Requirements:

1. 2.5 credits in:		2.5
BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
BIOM 5100 [0.5]	Biomedical Instrumentation	
BIOM 5200 [0.5]	Medical Imaging Modalities	
BIOM 5406 [0.5]	Clinical Engineering	
HLTH 5201 [0.5]	Fundamentals of Policy I: Policy Analysis	
2. 0.0 credit in:		
BIOM 5800 [0.0]	Biomedical Engineering Seminar	
3. 1.5 credit in:		1.5
BIOM 5901 [1.5]	Clinical Engineering Project	
4. 1.0 credit in:		1.0
BIOM 5801 [1.0]	Clinical Engineering Internship	
Total Credits		**5.0**

M.Eng. Biomedical Engineering with Collaborative Specialization in Accessibility (5.0 credits)

Requirements - coursework pathway

1. 0.5 credit in:		0.5
BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2. 1.0 credit in:		1.0
ACCS 5001 [0.5]	Critical Disability Studies	
ACCS 5002 [0.5]	Accessibility and Inclusive Design Seminar	
3. 2.0 credits in BIOM (BMG) courses		2.0
4. 0.5 credit in the area of the specialization at either Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director		0.5
4. 1.0 credit in elective courses at either Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director		1.0
5. 0.0 credit in:		
BIOM 5800 [0.0]	Biomedical Engineering Seminar	
Total Credits		**5.0**

Requirements - by project:

1. 0.5 credit in:		0.5
BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2. 1.0 credit in:		1.0
ACCS 5001 [0.5]	Critical Disability Studies	
ACCS 5002 [0.5]	Accessibility and Inclusive Design Seminar	
3. 1.5 credits in BIOM (BMG) courses		1.5
4. 0.5 credit in elective courses at either Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director		0.5
5. 0.0 credit in:		
BIOM 5800 [0.0]	Biomedical Engineering Seminar	
6. 1.5 credit in:		1.5
BIOM 5900 [1.5]	Biomedical Engineering Project (in the specialization)	
Total Credits		**5.0**

M.Eng. Biomedical Engineering with Collaborative Specialization in Data Science (5.0 credits)

Requirements - by coursework:

1. 0.5 credit in:		0.5
BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2. 0.5 credit in:		0.5
DATA 5000 [0.5]	Data Science Seminar	
3. 2.0 credits in BIOM (BMG) courses		2.0
4. 2.0 credits in elective courses at either Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director		2.0
5. 0.0 credit in:		
BIOM 5800 [0.0]	Biomedical Engineering Seminar	
Total Credits		**5.0**

Note: for the course work Item 3 and Item 4 above, three 0.5-credit data science elective courses must be taken (three of BIOM 5400,BIOM 5405, COMP 5100, COMP 5101, COMP 5107, COMP 5108, COMP 5111, COMP 5112, COMP 5204, COMP 5209, COMP 5305,COMP 5306, COMP 5307, COMP 5308, COMP 5401,COMP 5703, COMP 5704, PHYS 5002, SYSC 5001, SYSC 5003,SYSC 5004, SYSC 5007, SYSC 5101, SYSC 5102, SYSC 5103, SYSC 5108, SYSC 5201, SYSC 5207, SYSC 5300, SYSC 5303, SYSC 5306, SYSC 5401,SYSC 5404, SYSC 5405, SYSC 5407, SYSC 5500, SYSC 5703, SYSC 5706)

Requirements - by project:

1. 0.5 credit in:		0.5
BIOM 5010 [0.5]	Introduction to Biomedical Engineering	
2. 0.5 credit in:		0.5

	DATA 5000 [0.5] Data Science Seminar	
3.	**1.5 credits in** BIOM (BMG) courses	1.5
4.	**1.0 credit in** elective courses at either Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director	1.0
5.	**0.0 credit in:**	
	BIOM 5800 [0.0] Biomedical Engineering Seminar	
6.	**1.5 credit in:**	1.5
	BIOM 5900 [1.5] Biomedical Engineering Project (in the specialization)	
Total Credits		**5.0**

Note: for the course work Item 3 and Item 4 above, three 0.5-credit data science elective courses must be taken (three of BIOM 5400,BIOM 5405, COMP 5100, COMP 5101, COMP 5107, COMP 5108, COMP 5111, COMP 5112, COMP 5204, COMP 5209, COMP 5305,COMP 5306, COMP 5307, COMP 5308, COMP 5401,COMP 5703, COMP 5704, PHYS 5002, SYSC 5001, SYSC 5003,SYSC 5004, SYSC 5007, SYSC 5101, SYSC 5102, SYSC 5103, SYSC 5108, SYSC 5201, SYSC 5207, SYSC 5300, SYSC 5303, SYSC 5306, SYSC 5401,SYSC 5404, SYSC 5405, SYSC 5407, SYSC 5500, SYSC 5703, SYSC 5706)

Notes:

- University of Ottawa course numbers are in parentheses.
- Course selection: only a selection of courses listed is given in a particular academic year. For information on courses offered in a given year please consult the Institute's web site (www.ocibme.ca).
- Given that the students admitted to this program are from different academic backgrounds, any elective course listed in this program can only be taken by qualified students who satisfy the prerequisites.

Ph.D. Biomedical Engineering (1.5 credits)

Requirements:

1.	**0.5 credit in:**	0.5
	BIOM 5010 [0.5] Introduction to Biomedical Engineering	
2.	**0.5 credit in** BIOM (BMG) courses	0.5
3.	**0.5 credit in** elective courses at either Carleton University or University of Ottawa with the approval of the OCIBME Director or Associate Director	0.5
4.	Completion of:	0.0
	BIOM 6800 [0.0] Biomedical Engineering PhD Seminar	
5.	Successful completion of the comprehensive examination before the end of the fourth term of registration	
6.	A written thesis proposal and oral examination to take place before the end of the sixth term of registration	
7.	**0.0 credits in:**	0.0
	BIOM 6909 [0.0] Ph.D. Thesis	
Total Credits		**1.5**

Regulations

See the General Regulations section of this Calendar.

Regularly Scheduled Break

For immigration purposes, the summer term (May to August) for the M.Eng. Biomedical Engineering (coursework and research project pathways only), including all concentrations and specializations, is considered a regularly scheduled break approved by the University. Students should resume full-time studies in September.

Admission

M.A.Sc. Biomedical Engineering

The normal requirement for admission is a four-year bachelor's degree in engineering, science, computer science, or a related discipline, with an average of at least B+.

M.A.Sc. Biomedical Engineering Accelerated Pathway

The accelerated pathway in the M.A.Sc. Biomedical Engineering is a flexible and individualized plan of graduate study. Students in their final year of a Carleton B.Eng. degree with demonstrated academic excellence and aptitude for research may qualify for this option.

Students in their third-year of study in the B.Eng. degree should consult with both their Undergraduate Program Coordinator and the Associate Chair for Graduate Studies to determine if the accelerated pathway is appropriate for them and to confirm their selection of courses for their final year of undergraduate studies.

Accelerated Pathway Requirements

1. At least 0.5 credit in a BIOM courses (5000 level or higher) with a grade of B+ or higher.
2. Minimal overall CGPA of A-.

Students may receive advanced standing with transfer of credit of up to 1.0 credit which can reduce their time to completion.

Admission

M.Eng. Biomedical Engineering

The normal requirement for admission is a four-year bachelor's degree in engineering, science, computer science, biomedical sciences, health sciences, or a related discipline, with an average of at least B+. Applicants should note that simply meeting the minimum standards for admission will not guarantee admission to the program as there are only a limited number of positions available each year.

Admission

Ph.D. Biomedical Engineering

The normal requirement for admission into the Ph.D. program is a master's degree with thesis in engineering, science, computer science, or a related discipline, with an average of at least B+.

Students registered full-time in the M.A.Sc. in Biomedical Engineering program at Carleton University, who shows outstanding academic performance and demonstrates significant promise for advanced research, may be permitted to transfer into the doctoral program, without

completing the master's program, upon recommendation of the student's home academic unit.

Biomedical Engineering (BIOM) Courses

BIOM 5010 [0.5 credit]
Introduction to Biomedical Engineering
Research ethics and methods. Engineering systems approach to analysis and modelling of human anatomy and physiology. Introduction to topics including biomechanics, electrophysiology, and computational biology. Biomedical technologies. Impact of technology on society.

BIOM 5100 [0.5 credit] (BMG 5103)
Biomedical Instrumentation
Instrumentation designed to measure physiological variables related to the function of the heart,lungs, kidney, nervous and musculo-skeletal system; emergency, critical care, surgery and anaesthesia equipment.
Also listed as SYSC 5302 (ELG 6320).
Prerequisite(s): permission of the instructor.

BIOM 5101 [0.5 credit] (BMG 5104)
Biological Signals
Modeling of neuromuscular biological signals, including subthreshold phenomena, active behaviour of cell membranes, and innervation processes. Measurement of biological signals, including electrode effects. Time domain, frequency domain, and adaptive filtering techniques for noise reduction.
Also listed as SYSC 5307 (ELG 6307).

BIOM 5106 [0.5 credit] (BMG 5109)
Advanced Topics in Medical Instrumentation
Recent and advanced topics in the field of medical instrumentation and its related areas.

BIOM 5200 [0.5 credit] (BMG 5105)
Medical Imaging Modalities
Mathematical models of image formation based on the image modality and tissue properties. Linear models of image degradation and reconstruction. Inverse problems, regularization for image reconstruction. Image formation in radiology, computed tomography, MRI, nuclear medicine, ultrasound, positron emission tomography.
Also listed as SYSC 5304 (ELG 5127).

BIOM 5201 [0.5 credit] (BMG 5106)
Introduction to Medical Imaging Principles and Technology
Basic principles and technological implementation of x-ray, nuclear medicine, magnetic resonance imaging (MRI), and other imaging modalities used in medicine. Contrast, resolution, storage requirements for digital images. Applications outside medicine, future trends.
Also listed as PHYS 5201.
Prerequisite(s): permission of the Physics department.

BIOM 5202 [0.5 credit] (BMG 5107)
Applications in Biomedical Image Processing
Image processing methods applied to biomedical images. Overview of medical imaging modalities. Image enhancement, segmentation, registration and fusion. Image quality metrics. Image formats. Application examples.
Includes: Experiential Learning Activity
Also listed as SYSC 5202.

BIOM 5203 [0.5 credit] (BMG 5108)
Advanced Topics in Biomedical Image Processing
Recent and advanced topics in the field of biomedical image processing and its related areas.
Prerequisite(s): permission of the instructor.

BIOM 5300 [0.5 credit] (BMG 5300)
Biological and Engineering Materials
Properties of structural biological materials (bone, tendon, ligament, skin, cartilage, muscle, and blood vessels) from an engineering materials viewpoint. Selection of engineering materials as biomaterials. Introduction to biocompatibility. Histology of soft tissues. Viscoelasticity, mechanical properties and models of muscles, ligaments and tendons.
Prerequisite(s): permission of the instructor.

BIOM 5301 [0.5 credit] (BMG 5301)
Biomechanics of Skeletal System, Motion and Tissue
Analysis of human motion. Kinematics and kinetics of various activities. Engineering analysis and modeling techniques applied to human motion. Injury mechanics, treatment, prosthetic replacements. Fracture behaviour and healing processes.
Prerequisite(s): permission of the instructor.

BIOM 5302 [0.5 credit] (BMG 5302)
Biofluid Mechanics
Properties of blood. Blood flow models for vessels, circulation systems and the heart. Artificial blood vessels. Kidney flow and exchange. Modeling of perfused tissues and cells. Transport phenomena across membranes. Molecular and ionic transport. Other body fluids.
Prerequisite(s): permission of the instructor.

BIOM 5304 [0.5 credit] (BMG 5110)
Advanced Topics in Biomechanics and Biomaterials
Recent and advanced topics in the field of biomechanics and biomaterials and its related areas.

BIOM 5306 [0.5 credit] (BMG 5306)
Special Topics in Mechanical and Aerospace Engineering: Biomechanics
Overview of human anatomy and physiology with emphasis on artificial organ and prosthetic device design requirement. Application of engineering principles to cells and tissues, biofluid mechanics, human body energetics, measurement techniques, mechanics of human body systems, with emphasis on the artificial heart.

BIOM 5311 [0.5 credit] (BMG 5311)
Design of Medical Devices and Implants
Solutions to clinical problems through the use of implants and medical devices. Pathology of organ failure and bioengineering and clinical aspects of artificial organs. Examples: blood substitutes, oxygenators, cardiac support, vascular substitutes, pacemakers, ventricular assist devices, artificial hearts and heart valves.
Prerequisite(s): permission of the instructor.

BIOM 5312 [0.5 credit] (BMG 5312)
Design of Orthopaedic Implants and Prostheses
Anatomy of the musculo-skeletal system. Electromyography. Static and dynamic analysis of the human skeleton. Materials and manufacturing considerations for orthopaedic devices. Strength and failure theories. Implant fatigue, fracture and corrosion.
Prerequisite(s): permission of the instructor.

BIOM 5315 [0.5 credit] (BMG 5315)
Biorobotics
Interpretation of physical laws as applied to human motion, kinematics and dynamics of humanoid robots, modeling of biological sensors and actuators, artificial muscles, tele-manipulation, robot assisted surgery, and multi-fingered end-effectors. Design of mechatronic devices including rehabilitators, extenders, haptic devices, and minimally invasive surgery systems.
Prerequisite(s): permission of the instructor.

BIOM 5320 [0.5 credit] (BMG 5120)
Biomechanics of Movement
Human and animal movement examined through the lens of mechanics. Biological, mechanical, and neurological processes by which muscles produce movement. Experimental, mathematical, and computational tools. Clinical and sports applications. Recent advances in biomedical research. Assignments, computer simulations, and a small research project.
Prerequisite(s): permission of the department.

BIOM 5322 [0.5 credit] (BMG 5122)
Biomaterials and Tissue Engineering: Theories and Applications
Principles of materials science and cell biology that apply to biomaterials and tissue engineering. Polymers, ceramics, metals, biomaterial surface modifications, molecular and cellular interactions with biomaterials, immune response, tissue engineering principles, ethical considerations and regulatory overview. Technical analysis of a biomaterial-based medical device.

BIOM 5324 [0.5 credit] (BMG 5319)
Introduction to Microfluidics
Physics of liquid transport in micro-fabricated systems including physics at the microscale, hydrodynamics of microfluidic systems, diffusion mixing, introduction to microfabrication, examples of microfluidics devices and Micro PIV techniques, project.

BIOM 5330 [0.5 credit] (BMG 5330)
Electromagnetic Fields and Biological Systems
Review of electromagnetic waves at radio and microwave frequencies. Electrical and magnetic properties of tissue. Impact of electromagnetic waves on tissue. Cellular effects.
Prerequisite(s): permission of the instructor.

BIOM 5402 [0.5 credit] (BMG 5304)
Interactive Networked Systems and Telemedicine
Telemanipulator; human motoring and sensory capabilities; typical interface devices; mathematical model of haptic interfaces; haptic rendering; stability and transparency; remote control schemes; time delay compensation; networking and real-time protocols, history and challenges of telemedicine; telemedicine applications: telesurgery, tele-monitoring, tele-diagnosis and tele-homecare.
Also listed as SYSC 5303 (ELG 6133).
Prerequisite(s): permission of the instructor.

BIOM 5403 [0.5 credit] (BMG 5111)
Advanced Topics in Medical Informatics and Telemedicine
Recent and advanced topics in the field of medical informatics and telemedicine and its related areas.

BIOM 5405 [0.5 credit] (BMG 5305)
Pattern Classification and Experiment Design
Introduction to a variety of supervised and unsupervised pattern classification techniques with emphasis on correct application. Statistically rigorous experimental design and reporting of performance results. Case studies will be drawn from various fields including biomedical informatics.

Includes: Experiential Learning Activity
Also listed as SYSC 5405 (ELG 6102).
Prerequisite(s): undergraduate introductory probability and statistics.

BIOM 5406 [0.5 credit]
Clinical Engineering
Overview of the Canadian health care system; brief examples of other countries; clinical engineering and the management of technologies in industrialized and in developing countries; safety, reliability, quality assurance; introduction to biomedical sensor technologies; applications of telemedicine; impact of technology on health care.
Prerequisite(s): enrolment in M.Eng. Biomedical Engineering with Concentration in Clinical Engineering.
Also offered at the undergraduate level, with different requirements, as SYSC 4202, for which additional credit is precluded.

BIOM 5800 [0.0 credit] (BMG 6996)
Biomedical Engineering Seminar
This course is in the form of seminars presented by graduate students and other researchers in the area of Biomedical Engineering. To complete this course, a student must attend at least ten seminars and make one presentation in the context of this seminar series.
Includes: Experiential Learning Activity

BIOM 5801 [1.0 credit]
Clinical Engineering Internship
Internship placements are set in an institutional setting outside of the University. Students must complete a formal written paper in addition to their internship activities.
Includes: Experiential Learning Activity

BIOM 5900 [1.5 credit]
Biomedical Engineering Project
Students pursuing the project-based M.Eng. completion option conduct a biomedical engineering study, analysis, and/or design project under the supervision of a faculty member.
Includes: Experiential Learning Activity

BIOM 5901 [1.5 credit]
Clinical Engineering Project
Students pursuing the M.Eng. Clinical Engineering completion option conduct a clinical engineering study, analysis, and/or design project under the supervision of a faculty member.
Includes: Experiential Learning Activity

BIOM 5906 [0.5 credit] (BMG 7199)
Directed Studies in Biomedical Engineering
Various possibilities exist for pursuing directed studies on topics approved by a course supervisor, including the above-listed course topics where they are not offered on a formal basis.

BIOM 5909 [2.5 credits]
M.A.Sc. Thesis
Includes: Experiential Learning Activity

BIOM 6800 [0.0 credit]
Biomedical Engineering PhD Seminar
This course is in the form of seminars presented by graduate students and other researchers in the area of Biomedical Engineering.

BIOM 6909 [0.0 credit]
Ph.D. Thesis
Includes: Experiential Learning Activity