UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

Report No. 3408 Revised

MEMORANDUM

To: Executive Committee of Faculty Council

From: Professor Markus Bussmann
Chair, Engineering Graduate Education Committee

Date: November 19, 2013 for December 11, 2013 Faculty Council Meeting

Re: **Institute of Biomaterials and Biomedical Engineering Proposal to Create Fields**

REPORT CLASSIFICATION

This is a major policy matter that will be considered by the Executive Committee for endorsing and forwarding to Faculty Council for vote as a regular motion (requiring a simple majority of members present and voting to carry).

SUMMARY

The Master of Applied Science (MASc) and Doctor of Philosophy (PhD) degrees in Biomedical Engineering are both full time, research-intensive programs. The programs provide a strong academic foundation for students who want to become immersed in the discipline of biomedical engineering and are designed to offer students challenging and rewarding research opportunities to enhance the quality of our health care system and prepare future leaders in academic and non-academic careers. These graduate programs are primarily intended for students holding a Bachelor's or a Master's degree in Dentistry, Engineering, or in the Medical, Physical, Chemical, or Biological Sciences.

Currently the MASc and PhD programs in IBBME each have a general "Biomedical Engineering" field, and the PhD program only also offers a concentration in "Clinical Engineering".

The objectives of this proposal are to close the existing general field of Biomedical Engineering (MASc and PhD) and to create four new fields for both the MASc and PhD programs:

1) Neural/Sensory Systems Rehabilitation
2) Biomaterials, Tissue Engineering and Regenerative Medicine
3) Nanotechnology, Molecular Imaging and Systems Biology
4) Engineering in a Clinical Setting

These fields represent well-established areas of research strength in IBBME.

For the PhD program only, the proposal is to convert the current concentration in Clinical Engineering to a fifth field in Clinical Engineering, now that fields and concentrations are equivalent.

PROPOSAL/MOTION

THAT the attached IBBME proposal to create fields be adopted.

Major Modification Proposal, Type B

New Graduate Fields in the Institute of Biomaterials and Biomedical Engineering's Existing Graduate Programs

A field/concentration within a graduate program refers to an area of specialization or focus that is related to the demonstrable and collective strengths of the program's Faculty. Graduate programs are not required to have fields/concentrations in order to highlight an area of strength within a program.

Parent Program:	Biomedical Engineering, MASc and PhD
Existing Fields/Concentrations:	Biomedical Engineering field (MASc, PhD) Clinical Engineering Concentration (PhD only)
Proposed New Fields:	1. Neural/Sensory Systems Rehabilitation 2. Biomaterials, Tissue Engineering and Regenerative Medicine 3. Nanotechnology, Molecular Imaging and Systems Biology 4. Engineering in a Clinical Setting 5. Clinical Engineering Fields 1 to 5 will apply to the PhD Fields 1 to 4 only will apply to the MASc
Unit (if applicable) where Program will Reside:	Institute of Biomaterials and Biomedical Engineering (IBBME) St. George Campus
Faculty/Academic Division:	Faculty of Applied Science & Engineering
Faculty/Academic Division Contact:	Markus Bussmann Vice-Dean, Graduate Studies
Graduate Unit Contact:	Julie Audet IBBME Graduate Coordinator Christopher Yip IBBME Director
Anticipated Start Date of New Fields:	September 2014
Proposal Version Date:	November 25 2013

1 Executive Summary

The Master of Applied Science (MASc) and Doctor of Philosophy (PhD) degrees in Biomedical Engineering are both full time, research-intensive programs. The programs provide a strong academic foundation for students who want to become immersed in the discipline of biomedical engineering and are designed to offer students challenging and rewarding research opportunities to enhance the quality of our health care system and prepare future leaders in academic and non-academic careers. These graduate programs are primarily intended for students holding a Bachelor's or a Master's degree in Dentistry, Engineering, or in the Medical, Physical, Chemical, or Biological Sciences.

Currently the MASc and PhD programs in IBBME each have a general "Biomedical Engineering" field, and the PhD program only also offers a concentration in "Clinical Engineering".

The objectives of this proposal are the following:

- to close the existing general field of Biomedical Engineering (MASc and PhD)
- to create four new fields for both the MASc and PhD programs: 1) Neural/Sensory Systems Rehabilitation; 3) Biomaterials, Tissue Engineering and Regenerative Medicine; 2) Nanotechnology, Molecular Imaging and Systems Biology; 4) Engineering in a Clinical Setting**.** These fields represent well-established areas of research strength in IBBME.
- for the PhD program only, convert the current concentration in Clinical Engineering to a fifth field in Clinical Engineering (see Figure 1), now that fields and concentrations are equivalent
- to clarify the requirements for the clinical engineering field (which was introduced as a concentration a few year ago).

Our faculty, staff, current students, and prospective students already commonly refer to these fields, since they precisely identify and communicate the areas of research interest and expertise within IBBME.

2 Rationale

Field 1: Neural/Sensory Systems and Rehabilitation

Students interested in this field seek to understand, analyze, and rehabilitate the brain and body. They seek to improve quality-of-life through research in sensory communications, neural engineering, and rehabilitation for the elderly, disabled, and those affected by chronic disease.

Assistive Technologies:

- Mobility enhancing devices
- Intelligent prompting
- Gait and movement analysis
- Novel prosthetic and orthotic design

- Physiological access pathways
- Environmental control

Neural Systems:

- Computational neuroscience
- Neural system model & analysis
- Neural bioelectricity
- Cognitive brain devices
- Nerve regeneration
- Neuro-muscular implants
- Brain-computer interfaces
- Neuroplasticity technologies

Sensory Systems:

- Eye tracking
- Biomedical acoustics
- Motor and cognitive function assessment
- Human communication
- Speech enhancement
- Hearing assistive technologies

Field 2. Biomaterials, Tissue Engineering and Regenerative Medicine

Students interested in this field seek to repair damaged tissue, strengthen bones, control stem cell growth and differentiation, and discover materials, drugs and devices to accelerate healing. IBBME and its network are at the heart of stem cell and regenerative medicine research in Canada. This field is focused on three areas:

Tissue Engineering:
Constructing devices, combining cells and biocompatible materials to effect tissue repair or replacement in the context of cardiovascular disease, diabetes, and cartilage and bone repair.

Stem Cell Bioengineering:
Devising processes to control the differentiation and/or self-renewal of embryonic, mesenchymal and adult progenitor cells and understanding the underlying mechanisms of these processes.

Biomaterials:
Creating new materials for tissue engineering and stem cell delivery, as well as for other applications such as drug delivery, and understanding the molecular mechanisms of the host response to biomaterials and biomaterial-based devices.

Field 3. Nanotechnology, Molecular Imaging and Systems Biology

Whether it is designer biomolecules for biosensing and control, nanoscale multifunctional materials for detection, visualization, and treatment of disease, high-throughput tools for systems biology, or high-resolution functional imaging platforms, students in this field focus on developing innovative tools and technologies that address long-standing problems in biology, and enable hypothesis-driven research. This field is leading the way in the development of next generation enabling nano and molecular scale tools and technologies.

Tools being developed at IBBME include:

- Fluorescent, chemical and scanning probe microscope
- Optical devices
- In situ brain imaging nanostructures
- Nano- and micro-electrical-mechanical systems
- Cellular systems modelling
- Quantum dots
- Microfluidics and lab-on-a-chip technologies
- Genetic circuits
- Microarray technologies

Field 4. Engineering in a Clinical Setting

Students working in this field create safer, more effective systems and technology for health care, and develop technologies to support the independence of people with physical and cognitive disabilities, and to assist caregivers. They use simulated clinical environments to test medical device usability and health care process safety. They create advanced body-machine devices and enabling technologies for people with severe disabilities.

Field 5. Clinical Engineering

This field only applies to the PhD program. It prepares talented engineers to innovate new solutions to clinical challenges, to enhance patient safety, and to optimize the delivery, integration and management of contemporary technology-mediated healthcare. Researchers in the Clinical Engineering field have a strong relationship with several of the 10 academically affiliated teaching hospitals. As a consequence, PhD students benefit from rich learning environments in state-of-the-art hospital-based laboratories, instrumentation suites, surgical theatres and clinical care areas. In this field, the students are provided with advanced education and training in the application of engineering principles to the clinical environment and patient care and safety; working knowledge of the Canadian healthcare system, human physiology, human factors, systems analysis, measurement, and instrumentation; an understanding of clinical practice. In the field of clinical engineering, students must conduct clinically applied research in a healthcare setting under the co-supervision of both engineering and health sciences faculty members. One of the unique components of the Clinical Engineering field is the opportunity to acquire practical experience and knowledge through a series of internship placements. The clinical engineering field is reserved for students who are eligible to apply for professional certification in clinical engineering through the American College of Clinical Engineering, typically through a pre-existing Clinical Engineering degree. Although this eligibility is an integral part of the PhD program, it is not a degree on its own but rather an enhancement of a student's PhD experience.

Distinctions between Field 4 (Engineering in a Clinical Setting) and Field 5 (Clinical Engineering):

The revised calendar entry for the PhD program will emphasize the additional admission and program requirements (see sections 4 and 5 of this proposal) for students that will choose the field of Clinical Engineering compared with the field of Engineering in a Clinical Setting, or one of the three other fields. The most important distinctions are 1) students in the field of Clinical Engineering are eligible to apply for certification by the American College of Clinical Engineering and 2) students are required to complete (or to have previously completed) clinical internships. This requirement does not exist in the other PhD fields.

3 Need and Demand

Our faculty, staff, current students and prospective students already commonly refer to these fields because they are necessary to identify and communicate areas of research interests and expertise within IBBME.

Table 1: Graduate Enrolment Projections
Total enrolment by academic year and time-in-program

Fields 1 - 4 (MASc)

Year in program	Academic year 2013	Academic year 2014	Academic year 2015	Academic year 2016	Academic year 2017	Academic year 2018
1	29	29	41	39	46	54
2	24	29	29	41	39	46
3	10	12	10	10	15	10
Total	63	70	80	90	100	110

Fields 1 - 4 (PhD)

Year in program	Academic year 2013	Academic year 2014	Academic year 2015	Academic year 2016	Academic year 2017	Academic year 2018
1	20	47	36	33	32	37
2	15	20	47	36	33	32
3	13	15	20	47	36	33

4	17	13	15	20	47	36
5	18	10	7	7	10	25
6	14	10	6	4	4	4
>6	10	5	4	3	3	3
Total	107	120	135	150	165	170

Field 5 (Clinical Engineering, PhD)

Year in program	Academic year 2013	Academic year 2014	Academic year 2015	Academic year 2016	Academic year 2017	Academic year 2018
1	0	2	4	6	4	2
2	3	1	2	4	6	4
3	2	3	1	2	4	6
4	1	2	3	1	2	4
Total	6	8	10	13	16	16

4 Admission Requirements

Graduate students will not be admitted to a specific field. The admission requirements for both MASc and PhD students intending to pursue research in Fields 1 to 4 are those of the programs and they will not be changed. Admission into the PhD Field 5 (Clinical Engineering) has additional requirements compared with Fields 1 to 4.

Introducing the new Fields 1 to 4, and converting the concentration in Clinical Engineering to Field 5 (PhD only) will allow IBBME to more clearly articulate and advertise its already well-established areas of research strength, allow applicants to more easily identify and indicate area(s) of interest, and make it easier for potential supervisors to recruit them.

Candidates for the MASc or PhD programs (Fields 1 to 4) must hold a bachelor's degree (direct entry) or a master's degree in dentistry, engineering, medicine, physical or biological sciences from a recognized university, and are expected to have obtained a minimum academic standing of A- in the final two years of study.

The PhD in the Field of Clinical Engineering (Field 5) is reserved for students eligible for certification in clinical engineering through the American College of Clinical Engineering. Students applying to IBBME's PhD program may apply to the field of Clinical Engineering if they satisfy the following requirements:

- Meet the minimum admission requirements of the PhD (for Fields 1 to 4)
- Have an undergraduate degree in engineering
- For students already holding a Master's degree, their Master's degree must be in clinical engineering or other clinically-related engineering field

Highly qualified Master's students (MHSc students in clinical engineering or MASc students in any fields) may be considered for transfer into the PhD program in any of the five fields. Applicants must meet the following requirements:

- Clinical Engineering MHSc students must complete 3.0 full-course equivalents within the MHSc curriculum
- All students (transfer or direct entry) must pass a PhD transfer/qualifying exam consisting of an oral defense of a written PhD proposal before a committee of 3 SGS-appointed faculty members within 12 months of initial registration. In the case of the students transferring to the PhD program in the clinical engineering field (5), at least one of the three SGS-appointed members must be a clinically-appointed faculty member

For all fields (1 to 5) of the PhD program, direct admission from a Bachelor's degree may be considered in exceptional cases.

5 Program Requirements

MASc Program Requirements

The graduate program leading to the Master of Applied Science (MASc) degree requires full-time study with students committed to completing the degree requirements in 20 months of registration (Fall/Winter/Summer/Fall/Winter). The program of study normally consists of at least four half-credit courses, plus two seminar half courses, an Ethics seminar, all applicable lab safety workshops and a research thesis completed under the guidance of a supervisor. A half credit course is defined as one session long.

The requirements of the Master's degree program comprise:

- At least four half-credit courses (2.0 FCEs), one of which must be BME 1450H Bioengineering Science. Students with engineering or physical science backgrounds must take a life science course, such as JPB 1022H or equivalent; students with a life sciences background must take an engineering or physical science course, such as JPB 1055H or equivalent
- Two seminar courses: one of BME1010H or BME1011H
- Health & Safety Training Workshop
- JDE 1000H – Ethics in Research
- Completion of a research thesis

Four fields (1 to 4) of research are available to MASc students and the chosen field does not affect the program requirements.

PhD Program Requirements

Five fields (1 to 5) of research are defined for the PhD program. Students admitted into the PhD program (with a Master's degree) normally must complete two half-credit courses and an extensive research thesis. All required courses should be completed within the first year; the PhD Program length is four years for completion of all degree requirements.

The requirements of the PhD degree program comprise:

- Normally, at least two half-credit courses (1.0 FCE) in addition to those required at the Master's level. Students who transfer without completion of the Master's degree in Biomedical Engineering must complete the total course requirements for both degrees (2.0 FCE for the Master's level + 1.0 FCEs for the PhD level for a total of 3.0 FCEs). Students with engineering or physical science backgrounds must take a life science course, such as JPB 1022H or equivalent; students with a life sciences background must take an engineering or physical science course, such as JPB 1055H or equivalent.
- Two seminar courses: one of BME1010H or BME1011H
- Health & Safety Training Workshops
- JDE 1000H – Ethics in Research
- Completion of a research thesis

Doctoral students are subject to the School of Graduate Studies policy on "Timely Completion of Graduate Program Requirements". A PhD student at the end of year three (year four for direct-entry students) is expected to have completed all program requirements exclusive of the thesis.

In addition, students in the PhD program in any of the five fields must pass a qualifying examination within 12 months of registration, must have annual supervisory committee meetings, and hold a final oral defense of the thesis (departmental and senate oral exams).

At the PhD level, there are additional requirements for students who have chosen the field of Clinical Engineering (5). In the Clinical Engineering (5) field, students complete the requirements of the PhD. However, students without a clinical engineering background are required to complete an additional specified half-course (clinical internship):

- 0.5 FCE from one of the IBBME clinical engineering courses (BME 1405, BME 1439, BME 1436 or BME 4444)*

  * A student who possesses protracted professional clinical engineering experience (five or more years) will be exempt from this requirement.

Students in the clinical engineering field normally must be co-supervised by a member of the IBBME Engineering Faculty and a member of the IBBME Health Sciences Faculty; the primary supervisor must be IBBME appointed; co-supervisor must be a member of the Graduate Faculty and may be from a clinical unit other than IBBME. All students in the field must conduct research within a clinical healthcare environment. This is broadly understood to be any setting where a person is receiving care, for example, including, but not limited to a hospital-based laboratory, an assisted living centre, nursing home or outpatient clinic, where human subjects will be engaged.

PhD students studying in any of the five fields will adhere to the same level of research excellence, critical thought, originality and research output. Please also refer to the revised Calendar Entry. All course requirements must be fulfilled with graduate level courses.

Program Length

The field of research chosen by the student will not impact the established program length for the IBBME PhD program, namely, four years (full-time) from a Master's degree or five years (full-time) for direct entry or transfer students. It is anticipated that the additional 0.5 FCE required of those without a clinical engineering master's degree would not prolong the residency in the program.

Figure 1 illustrates the requirements for the PhD program depending on the field chosen and previous graduate studies completed by the student.

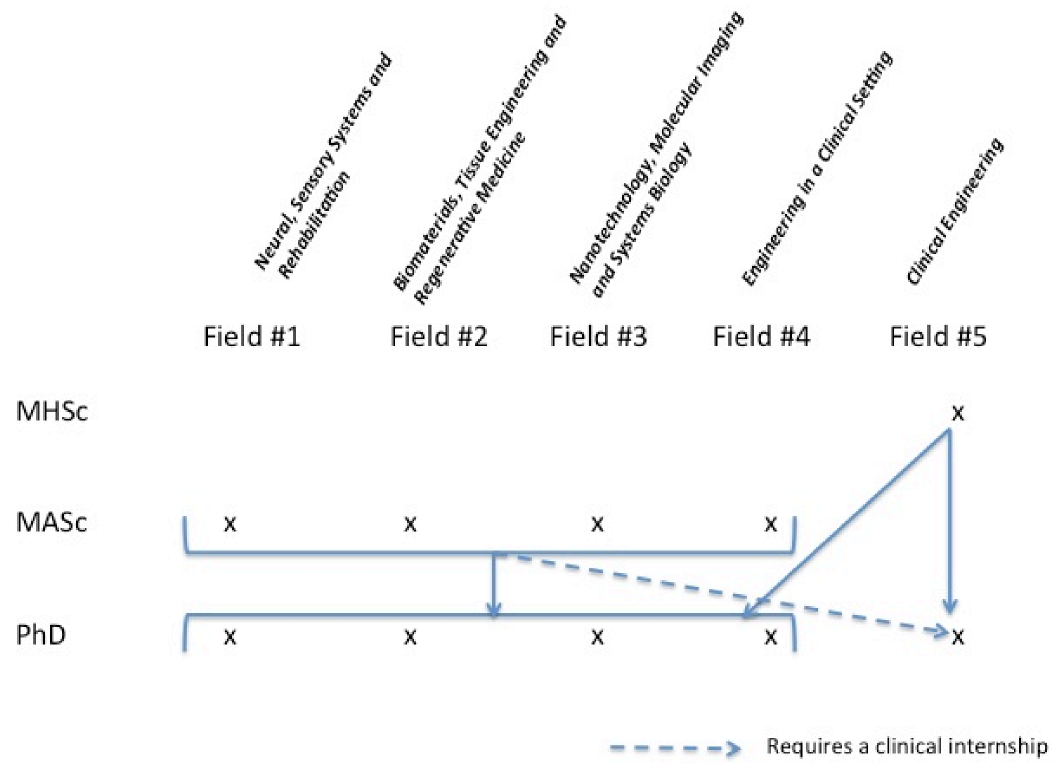

Figure 1. Specific PhD requirement in the 5th field (Clinical Engineering). The PhD in Clinical Engineering is primarily intended for students who have completed a MHSc in Clinical Engineering. Students who have obtained a MASc will be required to complete a clinical internship. This requirement does not exist for the four other fields (1-4) in the PhD program.

6 Degree Level Expectations, Program Learning Outcomes and Program Structure

In any of the fields, the MASc and PhD programs address the following FASE learning objectives. The following DLEs are common across all graduate degrees that we offer although a higher level of achievement is expected of PhD students than of MASc students. DLEs are satisfied via a combination of courses and a research-based thesis. Course selection for MASc and PhD students is approved by the research advisor and supervisory committee and are overseen by the Associate Chair, Graduate Studies. For PhD students in Field 5 (Clinical Engineering), additional DLEs are satisfied via clinical internships.

Students in the five fields of the PhD program integrate the study of biology and medicine with the physical and engineering sciences. Our students transform biological concepts into an analytical engineering form. IBBME programs provide the skills, philosophy and values to enable students to reach the forefront of leadership in the biomedical engineering field, and have a direct impact on health care under the guidance of world-class faculty who shape the cutting edge of research. The PhD program has an existing clinical engineering concentration that has allowed our students to integrate elements of the MHSc program in Clinical Engineering into their PhD curriculum. Within this concentration (which will be transitioned into Field 5), our students conduct clinically-relevant research in a healthcare setting (e.g., hospital, nursing home, community clinic), under the co-supervision of both engineering and health sciences faculty members.

Table 2: Master's DLEs

MASTER'S DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice-Presidents DLEs)	**MASTER'S PROGRAM LEARNING OBJECTIVES AND OUTCOMES**	**HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES**
EXPECTATIONS: This MASc in Biomedical Engineering is awarded to students who have demonstrated:		
1. Depth and Breadth of Knowledge A systematic understanding of knowledge, and a critical awareness of current problems and/or new insights, much of which is at, or informed by, the forefront of the academic discipline, field of study, or area of professional practice.	Depth and breadth of knowledge is defined in MASc in Biomedical Engineering as: Depth of knowledge is demonstrated for MASc students by the ability to undertake a research-based thesis in one if the 4 fields of the biomedical engineering MASc program. Breadth of knowledge is defined by a fluency in both biomedical sciences and engineering disciplines. This is reflected in students who are able to develop and apply	The program design and requirement elements that ensure these student outcomes for depth and breadth of knowledge are: – Students with a background in life sciences are required to take at least one graduate-level half course in engineering or physical sciences (approved by the graduate office). – Students with a background in engineering/physical sciences are required to take at least one graduate-level half course in life science courses

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	interdisciplinary skills that span the biological sciences and the engineering disciplines to design, develop and implement cutting-edge biomedical technologies in industry, academia, clinical medicine, and health sciences. Students apply these skills either in a research or industrial or clinical context.	(approved by the graduate office). In addition, the program includes comprehensive course selections with a research thesis component. The students acquire broad exposure to the fields through: – Student seminar programs. – BME 1450H Bioengineering Science course (mandatory course that introduces students to the scope of IBBME research, and acquaints clinical and basic scientists and engineers with each other's skill sets in design projects). – Annual research day events.
2. Research and Scholarship A conceptual understanding and methodological competence that i) Enables a working comprehension of how established techniques of research and inquiry are used to create and interpret knowledge in the discipline; ii) enables a critical evaluation of current research and advanced research and scholarship in the discipline or area of professional competence; and iii) Enables a treatment of complex issues and judgments based on established principles and techniques; and, on the basis of that competence, has shown at least one of the following: i) The development and support of a sustained argument in written form; or ii) Originality in the application of knowledge.	Research and Scholarship is defined in MASc in Biomedical Engineering as: Demonstration of a working comprehension of how established techniques of research and inquiry are used to create and interpret knowledge in the discipline, critical evaluation of current research and advanced research and scholarship in the discipline, and treatment of complex issues and judgments based on established principles and techniques. This is reflected in students who are able to: – Articulate a clear hypothesis or a clear overall goal for their Master's research project (e.g. create a novel design, solve a specific problem, develop a new technology, challenge a current paradigm or practice, address a critical bottleneck in	The program design and requirement elements that ensure these student outcomes for research and scholarship are: – Through their research-based thesis work, students gain a conceptual understanding and methodological competence. – Through their dissertation, MASc students demonstrate the development and support of a sustained argument in written form, and originality in the application scientific knowledge in biomedical sciences and engineering. – Through their Master's final oral examination, students demonstrate the development and support of a sustained argument in verbal form.

MASTER'S DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice-Presidents DLEs)	MASTER'S PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
	the field). – Interpret experimental data/outcomes and appreciate the limitations of the approaches used. – Acquire a familiarity with the relevant literature and/or understand scientific biomedical and engineering concepts relevant to their master's thesis project.	
3. Level of Application of Knowledge Competence in the research process by applying an existing body of knowledge in the critical analysis of a new question or of a specific problem or issue in a new setting.	Application of Knowledge is defined in MASc in Biomedical Engineering as: (same as FASE) This is reflected in students who are able to achieve a level of competence in the application of knowledge beyond that of the undergraduate level. For their Master's research thesis, apply an existing body of knowledge in the critical analysis of a new question or of a specific biomedical problem or issue in a new setting, and the ability to exercise leadership in research innovation.	The program design and requirement elements that ensure these student outcomes for level and application of knowledge are: – Via coursework and a research thesis, the program trains students to independently conceive solutions to problems and to execute research plans by accessing a broad range of resources located in three faculties (FASE, Dentistry and Medicine) and across the hospital network. – This level of application of knowledge is measured by the rigor of thesis committees (for all its programs), which meet annually with the students and the final Master's thesis exam committees.
4. Professional Capacity/Autonomy a. The qualities and transferable skills necessary for employment requiring i) the exercise of initiative and of personal responsibility and accountability; and ii) decision-making in complex situations; b. The intellectual independence required for continuing professional development;	Professional Capacity/Autonomy is defined in MASc in Biomedical Engineering as personal responsibility, accountability, complex decision making skills, intellectual independence, and academic integrity. This is reflected in students who are able to conduct research and complete a Master's research	The program design and requirement elements that ensure these student outcomes for professional capacity/autonomy are: – All graduate students in all fields practice personal responsibility, accountability, complex decision making skills, intellectual independence, and academic integrity via

MASTER'S DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice-Presidents DLEs)	**MASTER'S PROGRAM LEARNING OBJECTIVES AND OUTCOMES**	**HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES**
c. The ethical behavior consistent with academic integrity and the use of appropriate guidelines and procedures for responsible conduct of research; and d. The ability to appreciate the broader implications of applying knowledge to particular contexts.	thesis.	coursework. – Leadership skills are also improved via team projects as part of courses. Master's students further these skills via their research-based thesis, and also attend a mandatory "Ethics in Research" seminar. – Students are required to demonstrate significant autonomy in determining specific sub-problems, strategies and methodologies for completing their master's thesis.
5. Level of Communications Skills The ability to communicate ideas, issues and conclusions clearly.	Communications Skills is defined in MASc as: (same as APSE) This is reflected in students who are able to present effectively research in such a way that it is easily understood, encourages discussion and promotes participation and collaboration in research through verbal, written and other non-verbal means of communication.	The program design and requirement elements that ensure these student outcomes for level of communication skills are: – Graduate students present their work orally in front of their peers at least once in the graduate seminar course; they engage by presenting their work in significant numbers (1/3 of students) at the annual research day. – Annual presentations are given to their supervisory committee. – Students are likewise provided the opportunity to participate in teaching undergraduate curriculum through teaching assistantships; all students present conference and/or workshop abstract(s) during the course of their graduate programs.

Table 3: Doctoral DLEs

DOCTORAL DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice-Presidents DLEs)	**DOCTORAL PROGRAM LEARNING OBJECTIVES AND OUTCOMES**	**HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES**
EXPECTATIONS: This PhD in Biomedical Engineering extends the skills associated with the Master's degree and is awarded to students who have demonstrated:		
1. Depth and Breadth of Knowledge A thorough understanding of a substantial body of knowledge that is at the forefront of their academic discipline or area of professional practice.	Depth and breadth of knowledge is defined in PhD in Biomedical Engineering as: Great depth of knowledge is demonstrated for PhD students by the ability to undertake a research-based thesis in one if the 5 fields of the biomedical engineering PhD program. Breadth of knowledge is defined by a fluency in both biomedical sciences and engineering disciplines. This is reflected in students who are able to: – acquire and apply advanced interdisciplinary knowledge that span the biological science and the engineering disciplines to design, develop and implement cutting-edge biomedical technologies in industry, academia, clinical medicine, and health sciences. Students are able to apply this knowledge in a research, industrial or clinical context.	The program design and requirement elements that ensure these student outcomes for depth and breadth of knowledge are: – Students with a background in life sciences are required to take at least one graduate-level half course in engineering or physical sciences (approved by the graduate office). – Students with a background in engineering/physical sciences are required to take at least one graduate-level half course in life science courses (approved by the graduate office). – In addition, the program includes comprehensive course selections with a research thesis component. – The students acquire broad exposure to the fields through the student seminar programs; the BME 1450H Bioengineering Science course (mandatory course that introduces students to the five fields of IBBME research, and acquaints clinical and basic scientists and engineers with each other's skill sets in design projects). – Students also attend annual research day events.
2. Research and Scholarship a. The ability to conceptualize, design, and implement research for the generation of new knowledge,	Research and Scholarship is defined in the PhD in biomedical engineering as: Demonstration of a working	The program design and requirement elements that ensure these student outcomes for research and scholarship are:

DOCTORAL DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice-Presidents DLEs)	**DOCTORAL PROGRAM LEARNING OBJECTIVES AND OUTCOMES**	**HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES**
applications, or understanding at the forefront of the discipline, and to adjust the research design or methodology in the light of unforeseen problems; b. The ability to make informed judgments on complex issues in specialist fields, sometimes requiring new methods; and c. The ability to produce original research, or other advanced scholarship, of a quality to satisfy peer review, and to merit publication.	comprehension of how established techniques of research and inquiry are used to create and interpret knowledge in the discipline, critical evaluation of current research and advanced research and scholarship in the discipline, and treatment of complex issues and judgments based on established principles and techniques. On the basis of that competence and through their dissertation, PhD students further demonstrate the development and support of a sustained argument in written form, and originality in the application scientific knowledge. This is reflected in students who are able to: – Articulate a clear hypothesis or a clear overall goal for their PhD research project (e.g. create a novel design, solve a specific problem, develop a new technology, challenge a current paradigm or practice, address a critical bottleneck in the field). – Plan and design critical experiments to prove or disprove hypotheses or to achieve the overall goal stated in their PhD proposal – Interpret experimental data/outcomes and appreciate the limitations of the approaches used. – Acquire in depth knowledge of the relevant literature and/or understand scientific biomedical and engineering concepts relevant to their PhD	– Via the research-based thesis, PhD students gain a conceptual understanding and methodological competence that enable a number of abilities. These abilities are evaluated by supervisory committee meetings, the PhD qualifying examination and the final PhD oral examination.

DOCTORAL DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice-Presidents DLEs)	DOCTORAL PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
	project.	
3. Level of Application of Knowledge The capacity to i) Undertake pure and/or applied research at an advanced level; and ii) Contribute to the development of academic or professional skills, techniques, tools, practices, ideas, theories, approaches, and/or materials.	Level of Application of Knowledge is defined in PhD in Biomedical Engineering as: – Via coursework, all graduate students achieve a level of competence in the application of knowledge beyond that of the undergraduate level. – Through their research-based thesis, PhD students demonstrate competence in the research process by applying an existing body of knowledge in the critical analysis of a new question or of a specific problem or issue in a new setting, and the ability to exercise leadership in research innovation. This is reflected in students who are able to: – Plan and execute an original and conclusive scientific investigation that develops into a full PhD thesis (ideally publication of three peer reviewed first-author papers).	The program design and requirement elements that ensure these student outcomes for level of application of knowledge are: – The program trains students to independently conceive solutions to problems and to execute research plans by accessing a broad range of resources located in three faculties (FASE, Dentistry and Medicine) and across the hospital network. – This level of application of knowledge is measured by the rigor of annual thesis committee meetings (for all its programs), the PhD qualifying examination (which evaluate the research proposal in addition to the student research skills) and the final oral PhD examination.
4. Professional Capacity/Autonomy a. The qualities and transferable skills necessary for employment requiring the exercise of personal responsibility and largely autonomous initiative in complex situations; b. The intellectual independence to be academically and professionally engaged and current; c. The ethical behavior consistent with academic integrity and the use of appropriate guidelines and procedures for responsible conduct of research; and d. The ability to evaluate the broader	Professional Capacity/Autonomy is defined in PhD in biomedical engineering as: – In fields 1 to 5: personal responsibility, accountability, complex decision making skills, intellectual independence, and academic integrity. – For PhD students in field 5 (clinical engineering): the ability to consider patient care and safety, as having a working knowledge of the	The program design and requirement elements that ensure these student outcomes for professional capacity/autonomy are: – All graduate students in all fields (1 to 5): practice personal responsibility, accountability, complex decision making skills, intellectual independence, and academic integrity via coursework. Leadership skills are also improved via team projects as part of courses.

DOCTORAL DEGREE LEVEL EXPECTATIONS (based on the Ontario Council of Academic Vice-Presidents DLEs)	DOCTORAL PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
implications of applying knowledge to particular contexts.	Canadian healthcare system and an understanding of clinical practice. This is reflected in students who are able to: – In fields 1 to 5: conduct research and complete a PhD research thesis. – For PhD students in field 5 (clinical engineering): conduct research in a clinical environment.	– PhD students further these skills via their research-based thesis, and also attend a mandatory "Ethics in Research" seminar. – PhD students are required to demonstrate significant autonomy in determining specific sub-problems, strategies and methodologies for completing their PhD thesis. In field 5 **(Clinical Engineering)**: students must complete the following requirements in addition to those of the PhD program in fields 1 to 4: – If a student does not have a formal degree in clinical engineering, 0.5 FCE from one of the IBBME clinical engineering courses (BME 1405, BME 1439, BME 1436 or BME4444) is required. A student who possesses protracted professional engineering experience (5 or more years) will be exempt from this requirement. – Students must conduct their research in a clinical environment. Students will normally be co-supervised by both engineering and health science faculty. The primary supervisor must be IBBME-appointed, however the co-supervisor could be from a clinical unit other than IBBME, however must be appointed to SGS. IBBME’s PhD program currently allows for co-supervision from non-IBBME SGS appointed faculty.

5. Level of Communication Skills The ability to communicate complex and/or ambiguous ideas, issues and conclusions clearly and effectively.	Level of Communications Skills is defined in PhD in Biomedical Engineering as: (same as APSE) This is reflected in students who are able to: – Present effectively research in such a way that it is easily understood, encourages discussion and promotes participation and collaboration in research through verbal, written and other non-verbal means of communication. – Articulate a clear hypothesis or a clear overall goal for their PhD research project. – Prepare a PhD project proposal and pass a PhD qualifying examination and participate in publication of research results in formal venues, as well as presentations at conferences and workshops.	The program design and requirement elements that ensure these student outcomes for level of communication skills are: – Graduate students present their work orally in front of their peers once every 2 years in the graduate seminar course; they engage by presenting their work in significant numbers (1/3 of students) at the annual research day. – Annual presentations are given to their supervisory committee. – Students are likewise provided the opportunity to participate in teaching undergraduate curriculum through teaching assistantships; the opportunity and all students present conference and/or workshop abstract(s) during the course of their graduate programs.
6. Awareness of Limits of Knowledge An appreciation of the limitations of one's own work and discipline, of the complexity of knowledge, and of the potential contributions of other interpretations, methods, and disciplines. Competence in the research process by applying an existing body of knowledge in the critical analysis of a new question or of a specific problem or issue in a new setting.	Level of Awareness of Limits of Knowledge is defined in PhD in Biomedical Engineering as: For all graduate students, coursework provides a cognizance of the complexity of knowledge and its underlying assumptions. Through the breadth of courses taken, and exposure to other areas via the mandatory Distinguished Lecture Series, students learn about the potential contributions of other interpretations, methods, and disciplines. This is reflected in students who are able to: – Plan and design critical experiments to prove or disprove the hypothesis or to achieve the overall goal stated	The program design and requirement elements that ensure these student outcomes for awareness of limits of knowledge are: – By exposing students to many cross-Institute research events, an awareness of the limitations of their knowledge is fostered. The assessment forms for students' annual committee meetings provides students with an assessment of their knowledge and where their weaknesses reside, while their seminar program allows them to benchmark themselves relative to their peers. – The graduate courses also provide them with solid yardsticks of their knowledge

	in their PhD thesis. – Interpret experimental data/outcomes and appreciate the limitations of the approaches used.	through comprehensive assessment tools. By attending national and international conferences and workshops, as well as local events of this nature, students become aware of how to measure their knowledge base relative to the field. – Yearly supervisory committee meetings, PhD qualifying examination and PhD final oral examination evaluate student's ability to interpret experimental data/outcomes and appreciate the limitations of the approaches used.

7 Assessment of Teaching and Learning

Assessment of learning in the MASc program: For the graduate courses, evaluations are based on midterms, final exams, assignments and group projects. For the research-based component, students have yearly supervisory committee meetings and final thesis oral exam. At each meeting, the committee provides a written assessment of the student's progress along with recommended considerations or changes, as appropriate.

Assessment of teaching and learning in the PhD program: Assessment of student achievement is initially similar to the MASc program with additional requirements after the first year. After completion of the PhD qualifying exam, students will continue to meet with their supervisory committee at least once every 12 months until a recommendation for the Departmental Oral Examination is made and, subsequently, the final PhD Oral examination. At each meeting, the committee provides a written assessment of the student's progress along with recommended considerations or changes, as appropriate.

8 Consultation

IBBME's Director, the Vice-Dean Graduate Studies (FASE) and the School of Graduate Studies have been consulted.

9 Resources

Faculty Complement

The research expertise of our Faculty within these five research fields is illustrated in Appendix A. Note that this expertise has also generated a core list of curriculum courses that reflects both the intensity and current relevance of the topics in the individual fields of study. Please refer to the website for a full description of each course: http://ibbme.utoronto.ca/students/courses-in-biomedical-engineering/.

Space/Infrastructure

There are no unique space/infrastructure requirements including information technology, laboratory space and equipment, etc.

10 Governance Process

- Provostial sign-off
- Graduate Unit approval
- Faculty/Divisional Council approval
- Submission to Provost's Office
- Report to AP&P
- Report to Ontario Quality Council

APPENDIX A

List of Core and Cross-appointed Faculty with their Main Field(s) of Research

(* IBBME core full-time professors)

	Field #1	Field #2	Field #3	Field #4	Field #5
Berj Bardakjian*	X				
Elaine Biddiss*	X			X	X
Sandra Black	X				
Peter Carlen	X				
Tom Chau	X			X	X
Angela Cheung	X			X	
James Drake	X			X	
Moshe Eizenman*	X			X	
Goeff Fernie*	X				X
R.V. Harrison	X				
Sasha John	X				
Mike Joy	X			X	
Han Kunov	X				
Ofer Levi*	X		X		
Brian Maki	X				
K McConville	X				
Alex Mihailidis*	X				X
Mary Nagai	X				
Ken Norwich	X			X	
Milos Popovic	X				
Tom Schweizer	X				
Catriona Steele	X				
Pascal van Lieshout	X				
Willy Wong*	X				
Christine Allen		X			
Cristina Amon		X		X	
Julie Audet*		X			
Yu-Ling Cheng		X			

	Field #1	Field #2	Field #3	Field #4	Field #5
D Cvitkovitch		X			
John Davies*		X			
Marc Grynpas*		X			
Boris Hinz		X			
Rita Kandel*		X			
Armand Keating		X			
Dawn Kilkenny*		X			
Alison McGuigan*		X			
Bob Pilliar		X			
Milica Radisic*		X			
Paul Santerre*		X			
Michael Sefton		X			
Molly Shoichet*		X			
Craig Simmons*		X			
David Steinman*		X		X	
Eli Sone*		X			
Cari Whyne		X			X
Lidan You*		X			
Peter Zandstra*		X	X		
Beno Benhabib				X	
Jan Andrysek*				X	
Gregory Borschel				X	
Kristy Brock				X	
Christopher Caldarone				X	X
Joseph Cafazzo				X	X
Allan Coates				X	
Richard Cobbold				X	X
Alf Dolan				X	
Tony Easty*				X	X
Rick Frecker				X	
A.A. Goldenberg				X	
Teodor Grantcharov				X	
Allan Gross				X	
Kullervo Hynynen				X	

	Field #1	Field #2	Field #3	Field #4	Field #5
David Jaffray			X	X	X
Wayne Johnston				X	
Stephen Lapinsky				X	
Andreas Mandelis				X	
Paul Milgram				X	
Narinder Paul				X	
Ken Pritzker				X	
Kaveh Shojania				X	
Brad Strauss				X	
Patricia Trbovich*				X	X
Graham Wright				X	
Albert Yee				X	
Warren Chan*					
Axel Guenther					
Shana Kelley			X		
Krishna Mahadevan			X		
Jonathan Rocheleau*			X		
William Ryu			X		
John Sled			X		
Yu Sun			X		
Mike Thompson			X		
Kevin Truong*			X		
Aaron Wheeler*			X		
Chris Yip*			X		
Geng Zheng			X		

Calendar Entry

BIOMEDICAL ENGINEERING

Faculty Affiliation

Applied Science and Engineering

Degree Programs Offered

Biomedical Engineering—MASc, PhD
Fields: Neural/Sensory Systems and Rehabilitation
Biomaterials, Tissue Engineering and Regenerative Medicine
Nanotechnology, Molecular Imaging and Systems Biology
Engineering in a Clinical Setting
Clinical Engineering (PhD only)

Clinical Engineering—MHSc

Collaborative Programs

The following collaborative programs are available to students in participating degree programs as listed below:

1. **Addiction Studies**
   Biomedical Engineering, MASc, PhD
2. **Cardiovascular Sciences**
   Biomedical Engineering, MASc, PhD
3. **Genome Biology and Bioinformatics**
   Biomedical Engineering, PhD
4. **Health Care, Technology, and Place**
   Biomedical Engineering, PhD
5. **Musculoskeletal Sciences**
   Biomedical Engineering, MASc, PhD
6. **Neuroscience**
   Biomedical Engineering, MASc, MSc, PhD
7. **Resuscitation Sciences**
   Biomedical Engineering, PhD
   Clinical Engineering, MHSc

Overview

The Institute of Biomaterials and Biomedical Engineering (IBBME) offers facilities for research in biomedical engineering and for three educational programs leading to master's and doctoral degrees. Students may be registered in the MASc, MHSc or PhD programs through the institute. Students interested in the Collaborative Program in Biomedical Engineering may register through one of the collaborating graduate units.

Biomedical engineering is a multidisciplinary field that integrates engineering and biology/medicine. It uses methods, principles, and tools of engineering, physical sciences, and mathematics to solve problems in the medical and life sciences for the study of living systems; the enhancement and replacement of those systems; the design and construction of systems to measure basic physiological parameters; the development of instruments, materials, and techniques for biological and medical practice; and the development of artificial organs and other medical devices. By its nature, the majority of the institute's work is interdisciplinary.

See list above for research fields in the Biomedical Engineering program (MASc and PhD).

IBBME also offers a MHSc. in Clinical Engineering which is described in the section below.

Contact and Address

Web: www.ibbme.utoronto.ca

Institute of Biomaterials and Biomedical Engineering (IBBME) Graduate Office:

Email: admissions.ibbme@utoronto.ca
Telephone: (416) 978-4841
Fax: (416) 978-4317
Institute of Biomaterials and Biomedical Engineering
University of Toronto Room 407, Rosebrugh Building
164 College Street Toronto, Ontario M5S 3G9 Canada

IBBME Clinical Engineering Office:

Email: clinicaleng.ibbme@utoronto.ca
Telephone: (416) 978-6102
Fax: (416) 978-4317
Institute of Biomaterials and Biomedical Engineering
University of Toronto Room 407, Rosebrugh Building
164 College Street Toronto, Ontario M5S 3G9 Canada

Degree Programs
Biomedical Engineering

Master of Applied Science

The MASc program is offered in the fields of 1) Neural/Sensory Systems and Rehabilitation; 2) Biomaterials, Tissue Engineering and Regenerative Medicine; 3) Nanotechnology, Molecular Imaging and Systems Biology; and 4) Engineering in a Clinical Setting.

Admission Requirements

Applicants are admitted under the General Regulations of the School of Graduate Studies. Applicants must also satisfy IBBME's additional admission requirements stated below.

A bachelor's degree in dentistry, engineering, medicine, or one of the physical or biological sciences from a recognized university with a minimum academic standing of A- in the final two years of study.

Program Requirements

The program normally comprises at least 2.0 full-course equivalents (FCEs), one of which must be BME 1450H *Bioengineering Science*. and an appropriate life science or engineering course. Engineering and physical science students must take a life sciences course, such as JPB 1022H (or an equivalent); life science students must take an engineering or physical science course, such as JPB 1055H (or an equivalent).

Students participate in two seminar courses: either BME 1010H or BME 1011H *Graduate Seminar* series, and JDE 1000H *Ethics in Research*.

Health and safety training workshops.

Successful completion of a research thesis in at least one of the biomedical engineering research fields: 1) Neural/Sensory Systems and Rehabilitation; 2) Biomaterials, Tissue Engineering and Regenerative Medicine; 3) Nanotechnology, Molecular Imaging and Systems Biology; or 4) Engineering in a Clinical Setting.

Program Length: 5 sessions full-time

Time Limit: 3 years full-time

Doctor of Philosophy

The PhD program is offered in the fields of 1) Neural/Sensory Systems and Rehabilitation; 2) Biomaterials, Tissue Engineering and Regenerative Medicine; 3) Nanotechnology, Molecular Imaging and Systems Biology; 4) Engineering in a Clinical Setting and 5) Clinical Engineering.

Admission Requirements

Applicants are admitted under the General Regulations of the School of Graduate Studies. Applicants must also satisfy IBBME's additional admission requirements stated below.

A master's degree in dentistry, engineering, medicine, or one of the physical or biological sciences. Applicants to the PhD in the field of clinical engineering must have an undergraduate degree in engineering.

Highly qualified master's students (MHSc students in clinical engineering or MASc students in any field) may be considered for transfer into the PhD program in any of the five fields. Clinical Engineering MHSc students must complete 3.0 full-course equivalents (FCEs) within the MHSc curriculum.

Direct admission with a bachelor's degree may be considered in exceptional cases.

Program Requirements

All fields:

Normally, at least 1.0 full-course equivalent (FCE) and successful completion of a thesis, representing an original investigation in biomedical engineering. Students who transfer without completing a master's degree in biomedical engineering must complete the total course requirements for both degrees (2.0 FCEs for the master's level plus 1.0 FCE for the PhD level, for a total of 3.0 FCEs). Engineering and physical science students are required to take a life sciences course, such as JPB 1022H (or an equivalent); life science students are required to take a physical science course, such as JPB 1055H (or an equivalent).

Within 12 months of registration, students must pass a qualifying examination covering the broad field of biomedical engineering appropriate to their background.

Students will continue to meet with their supervisory committee at least once every 12 months until recommendation for the departmental oral examination is made. On the recommendation of the supervisory committee and special approval from their department Graduate Chair or Coordinator, candidates have the opportunity to waive the departmental oral examination and proceed directly to the Doctoral Final Oral Examination.

Two seminar courses: either BME 1010H or BME 1011H *Graduate Seminar* series, and JDE 1000H *Ethics in Research*.

Health and safety training workshops.

Students are also expected to take BME 1450H *Bioengineering Science* and pursue a thesis topic relevant to at least one of the following biomedical engineering research fields: 1) Neural/Sensory Systems and Rehabilitation; 2) Biomaterials, Tissue Engineering and Regenerative Medicine; 3) Nanotechnology, Molecular Imaging and Systems Biology; 4) Engineering in a Clinical Setting or 5) Clinical Engineering.

Clinical Engineering field:

*Complete the following requirements in addition to those listed above:

If a student does not have a formal degree in clinical engineering, 0.5 FCE from one of the IBBME clinical engineering courses (BME 1405H, BME 1439H, BME 1436H, or BME4444H) is required. A student who possesses protracted professional engineering experience (five or more years) will be exempt from this requirement.

Students in the Clinical Engineering field must (1) conduct their research in a clinical environment, and; (2) be co-supervised by both engineering and health science faculty. The primary supervisor must be IBBME-appointed; however, the co-supervisor could be from a clinical unit other than IBBME but must be appointed to SGS.

Program Length: 4 years full-time; 5 years direct-entry

Time Limit: 6 years full-time; 7 years direct-entry

Clinical Engineering

Master of Health Science

Minimum Admission Requirements

Applicants are admitted under the General Regulations of the School of Graduate Studies. Applicants must also satisfy IBBME's additional admission requirements stated below.

Selected students who hold a bachelor of applied science degree in engineering.

Program Requirements

Normally 4.0 full-course equivalents (FCEs), including BME 1405H, BME 1436H, BME 1439H, and one elective, relevant to a student's area of research. All students are required to take BME 1450H, a life sciences course, such as JPB 1022H (or an equivalent), and 1.0 FCE of internships (completed over two or three separate internships) in health care facilities, the medical device industry, or health care consulting firms.

Students participate in two seminar courses: one of BME 1010H or BME 1011H *Graduate Seminar* series, and JDE 1000H *Ethics in Research*.

Successful completion of a thesis.

Program Length: 6 sessions full-time

Time Limit: 3 years full-time

Course List

Not all courses are offered every year. Students should contact the institute office for information about course availability. Outlines of these and other closely related courses may be obtained from the institute office.