UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

Report No. 3716 Revised

MEMORANDUM

To: Executive Committee of Faculty Council (April 6, 2022)
Faculty Council (April 27, 2022)

From: Professor Julie Audet
Chair, Engineering Graduate Education Committee (EGEC)

Date: April 22, 2022

Re: Creation of Collaborative Specialization in Neuromodulation

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).

PROPOSED

It is proposed to establish a Collaborative Specialization in Neuromodulation, a multidisciplinary endeavor that will initially involve collaboration between the Departments of Electrical & Computer Engineering, Chemical Engineering & Applied Chemistry, Materials Science & Engineering, Mechanical & Industrial Engineering; the Institute of Biomedical Engineering; and the Institute of Medical Science in the Temerty Faculty of Medicine. It will eventually integrate different streams of research within the University.

The collaborative specialization will be the first of its kind in Toronto and will introduce students to various neuromodulation modalities. It will prepare them for research or industrial endeavors in neuromodulation, and provide them with hands-on experience performing neuromodulation research. The CRANIA Neuromodulation Institute (CNMI), an EDU:C within the Faculty, will play a key role as the supporting unit of the collaborative specialization.

CONSULTATION PROCESS

The proposed Collaborative Specialization in Neuromodulation was developed in consultation with the participating graduate units. All were in support of the collaborative specialization and no major issues were identified.

RECOMMENDATION FOR COUNCIL

THAT the creation of a Collaborative Specialization in Neuromodulation, as described in Report 3716 Revised, be approved.

New Graduate Collaborative Specialization Proposal (Major Modification)

Collaborative Specialization in Neuromodulation

Faculty of Applied Science & Engineering
University of Toronto

This template has been developed in line with the University of Toronto's Quality Assurance Process and should be used to bring forward all proposals for new graduate collaborative specializations for governance approval under the University of Toronto's Quality Assurance Process.

Name of proposed collaborative specialization:	Collaborative Specialization in Neuromodulation
Lead Faculty/academic division:	Faculty of Applied Science & Engineering CRANIA Neuromodulation Institute (CNMI)
Lead Faculty/academic division contact:	Prof. Julie Audet, Vice Dean Graduate (FASE) Dr. Taufik Valiante (CNMI Director) Dr. Sindhu Menon (CNMI Program Coordinator)
Anticipated start date of new collaborative specialization:	September 2022
Version date:	April 21, 2022

Contents

1 Specialization Rationale

Collaborative Specialization in Neuromodulation

The Faculty of Applied Science & Engineering proposes to establish a Collaborative Specialization in Neuromodulation, a first of its kind in Toronto. The CRANIA Neuromodulation Institute (CNMI), an EDU:C within the Faculty, will play a key role as a supporting unit of the collaborative specialization. The proposed specialization will be a multidisciplinary endeavor that will initially involve collaboration between the Faculty of Applied Science & Engineering (FASE) and the Temerty Faculty of Medicine (FoM) and eventually integrate different streams of research within the University. The collaborative specialization aims to create an environment that enables students with multiple education/research backgrounds to solve critical problems in neuromodulation.

Rationale

Neuromodulation is the field of study encompassing neuroscience and engineering that focuses on developing implantable and non-implantable technologies, electrical or chemical, that impact upon neural interfaces to help improve the quality of life of individuals that suffer from neurological conditions. Neuromodulation-based therapeutics are already helping those with Parkinson's disease, epilepsy, stroke, depression, chronic pain, spinal cord injury, bladder dysfunction, anorexia, and Alzheimer's disease – conditions that affect millions of Canadians.

The University of Toronto is a clinical pioneer in neuromodulation research for brain disorders, leaders in computing and advanced manufacturing infrastructure, a home to deep learning and artificial intelligence, a hub for collaborations to transform the field and a home to the top engineering departments in the world.

However, each discipline relevant to neuromodulation exists as a discrete entity and a uniquely focused approach to integrating these disciplines into a coherent, wholesome study does not currently exist. Therefore, there is an urgent requirement to bring together this knowledge as well as converge diverse skills, technologies and know-how from intersecting fields to realize the full potential of neuromodulation research at UofT.

The collaborative specialization aims to provide students with equal exposure to a neuroscientist or clinician, and an engineer or computer scientist, which will allow them to work interchangeably as the roles require.

- Specifically, the collaborative specialization will:
  - Train students including future clinicians, researchers and neurologists, alongside future engineers, computer scientists and material scientists.
  - Create an interdisciplinary environment that enables students with varied education backgrounds to apply their expertise to solve critical problems in neuromodulation.
  - Provide both medical and engineering students with hands-on experience in neuromodulation research, which is currently not offered by any other Institute within UofT.
  - Explore bioengineering challenges and solutions at the neural interface to critically appraise the likelihood of therapeutic success.
  - Foster integrative thinking in the neuromodulation space.

More broadly, the specialization will strengthen ties between the Faculty of Applied Science & Engineering and the Temerty Faculty of Medicine. Through the establishment of this collaborative specialization, the University of Toronto has the potential to become a key player in an innovation drive towards technologically advanced neuromodulation therapeutics.

2 Participating Programs, Degrees and Names of Units

Faculty of Applied Science & Engineering

- Biomedical Engineering, MASc, PhD, Institute of Biomedical Engineering
- Electrical & Computer Engineering, MASc, PhD, The Edward S. Rogers Sr. Department of Electrical & Computer Engineering
- Chemical Engineering & Applied Chemistry, MASc, PhD, Department of Chemical Engineering & Applied Chemistry
- Mechanical & Industrial Engineering, MASc, PhD, Department of Mechanical & Industrial Engineering
- Materials Science & Engineering, MASc, PhD, Department of Materials Science & Engineering

Temerty Faculty of Medicine

- Medical Science, MSc, PhD, Institute of Medical Science

3 Objectives, Added Value for Students

The Collaborative Specialization in Neuromodulation aims to provide inter-disciplinary training opportunities for participating students and promote collaborative research in the field of neuromodulation. Presently, individuals are trained in specific disciplines such as engineering, medicine and neuroscience, rather than working collaboratively across these disparate fields. Our objective is to remove this barrier and specifically and intentionally develop neuromodulation professionals instead of training engineers or clinicians. This new generation of integrative thinkers will be able to operate seamlessly in the neuromodulation space in clinical/engineering environments.

The field of neuromodulation is experiencing unprecedented growth with novel, technologically advanced therapies driven by machine learning, optical interfaces, electronics, neuroscience and big data analyses being rapidly developed and deployed. Growth in this field is demonstrated by the current $8.4 billion global market for neurodevices, which is forecast to reach $15.1 billion by 2024 and will grow at a compound annual growth rate of more than 11% [*The Market for Neurotechnology: 2020-2024*, Neurotech Reports].

We launched the foundational course for the collaborative specialization, “BME1500H-Topics in Neuromodulation” in September 2021 as a lead-in for the collaborative specialization and to gain insight into student interest in the field. BME1500H filled to capacity (20 students) within 24 hours of opening the course for enrollment, which speaks for the high level of interest among students in the subject and validates the requirement for a neuromodulation focused offering. Additionally, the feedback received from discussions with participating faculty members and Chairs of various departments and institutes was extremely positive, with members looking forward to the integration of neuroscience within the engineering space. Given the student interest and subsequent enrollment in BME1500H, we anticipate an enrollment of 20 students in the collaborative specialization when it is launched.

The collaborative specialization will leverage existing graduate courses from participating departments and institutes in addition to the mandatory core neuromodulation course, BME1500H: Topics in Neuromodulation. The unique combination of courses currently available through this specialization will enable a multidisciplinary understanding of emerging neuromodulation technology and its clinical applications through collaborative and practical research projects. It will provide trainees with the strong skills and technical background necessary to be competitive in the field of neuromodulation. In addition, students will learn to

work collaboratively with team members and communicate effectively through oral presentations, presentations at research days and participation in team projects.

Students will engage in workshops on topics related to the commercialization of innovations, including “Entrepreneurship in the life-tech sector” and “Regulatory approval processes for technological applications.” The collaborative specialization will also leverage the University’s association with leading-edge Imaging facilities to offer hands-on workshops on various neuromodulation modalities such as Electroencephalography (EEG) and Repetitive transcranial magnetic stimulation (rTMS). These workshops will be available exclusively to students participating in the collaborative specialization and aim to equip trainees with the practical knowledge and technical skill-set necessary to advance their research to its therapeutic application.

The topics covered by the Collaborative Specialization in Neuroscience (CSIN) may reflect some degree of overlap with the proposed Collaborative Specialization in Neuromodulation. The CSIN provides students with an overview of neuroscience and encompasses courses covering a wide range of topics including developmental neuroscience, imaging technology, cellular and molecular neurobiology, among others. While the CSIN includes a course that gives a broad overview of neuromodulation (BME1473H: Fundamentals of Neuromodulation Technology and Clinical Applications), there are currently no courses or programs that cover the scope of neuromodulation techniques and its therapeutic applications. Over the past decade, the market for neurotechnology has substantially grown as a result of advances in several fields of science and technology and neuromodulation currently comprises the largest segment of this market. Consequently, there is a need to develop more comprehensive education, training and infrastructure to better prepare students to excel in this field. As Canada’s leading university, the University of Toronto has a distinctive role to play in bringing together the diverse skills and technologies from its disciplines and affiliated health care institutions. The coursework and workshops in the proposed Collaborative Specialization in Neuromodulation have been designed specifically with this vision to empower University of Toronto students with the skills and technical knowledge essential to advance the field of neuromodulation.

The Collaborative Specialization in Neuromodulation will provide students with the strong background necessary to excel in the field of neuromodulation by focusing its education mandate in the following key multidisciplinary research areas:

1. Neural Targets: Develop advanced surgical navigation technologies, advanced imaging and electrophysiological measurement techniques to identify disease-relevant regions or “targets” in the nervous system.
2. Electronics, Electrodes and Computing: Establish computational tools, bio-compatible electrodes and housings, implantable electronics, and wireless cloud-based data transfer technologies to capture and analyze neural activity.
3. Validated Closed-Loop Devices: Combine knowledge from 1) and 2), and linear and nonlinear control theory and practice, to create intelligent monitoring devices capable of synthesizing and analyzing neurological activity data in real-time to provide closed-loop strategies for stimulation of neural targets in a responsive manner.

Our expectation is that the proposed collaborative specialization will contribute to exciting changes in the neuromodulation sphere by fostering a new generation of scientists who will be well-equipped to create devices to improve brain, spinal cord and peripheral nerve health, and improve the quality of life of those suffering from neurological conditions.

4 Admission and Specialization Requirements

Admission Requirements

Students interested in joining must first apply to and be enrolled in a Master’s or PhD program in one of the collaborating departments or institutes. Once accepted into a program, students can then apply for admission to the Collaborative Specialization in Neuromodulation. Students are encouraged to enroll in the collaborative specialization as soon as possible after beginning their graduate studies.

It will be the applicant’s responsibility to find an appropriate supervisor to supervise them and support their thesis research. Applicants are therefore expected to contact and meet with potential supervisors among the core faculty of the collaborative specialization during the application process. The supervisor must provide a letter of recommendation in support of the student’s application to the collaborative specialization.

Participating students are also encouraged to have a co-supervisor or a member of their supervisory committee with research expertise in a different field of study to their home department, although this is not mandatory.

The final decision to admit the student into the collaborative specialization is up to the collaborative specialization director and specialization committee.

Students who have completed the collaborative specialization at the master's level will not be eligible to enroll in it again during their PhD.

Program Requirements

The student's thesis requirement for the home program must be focused on a topic in the area of neuromodulation.

The course BME1500H Topics in Neuromodulation (0.5 FCE) is mandatory for all students. In addition, all students must complete at least 0.5 full-course equivalents (FCEs) chosen from the list of courses approved by the CNMI (listed below). Students are encouraged to select this elective course from a non-home faculty. Note: Some modular courses are worth 0.25 FCE. In this case, students will have to complete two 0.25 FCE courses to complete the 0.5 FCE elective course requirement.

All students must attend the professional development workshops organized by CNMI for CS students. The workshops topics may change from year to year and may include hands-on workshops on various neuromodulation modalities, translational neurophysiology workshops and lectures on Entrepreneurship in the life sciences sector. These workshops are designed to equip CS students with technical and professional skills that will complement the knowledge required from the CS coursework and will be offered 2-3 times a year. Information about workshops will be posted online as well as emailed to students once the workshop is announced. Participation in the workshops is mandatory and students are expected to sign up for the workshops via Quercus. Attendance in the workshops will be tracked by CNMI using Quercus.

Students should enroll in the Specialization as soon as possible after beginning their graduate studies by completing the online application form that will be posted on CNMI website (*Link to be updated*). Students can contact CNMI at info.cnmi@utoronto.ca with any questions or concerns.

List of elective courses

Biomedical Engineering

BME1802H: Applying Human Factors to the Design of Medical Devices (0.5 FCE)
BME1473H: Acquisition and Processing of Bioelectric Signals (0.5 FCE)
BME1472H: Fundamentals of Neuromodulation Technology and Clinical Applications (0.5 FCE)
JEB1444H: Neural Engineering (0.5 FCE)
JPB1071H: Advanced Topics: Computational Neuroscience (0.5 FCE)
BME1466H: Advanced Topics on Magnetic Resonance Imaging (0.5 FCE)

Electrical & Computer Engineering

ECE516H1: Intelligent Image Processing (0.5 FCE)
ECE1656H: Nonlinear Modeling and Analysis of Biological Systems (0.5 FCE)
ECE537H1: Random Processes (0.5 FCE)
ECE1475H: Bio Photonics (0.5 FCE)
ECE1774H: Sensory Cybernetics (0.5 FCE)
ECE1777H: Computer Methods for Circuit Simulation (0.5 FCE)
ECE1647H: Introduction to Nonlinear Control Systems (0.5 FCE)

Mechanical & Industrial Engineering

MIE1359H: Engineering Cell Biology and Micro-Nanoengineered Platforms (0.5 FCE)
MIE1080H: Introduction to Healthcare Robotics (0.5 FCE)
MIE1208H: Microfluidic Biosensors (0.5 FCE)
MIE1232H: Microfluidics and Laboratory-on-a-Chip Systems (0.5 FCE)

Materials Science & Engineering

JMB1050H: Biological & Bio-Inspired Materials (0.5 FCE)
MSE1038H: Computational Materials Design (0.5 FCE)

Chemical Engineering & Applied Chemistry

CHE1333H: Biomaterials Engineering for Nanomedicine (0.5 FCE)
CHE1334H: Organ-on-a-Chip Engineering (0.5 FCE)
CHE1053H: Electrochemistry (0.5 FCE)

Medical Science

MSC1006H: Neuroanatomy (0.5 FCE)
MSC1087H: Neuroimaging Methods Using Magnetic Resonance Imaging (0.5 FCE)

MSC1085H: Molecular Approaches to Mental Health and Addictions (0.5 FCE)
MSC1102H: Psychiatric Implications of Traumatic Brain Injury (0.25 FCE)
MSC1104H: Neurodegenerative Disease (0.25 FCE)
MSC1109H: Introduction to Neuroimaging (0.25 FCE)
MSC1113H: Radiomics and Machine Learning for Medical Imaging (0.25 FCE)

Verification of Completion of Specialization Requirements

All students enrolled in the Collaborative Specialization in Neuromodulation must complete the specific course requirements of the collaborative specialization, in addition to or within those requirements for the degree program in their home graduate unit, where possible. Upon completion of the CS requirements, students should fill out the CS completion form that will be posted on the CNMI website (*Link to be updated*).

The CNMI Program coordinator will coordinate with BME graduate office (or FASE graduate studies office) and SGS to ensure that students have completed all the program requirements. The collaborative specialization director is responsible for certifying the completion of the collaborative specialization requirements, with recommendations from the Neuromodulation Specialization Committee. The home graduate unit is solely responsible for the approval of the student's home degree requirements.

SGS Calendar Copy

Collaborative Specialization in Neuromodulation

Lead Faculty

Faculty of Applied Science & Engineering

Participating Degree Programs

- Biomedical Engineering, MASc, PhD
- Chemical Engineering & Applied Chemistry, MASc, PhD
- Electrical & Computer Engineering, MASc, PhD
- Materials Science & Engineering, MASc, PhD
- Mechanical & Industrial Engineering, MASc, PhD
- Medical Science, MSc, PhD

Supporting Units

University of Toronto CRANIA Neuromodulation Institute (CNMI)

Overview

The primary goal of the Collaborative Specialization in Neuromodulation is to introduce students to various neuromodulation modalities, provide students with the knowledge to be prepared for research or industrial endeavours in neuromodulation, and provide hands-on experience performing neuromodulation research. Essentially, this specialization will train future researchers and clinicians alongside engineers and provide students with cross-disciplinary exposure to the various aspects of neuromodulation-based therapeutic innovation.

The collaborative specialization is open to master's and PhD students in the participating graduate degree programs listed above. Upon successful completion of the degree requirements of the home department and the collaborative specialization, students receive the notation "Completed Collaborative Specialization in Neuromodulation" on their transcript.

Contact and Address

Sindhu Menon
Web: *To be launched soon*
Email: info.cnmi@utoronto.ca
Telephone: *TBD*

Toronto Western Hospital
399 Bathurst Steet, McLaughlin Wing 14th Floor, Room 14MC413
Toronto, ON M5T 2S8

Master's Level

Admission Requirements

- Applicants must meet the admission requirements of both the home department and the collaborative specialization (CS).
- Applicants must apply to and be admitted to both the CS and a participating master's degree program.
- The supervisor must provide a letter of recommendation in support of the student's application to the CS.

Specialization Requirements

- The thesis topic must be in the neurotechnology/neuromodulation area.
- Participating students are encouraged to have a co-supervisor or a member of their supervisory committee with research expertise in an area of study different from their home department.
- The course BME1500H *Topics in Neuromodulation* is mandatory for all students. Students must attend all lectures in the course and present a project for course evaluation.
- In addition, all master's-level students must complete at least 0.5 full-course equivalent (FCE) chosen from the list of courses approved by CNMI.
- Students must attend the professional development workshops organized by CNMI as part of the CS. Students must enrol in the workshops via Quercus, which will be used to record and track attendance.
- Participating students from graduate units in FASE cannot count towards the total FCE requirements of their home program, the modular (0.25 FCE) MSC courses that are not letter graded.
- Participating Institute of Medical Science students may double-count the courses taken as part of the CS towards their degree, except in the case of some of the 0.25 FCE modular MSC courses, which are not letter graded. These students should consult with their graduate coordinator or the CNMI program coordinator to confirm this before opting for the modular elective courses.

Doctoral Level

Admission Requirements

- Applicants must meet the admission requirements of both the home department and the collaborative specialization (CS).
- Applicants must apply to and be admitted to both the CS and a participating doctoral degree program.
- The supervisor must provide a letter of recommendation in support of the student’s application to the CS.
- Students who have already taken the CS during their master’s degree program will not be eligible to take it again during their PhD.

Specialization Requirements

- The thesis topic must be in the neurotechnology/neuromodulation area.
- Participating students are encouraged to have a co-supervisor or a member of their supervisory committee with research expertise in an area of study different from their home department.
- The course BME1500H *Topics in Neuromodulation* is mandatory for all students. Students must attend all lectures in the course and present a project for course evaluation.
- In addition, all doctoral-level students must complete at least 0.5 full-course equivalent (FCE) chosen from the list of courses approved by CNMI.
- Students must attend the professional development workshops and seminars organized by CNMI as part of the CS. Students can enroll in the workshops via Quercus, which will be used to record and track attendance.
- In addition, doctoral students must attend the Annual CRANIA Research Day every year and are encouraged to present their research work at least once.
- Participating students from graduate units in FASE cannot count towards the total FCE requirements of their home program, the modular (0.25 FCE) MSC courses that are not letter graded.
- Participating Institute of Medical Science students may double-count the courses taken as part of the CS towards their degree, except in the case of some of the 0.25 FCE modular courses, which are not letter graded. These students should consult with their graduate coordinator or the CNMI program coordinator to confirm this before opting for the modular elective courses.

5 Degree Level Expectations, Program Learning Outcomes and Program Structure

A collaborative specialization is intended to provide an additional multidisciplinary experience for students enrolled in, and completing the requirements of, a degree program. The requirements for the Collaborative Specialization in Neuromodulation are **in addition to** the degree requirements and are not meant to extend the student's time to degree.

The primary purpose of the Collaborative Specialization in Neuromodulation is to provide engineers, clinicians and neuroscientists with the expertise required to accelerate the innovation pathway from discovery to therapeutic application. This will be made possible by providing graduate students with a multidisciplinary learning environment, in which they can perform translational neuromodulation research.

The principal benefit to students will be an improved capacity and knowledge to develop, validate and commercialize advanced neuromodulation technologies. Students will primarily achieve this capacity through the independent pursuit of a neuromodulation-based thesis supported by mentoring from an expert supervisor. This learning will be supported by the completion of a seminar course that will provide students with a basic understanding of neuromodulation modalities and attendance in workshops that improve students' skill set and practical knowledge.

Outcomes are goals that describe how a student will be different because of a learning experience. More specifically, learning outcomes are the knowledge, skills, attitudes and habits of mind that students take with them from a learning experience.

Participation in the Collaborative Specialization in Neuromodulation will enable students to critically analyze scientific data to improve treatment outcomes for neuromodulation, understand the bioengineering challenges and solutions at the neural interface and use this knowledge in the design of therapeutic innovations.

Details on the degree level expectations and learning outcomes for the Collaborative Specialization in Neuromodulation beyond those of the home program degree requirements are provided below. However, the primary degree level expectations will be met through the home department.

Table 1: Master's Degree Level Expectations

MASTER'S DEGREE-LEVEL EXPECTATIONS (based on the FASE GDLEs, approved March 8, 2011 by Faculty Council)	MASTER'S PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
EXPECTATIONS: This Collaborative Specialization in Neuromodulation 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 the Collaborative Specialization in Neuromodulation as: • A systematic understanding of the scientific principles and methodological aspects of neuromodulation and its clinical applications in the treatment of neurological disorders. • A critical awareness of current drawbacks in the field, with a vision towards advancing innovations in neuromodulation to its therapeutic application. This is reflected in students who are able to:	The program design and requirement elements that ensure these student outcomes for depth and breadth of knowledge are: • BME1500 core course that provides students with an overview of various neuromodulation modalities including interventions that are non-invasive, invasive, emerging and pre-clinical in the context of movement, psychiatric, pain, and memory disorders. • Elective coursework from non-home departments which will complement the knowledge and skills obtained through BME1500.

	• M1: Analyze current and emerging neuromodulation modalities and the scope of their therapeutic application. • M2: Interpret existing scientific literature in the field of neuromodulation, discuss and critique the strengths and limitations of new research studies and identify the broader context and implications of the research.	
2. Research and Scholarship A conceptual understanding and methodological competence that: • Enables a working comprehension of how established techniques of research and inquiry are used to create and interpret knowledge in the discipline. • Enables a critical evaluation of current research and advanced research and scholarship in the discipline or area of professional competence. • Enables a treatment of complex issues	Research and Scholarship is defined in the Collaborative Specialization in Neuromodulation as the ability to develop and implement research for the generation of novel therapeutics and technologies for their translational application. This is reflected in students who are able to: • M3: Design and carry out a research project that addresses the context, methods and novel, knowledge-generating aspects of the project and implications of their research in the	The program design and requirement elements that ensure these student outcomes for research and scholarship are: • Expert supervision and guidance of students' research project that will allow to pursue cross-disciplinary research topics and articulate their findings in a comprehensive, written dissertation. • Workshops organized by CNMI along with BME1500 term project provides students with hands-on experience

and judgments based on established principles and techniques; and, on the basis of that competence, has shown at least one of the following: ▶ The development and support of a sustained argument in written form; or ▶ Originality in the application of knowledge.	field of neuromodulation. • M4: Integrate the technical skills specific to the study of neuromodulation into their research project.	performing specific neuromodulation modalities and experience analyzing data from patients, which can be applied in their thesis projects as well as in the clinical translation of their research.
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.	Level of Application of Knowledge is covered through the program learning outcomes of the home program.	N/A
4. Professional Capacity/Autonomy • The qualities and transferable skills necessary for employment requiring: ▶ The exercise of initiative and of personal responsibility and accountability; and ▶ Decision-making in complex situations. • The intellectual independence required	Professional Capacity/Autonomy is covered through the program learning outcomes of the home degree program.	N/A

for continuing professional development. • The ethical behavior consistent with academic integrity and the use of appropriate guidelines and procedures for responsible conduct of research. • The ability to appreciate the broader implications of applying knowledge to particular contexts.		
5. Level of Communications Skills The ability to communicate ideas, issues and conclusions clearly.	The ability to communicate ideas, issues and conclusions clearly. Mainly covered through the program learning outcomes of the home program. Communications skill is defined in Collaborative Specialization in Neuromodulation as the ability to present their research clearly and concisely to peers in the field or to a person whose expertise lies outside that of the students' research. This is reflected in students who are able to: • M5: Pitch their research ideas in a clear and coherent manner.	The program design and requirement elements that ensure these student outcomes for level of communication skills are: • Team presentations of students' research projects in the core course BME1500 which presents a forum to practice, observe and improve students' communication skills and their ability to discuss their research findings. • Peer review of trainee research reports in BME1500 course project, which provides students with first-hand

	• M6: Understand and analyze research presentations and communicate their questions/suggestions effectively.	exposure to the peer-review process and helps students communicate scientific suggestions effectively.
6. Awareness of the Limits of Knowledge Cognizance of the complexity of knowledge, its underlying assumptions, and the potential contributions of other interpretations, methods, and disciplines.	Level of Awareness of Limits of Knowledge is covered through the program learning outcomes of the home program.	N/A

Table 2: Doctoral DLEs

DOCTORAL DEGREE LEVEL EXPECTATIONS (based on the FASE GDLEs, approved March 8, 2011 by Faculty Council)	DOCTORAL PROGRAM LEARNING OBJECTIVES AND OUTCOMES	HOW THE PROGRAM DESIGN AND REQUIREMENT ELEMENTS SUPPORT THE ATTAINMENT OF STUDENT LEARNING OUTCOMES
EXPECTATIONS: This Collaborative Specialization in Neuromodulation 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 the Collaborative Specialization in Neuromodulation as: • A systematic understanding of the scientific principles and methodological aspects in neuromodulation and its clinical applications in the treatment of neurological disorders. • A critical awareness of current drawbacks in the field, with a vision towards advancing innovations in neuromodulation to its therapeutic application. This is reflected in students who are able	The program design and requirement elements that ensure these student outcomes for depth and breadth of knowledge are: • BME1500 core course that provides students with an overview of various neuromodulation modalities including interventions that are non-invasive, invasive, emerging and pre-clinical in the context of movement, psychiatric, pain, and memory disorders. • Elective coursework from related to the engineering aspects of neuromodulation approaches

	to: • D1: Analyze current and emerging neuromodulation modalities and the scope of their therapeutic application. • D2: Interpret existing scientific literature, discuss, and critique the strengths and limitations of research methodologies in new research studies and identify the broader context and implications of the research.	which will complement the knowledge and skills students obtained through BME1500.
2. Research and Scholarship The ability to: • conceptualize, design, and implement research for the generation of new knowledge, applications, or understanding at the forefront of the discipline, and to adjust the research design or methodology in the light of unforeseen problems;	Research and Scholarship is defined in the Collaborative Specialization in Neuromodulation as the ability to develop and implement research for the generation of novel therapeutics and technologies for their translational application. This is reflected in students who are able to: • D3: Prepare a clearly written doctoral level dissertation outlining the context, methods and novel, knowledge-generating	The program design and requirement elements that ensure these student outcomes for research and scholarship are: • Expert supervision and guidance with students' research project will provide students with the opportunity to pursue cross-disciplinary thesis topics, develop research proposals and articulate their research findings in a

• make informed judgments on complex issues in specialist fields, sometimes requiring new methods; and • produce original research, or other advanced scholarship, of a quality to satisfy peer review, and to merit publication.	aspects of the project and implications of their research in the field of neuromodulation. The dissertation should meet the home program's doctoral level requirements. • D4: Translate research findings into novel strategies for implementation in clinical applications that require an advanced understanding of neuroscience and engineering science.	comprehensive, written doctoral dissertation. In these activities, students will develop an advanced understanding of a substantial body of knowledge that is at the forefront of the field of neuromodulation. • Workshops organized by CNMI along with BME1500 term project provides students with hands-on experience performing specific neuromodulation modalities as well as real brain data analysis, which can be applied in their thesis projects as well as in the clinical translation of their research.
3. Level of Application of Knowledge The capacity to: • undertake pure and/or applied research at an advanced level; and • contribute to the development of academic or professional skills, techniques, tools, practices, ideas,	Level of Application of Knowledge is covered through the program learning outcomes of the home program.	N/A

theories, approaches, and/or materials.		
4. Professional Capacity/Autonomy • The qualities and transferable skills necessary for employment requiring the exercise of personal responsibility and largely autonomous initiative in complex situations. • The intellectual independence to be academically and professionally engaged and current. • The ethical behaviour 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 implications of applying knowledge to particular contexts.	Professional Capacity/Autonomy is covered through the program learning outcomes of the home doctoral degree program.	N/A
5. Level of Communication Skills The ability to communicate complex and/or ambiguous ideas, issues and	Mainly covered through the program learning outcomes of the home program.	The program design and requirement elements that ensure these student outcomes for level of communication

conclusions clearly and effectively.	Communications skill is defined in Collaborative Specialization in Neuromodulation as the ability to present their research clearly and concisely to their peers in the field or to a person whose expertise lies outside that of the students' research. This is reflected in students who are able to: • D5: Pitch their research ideas in a clear and coherent manner. • D6: Analyze research presentations and communicate their questions/suggestions effectively. • D7: Lead, encourage and engage in peer-level advanced scientific discourse on topics related to neuromodulation, making claims and constructing credible arguments, and defending them logically and concisely using appropriate supporting evidence.	skills are: • Team presentations of students' research projects in the core course BME1500 and student research presentations at CRANIA Research day which present forums to practice, observe and improve students' communication skills and their ability to lead discussions related to their research findings or those of their peers. • Ongoing feedback and guidance from a supervisor and supervisory committee with expertise in neuromodulation throughout the documentation of their research and the preparation for its defence and presentation to internal and external reviewers. • Peer review of trainee research reports in BME1500 which provides students with first-hand

		exposure to the peer-review process and helps students communicate scientific suggestions effectively.
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 covered through the program learning outcomes of the home program.	N/A

6 Assessment of Learning

The collaborative specialization will use a variety of methods to assess student development and progression in the Degree Level Expectations of primary focus namely, a) Depth and Breadth of Knowledge, b) Research and Scholarship and c) Communication skills.

- Evaluation of the Neuromodulation-related research thesis and its defense through an oral examination: The student's supervisor(s) will assume the primary responsibility for monitoring and assessing how well the student is performing relative to the expected learning objectives and degree-level expectations. However, the thesis committee will share partial responsibility to provide assessments of the student's progress throughout their degree. The collaborative specialization director will review feedback to make sure the student has demonstrated the expected degree-level expectations for the collaborative specialization.
- Academic performance in the core seminar course BME1500H which will be evaluated based on participation (20%), term project (70%), and an individually submitted project peer-review (10%). Participation in the seminar course is mandatory. The course instructor will monitor attendance and feedback to ensure those enrolled for credit have met the attendance requirement and completed the course evaluation requirements.
  - **Participation (20.0):** Each student can earn 2.0 grade points per lecture. Each student will receive 0.5 points for attendance, and 1.5 points for a meaningful question or comment during the discussion period of the lectures.
  - **Project (70.0):** Each student will be part of a group (2-4 students) that will complete a term project. These projects have been designed to provide students with experience analyzing neural data and includes data sets comprising of EEG recordings acquired from patients with Parkinson's disease, single-neuron recordings acquired intraoperatively from patients with Parkinson's disease, and single-neuron recordings form the thalamic ventral intermediate nucleus, as well as accelerometry during postural tremor, to name a few. Based on the data set, students will work in groups to write a "short format" academic paper (max. 2500 words and two figures). This will involve conducting a literature review on a relevant topic which can be used to formulate the *Introduction* section, analyzing the sample human brain dataset, writing an appropriate *Methods* section, generating *Figures and figure legends*, interpreting the results and writing a *Results* and relevant *Discussion* section. Students will then

choose one delegate to present the paper in the form a *Conference Presentation* of up to 12 min + 8 min for questions and discussion. Students must submit a copy of their report for grade evaluation.

- **Peer-review (10.0):** Each student will be appointed one research project final document to peer-review. The peer reviews will be graded depending on completion, effort, and meaningfulness of the feedback provided.

- Academic performance in the elective course: This will be graded for direct assessment of course material knowledge by the faculty members teaching these units and having focused expertise in these topics.
- Attendance in CNMI workshops: Attendance in the workshops is mandatory and will be tracked by CNMI's program coordinator using Quercus.

The CNMI Program coordinator will coordinate with the Institute of Biomedical Engineering graduate office and BME1500 course instructors to track attendance and monitor course evaluations of students in the core course BME1500. CNMI will also track student attendance using Quercus and coordinate with SGS to confirm students' completion of all program requirements. Upon completion of requirements, combined feedback from the core and elective courses, workshops and research thesis will be provided to the CS director, who, with recommendations from the Neuromodulation Specialization Committee, will assess if the student demonstrates the expected Degree level expectation by the end of the collaborative specialization.

7 Resources

The collaborative specialization's core faculty members are available to students in the home program as advisors or supervisors. As all the participating programs include a research thesis, it is expected that a core faculty member in the student's home department will be involved in thesis supervision. Core faculty members contribute to the collaborative specialization through teaching of the core course(s) and participating in the delivery of seminar series and other common learning elements. Some faculty may teach courses in the subject area of the collaborative specialization in the home program. Not all core faculty members are active in the collaborative specialization every year and, in many cases, simply may remain available to interested students. The list of core faculty members is available in Appendix B. Each participating degree program contributes to the collaborative specialization through student enrolments, although not necessarily every year.

Each collaborative specialization has a director and a specialization committee. Together they are responsible for admitting students to the collaborative specialization and ensuring that the faculty associated with the program have the capacity to supervise all program students. Consequently, an assessment of supervisory capacity occurs twice: once when students are admitted to their home degree program and once on their application to the collaborative specialization.

The University finds that the participation in a collaborative specialization does not normally add significantly to a faculty member's supervisory load. For the most part, students in the collaborative specialization will continue to have their thesis or major research project supervised by a faculty member in their home program who also participates in the collaborative specialization.

Please see Appendix B for a list, by program, of core graduate faculty.

8 Administration

See Appendix C: Memorandum of Agreement.

9 Governance Processes

Steps and Approvals	**Date**
Development and consultation with unit(s)	June 2021-November 2021
Consultation with Dean's Office (and VPAP)	November 2021-March 2022
Graduate unit approval	March 2022
VPAP sign-off	April 13, 2022
Faculty/divisional governance	April 27, 2022
Submission to Provost's Office	April 27, 2022
Report to AP&P	Spring 2022
Report to Ontario Quality Council	Spring 2022

Appendix A: Collaborative Specialization Requirements and Degree Program Requirements

Please provide the following information for each participating program. The purpose is to clarify how the collaborative specialization requirements are accommodated within each participating program.

Following the format below, explain if the collaborative specialization requirements are in addition to the home program requirements or if they may be counted towards regular home program requirements. State explicitly, for example, "The core course (X FCE) may be counted as one of the electives."

For collaborative specialization students in a degree program that requires a thesis or major research paper, the topic should be in the area of the collaborative specialization. For students in a coursework-only master's degree program, at least 30% of the courses for the home degree must be in the area of the collaborative specialization — this includes the core course for the collaborative specialization (please see the Quality Assurance Framework "Collaborative Specialization" definition for more details). It is not necessary to reiterate all the requirements for each degree program.

Students who have completed the collaborative specialization at the master's level are not eligible to take it during their PhD.

Institute of Biomedical Engineering

PhD in Biomedical Engineering
PhD requirements: 1.0 FCEs total coursework
1.0 FCE of required core courses
0.0 FCEs elective space for courses
1.0 FCE (coursework) required for the collaborative specialization would be taken in addition to the total FCE home program requirements.

Note: PhD students within the Institute of Biomedical Engineering are free to self-enroll into a maximum of two half-courses (0.5 FCE each) in any given session. Therefore, completing the CS requirements in addition to the home department requirements should not extend students'

time to degree.

PhD in Biomedical Engineering (Transfer option for MASc students)
PhD requirements: 3.0 FCE total coursework
1.0 FCE required core courses
2.0 FCE elective space
1.0 FCE (coursework) required for the collaborative specialization would be taken as electives — no additional courses required

PhD in Biomedical Engineering (Direct-entry)
PhD requirements: 3.0 FCEs total coursework
1.0 FCE of required core courses
2.0 FCEs elective space for courses
1.0 FCE (coursework) required for the collaborative specialization would be taken as electives — no additional courses required

MASc in Biomedical Engineering
MASc requirements: 2.0 FCEs total coursework
1.0 FCE of required core courses
1.0 FCEs elective space for coursework
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives — no additional courses required

The Edward S. Rogers Sr. Department of Electrical and Computer Engineering

PhD in Electrical and Computer Engineering
PhD requirements: 2.5 FCEs total coursework
2.5 FCEs elective space for courses
1.0 FCE (coursework) required for the collaborative specialization may be counted as electives — no additional courses are required

PhD in Electrical and Computer Engineering (Transfer option)
PhD requirements: 4.0 FCEs total coursework (2.5FCE at the MASc level + minimum 1.5 FCE after transferring)
4.0 FCEs elective space for courses

1.0 FCE (coursework) required for the collaborative specialization may be counted as electives — no additional courses are required

PhD in Electrical and Computer Engineering (Direct-entry)
PhD requirements: 4.0 FCEs total coursework
4.0 FCEs elective space for courses
1.0 FCE (coursework) required for the collaborative specialization may be counted as electives — no additional courses are required

MASc in Electrical and Computer Engineering
MASc requirements: 2.5 FCEs total coursework
2.5 FCEs elective space for coursework
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives — no additional courses required

Department of Mechanical and Industrial Engineering

PhD in Mechanical and Industrial Engineering
PhD requirements: 2.5 FCEs total coursework
2.5 FCEs elective space for courses
1.0 FCE (coursework) required for the collaborative specialization may be counted as electives — no additional courses are required

PhD in Mechanical and Industrial Engineering (Transfer option)
PhD requirements: 3.5 FCEs total coursework
3.5 FCEs elective space for courses
1.0 FCE (coursework) required for the collaborative specialization may be counted as electives — no additional courses are required

PhD in Mechanical and Industrial Engineering (Direct-entry)
PhD requirements: 3.5 FCEs total coursework
3.5 FCEs elective space for courses
1.0 FCE (coursework) required for the collaborative specialization may be counted as electives—no additional courses are required

MASc in Mechanical and Industrial Engineering

MASc requirements: 2.0 FCEs total coursework
2.0 FCEs elective space for coursework
1.0 FCE (coursework) required for the collaborative specialization may be counted as electives—no additional courses are required

Department of Materials Science & Engineering

PhD in Materials Science & Engineering
PhD requirements: 2.0 FCEs total coursework
0.5 FCE of required core courses
1.5 FCEs elective space for courses, one of which must be chosen from the list of MSE graduate course offerings.
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required

PhD in Materials Science & Engineering (Transfer option)
PhD requirements: 2.5 FCEs total coursework
0.5 FCE of required core courses
2.0 FCEs elective space for courses, one of which must be chosen from the list of MSE graduate course offerings.
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required

PhD in Materials Science & Engineering (Direct-entry)
PhD requirements: 3.0 FCEs total coursework
0.5 FCE of required core courses
2.5 FCEs elective space for courses, one of which must be chosen from the list of MSE graduate course offerings.
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required

MASc in Materials Science & Engineering
MASc requirements: 2.0 FCEs total coursework
0.5 FCE of required core courses
1.5 FCEs elective space for courses, one of which must be chosen from the list of MSE graduate course offerings.

1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required

Department of Chemical Engineering & Applied Chemistry

PhD in Chemical Engineering & Applied Chemistry
PhD requirements: 2.0 FCEs total coursework
0.5 FCE of required core courses
1.5 FCEs elective space for courses
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required

PhD in Chemical Engineering & Applied Chemistry (Transfer option)
PhD requirements: 3.0 FCEs total coursework
0.5 FCE of required core courses
2.5 FCEs elective space for courses
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives – no additional courses required

PhD in Chemical Engineering & Applied Chemistry (Direct-entry)
PhD requirements: 3.0 FCEs total coursework
0.5 FCE of required core courses
2.5 FCEs elective space for courses
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives – no additional courses required

MASc in Chemical Engineering & Applied Chemistry
MASc requirements: 1.5 FCEs total coursework
0.5 FCE of required core courses
1.0 FCEs elective space for courses
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required

Institute of Medical Science

PhD in Medical Science

PhD requirements: 2.0 FCEs total coursework
0.5 FCE of required core courses
0.5 FCE modular courses
1.0 FCEs elective space for courses
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required

PhD in Medical Science (Transfer option)

PhD requirements: 3.0 FCEs total coursework
0.5 FCE of required core courses
0.5 FCE modular courses
2.0 FCEs elective space for courses
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required

PhD in Medical Science (Direct-entry)

PhD requirements: 3.0 FCEs total coursework
0.5 FCE of required core courses
0.5 FCE modular courses
2.0 FCEs elective space for courses
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required

MSc in Medical Science

MSc requirements: 2.0 FCEs total coursework
0.5 FCE of required core courses
0.5 FCE modular course
1.0 FCEs elective space for courses
1.0 FCEs (coursework) required for the collaborative specialization may be counted as electives—no additional courses required.

Note: Participating IMS students will be able to double count the courses taken as part of the CS towards their degree*, except in the case of some of the 0.25 FCE modular courses, which are not letter graded*. IMS students should consult with their graduate coordinator or the CNMI program coordinator to confirm this, before opting for the modular elective courses.

Appendix B: Core Faculty Research Synopses

Note for proponents: Please provide a full list **of all faculty** who intend to participate in the collaborative specialization from each participating degree program. In each instance, provide two to four recent publications that show active engagement in the field.

Core faculty members are those who are eligible to teach and/or supervise in the collaborative specialization, as appropriate. Core faculty members must hold graduate faculty membership in one of the participating degree programs. The process of identifying a graduate faculty member as a collaborative specialization core faculty member is initiated by the faculty member or the collaborative specialization director. Both the faculty member's home graduate unit chair or director and the collaborative specialization director must agree, as well as the faculty member involved. The collaborative specialization director is responsible for maintaining records of agreements concerning assignment of core faculty members to the collaborative specialization. Formal cross-appointments to the graduate faculty are not required for core faculty members.

There must be at least one faculty member listed from each participating graduate program. Collaborative specialization students must have a core collaborative specialization graduate faculty member from the student's home graduate unit as a supervisor, where a supervisor is required.

All teaching staff identified as members of the collaborative specialization are core faculty of the participating approved graduate programs and have been approved by the chair or director of their home unit for cross-appointment to the collaborative specialization. In bringing forward a proposal for a new collaborative specialization, the concern is that, in addition to being approved members of the graduate teaching staff, all proposed faculty be active in the area of the collaborative specialization. This list highlights peer review publications by the approved faculty members in the collaborative specialization area.

Institute of Biomedical Engineering

Milos Popovic

- KITE-BCI: A brain-computer interface system for functional electrical stimulation therapy. Jovanovic LI, Popovic MR, Marquez-Chin C.J Spinal Cord Med. 2021;44(sup1):S203-S214.
- Feasibility and significance of stimulating interscapular muscles using transcutaneous functional electrical stimulation in able-bodied individuals. Kapadia N, Moineau B, Marquez-Chin M, Myers M, Lon Fok K, Masani K, Marquez-Chin C, Popovic MR.J Spinal Cord Med. 2021;44(sup1):S185-S192.

Luka Milosevic

- Online Mapping With the Deep Brain Stimulation Lead: A Novel Targeting Tool in Parkinson's Disease. Milosevic L, Scherer M, Cebi I, Guggenberger R, Machetanz K, Naros G, Weiss D, Gharabaghi A. Mov Disord. 2020 Sep;35(9):1574-1586.
- A theoretical framework for the site-specific and frequency-dependent neuronal effects of deep brain stimulation. Milosevic L, Kalia SK, Hodaie M, Lozano AM, Popovic MR, Hutchison WD, Lankarany M. Brain Stimul. 2021 Jul-Aug;14(4):807-821.

Paul Yoo

- Computational Study on Spatially Distributed Sequential Stimulation for Fatigue Resistant Neuromuscular Electrical Stimulation. Agotici S, Masani K, Yoo PB.IEEE Trans Neural Syst Rehabil Eng. 2021;29:2578-2586.
- Enhanced transcutaneous electrical nerve stimulation achieved by a localized virtual bipole: a computational study of human tibial nerve stimulation. Roointan S, Tovbis D, Elder C, Yoo PB.J Neural Eng. 2020 May 4;17(2):026041.

Ofer Levi

- Real-time ultrasound sensing with a mode-optimized photonic crystal slab. Zhu EY, Charles-Herrera M, Rewcastle C, Gad R, Qian L, Levi O. Opt Lett. 2021 Jul 15;46(14):3372-3375.
- E. Y. Zhu, C. Rewcastle, R. Gad, L. Qian and O. Levi, "Refractive-Index-based ultrasound sensing with photonic crystal slabs", Optics Letters 44(10) pp. 2609-2612 (2019).

Kei Masani

- Co-contraction of ankle muscle activity during quiet standing in individuals with incomplete spinal cord injury is associated with postural instability. Fok KL, Lee JW, Unger J, Chan K, Musselman KE, Masani K. Sci Rep. 2021 Oct 1;11(1):19599.
- A Generic Sequential Stimulation Adapter for Reducing Muscle Fatigue during Functional Electrical Stimulation. Ye G, Ali SS, Bergquist AJ, Popovic MR, Masani K. Sensors (Basel). 2021 Oct 30;21(21):7248.

Jose Zariffa

- Identifying Hand Use and Hand Roles After Stroke Using Egocentric Video. Meng-Fen Tsai, Rosalie H Wang, Jose Zariffa. IEEE J Transl Eng Health Med, 2021 Apr 9;9:2100510.
- Properties of the surface electromyogram following traumatic spinal cord injury: a scoping review. Balbinot G, Li G, Wiest MJ, Pakosh M, Furlan JC, Kalsi-Ryan S, Zariffa J. J Neuroeng Rehabil. 2021 Jun 29;18(1):105.

Cesar Marquez

- Characterizing the stimulation interference in electroencephalographic signals during brain-computer interface-controlled functional electrical stimulation therapy. Lazar I Jovanovic, Milos R Popovic, Cesar Marquez-Chin. Artif Organs. 2021 Aug 30.
- Brain-computer interface-triggered functional electrical stimulation therapy for rehabilitation of reaching and grasping after spinal cord injury: a feasibility study. Lazar I Jovanovic, Naaz Kapadia, Vera Zivanovic, Hope Jervis Rademeyer, Mohammad Alavinia, Colleen McGillivray, Sukhvinder Kalsi-Ryan, Milos R Popovic, Cesar Marquez-Chin.

Paul Santerre

- Self-Assembled Oligo-Urethane Nanoparticles: Their Characterization and Use for the Delivery of Active Biomolecules into Mammalian Cells. Suja Shrestha, Meghan J McFadden, Allen C T Teng, Patrick Dong Min Chang, Joyce Deng, Tatianna W Y Wong, Ronald D Cohn, Evgueni A Ivakine, Anthony O Gramolini, J Paul Santerre. ACS Appl Mater Interfaces. 2021 Dec 15;13(49):58352-58368.
- Polymer-free corticosteroid dimer implants for controlled and sustained drug delivery. Kyle Battiston , Ian Parrag, Matthew Statham, Dimitra Louka, Hans Fischer, Gillian Mackey, Adam Daley, Fan Gu, Emily Baldwin, Bingqing Yang, Ben Muirhead, Emily Anne

- Hicks, Heather Sheardown, Leonid Kalachev, Christopher Crean, Jeffrey Edelman, J Paul Santerre, Wendy Naimark. Nat Commun. 2021 May 17;12(1):2875.

The Edward S. Rogers Sr. Department of Electrical & Computer Engineering

Willy Wong

- Magnetic seizure therapy reduces suicidal ideation and produces neuroplasticity in treatment-resistant depression. Y Sun, DM Blumberger, BH Mulsant, TK Rajji, PB Fitzgerald, MS Barr, Translational psychiatry 8 (1), 1-11.
- Use of Machine Learning for Predicting Escitalopram Treatment Outcome From Electroencephalography Recordings in Adult Patients With Depression. Andrey Zhdanov, Sravya Atluri, Willy Wong et al. JAMA Netw.2020;3(1):e1918377.

Ervin Sejdic

- Non-negative matrix factorization reveals resting-state cortical alpha network abnormalities in the first episode schizophrenia-spectrum. H. Phalen, B. A. Coffman, A. Ghuman, E. Sejdić, D. F. Salisbury, Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, vol. 5, no. 10, pp. 961-970, Oct. 2020.
- A novel motor imagery hybrid brain computer interface using EEG and functional transcranial Doppler ultrasound. A. Khalaf, E. Sejdić, M. Akcakaya. Journal of Neuroscience Methods, vol. 313, pp. 44-53, Feb. 2019.

Xilin Liu

- Edge deep learning for neural implants: a case study of seizure detection and prediction. X. Liu, A. G. Richardson. Journal of Neural Engineering, vol. 18, no. 4, pp. 046034, Apr. 2021.
- Electronic Neural Interfaces. M. Zhang, Z. Tang, X. Liu, J. Van der Spiegel. Nature Electronics, vol. 3, pp. 191–200, Mar. 2020.

Berj Bardakjian

- Altered neocortical oscillations and cellular excitability in an in vitro Wwox knockout mouse model of epileptic encephalopathy. Breton VL, Aquilino MS, Repudi S, Saleem A, Mylvaganam S, Abu-Swai S, Bardakjian BL, Aqeilan RI, Carlen PL. Neurobiol Dis. 2021.

- Glial Modulation of Electrical Rhythms in a Neuroglial Network Model of Epilepsy. Grigorovsky V, Breton VL, Bardakjian BL. IEEE Trans Biomed Eng. 2021. PMID: 32894704.

Roman Genov

- Safety-optimized Inductive Powering of Implantable Medical Devices: A Tutorial and Comprehensive Design Guide. N. Soltani, M. ElAnsary, Jianxiong Xu, R. Genov, subm., *IEEE Transactions on Biomedical Circuits and Systems*, 2021.
- Arbitrary-Waveform Electro-Optical Intracranial Neurostimulator with Load-Adaptive High-Voltage Compliance. H. Kassiri, F. D. Chen, M. T. Salam, M. Chang, B. Vatankhahghadim, P. Carlen, T. A. Valiante, R. Genov. *IEEE Transactions on Neural Systems & Rehabilitation Engineering,* Vol. 27, No. 4, pp. 582-593, Apr. 2019.

Department of Mechanical & Industrial Engineering

Axel Guenther

- Gao, W.; Vaezzadeh, N.; Chow, K.; Chen, H.; Lavender, P.; Jeronimo, M.D.; McAllister, A.; Laselva, O.; Jiang, J.X.; Gage, B.K.; Ogawa, S.; Ramchandran, A.; Bear, C.E.; Keller, G.M.; Guenther. A. "One-Step Formation of Protein-Based Tubular Structures for Functional Devices and Tissues" *Adv. Healthc. Mater.*, 2021.
- Yasotharan, S.; Pinto, S.; Sled, J.G.; Bolz, S.S.; Guenther, A. "Artery-on-a-chip platform for automated, multimodal assessment of cerebral blood vessel structure and function", *Lab Chip,* 15, 2660-2669, 2015.

Mihai Duduta

- Zhao H, Hussain AM, Israr A, Vogt DM, Duduta M, Clarke DR, Wood RJ. A Wearable Soft Haptic Communicator Based on Dielectric Elastomer Actuators. Soft Robot. 2020 Aug;7(4):451-461. doi: 10.1089/soro.2019.0113. Epub 2020 Jan 10. PMID: 31923364.
- Duduta M, Wood RJ, Clarke DR. Multilayer Dielectric Elastomers for Fast, Programmable Actuation without Prestretch. Adv Mater. 2016 Sep;28(36):8058-8063. doi: 10.1002/adma.201601842. Epub 2016 Jul 4. PMID: 27376638.

Department of Materials Science & Engineering

Hani Naguib

- Flexible, Air Dryable, and Fiber Modified Aerogel-Based Wet Electrode for Electrophysiological Monitoring. Saadatnia Z, Ghaffari Mosanenzadeh S, Marquez Chin M,

Naguib HE, Popovic MR. IEEE Trans Biomed Eng. 2021.

- A 3D Printed Device for Low-Cost Neural Stimulation in Mice. Morrison TJ, Sefton E, Marquez-Chin M, Popovic MR, Morshead CM, Naguib HE. Front Neurosci. 2019.

Benjamin D. Hatton

- A bioinspired omniphobic surface coating on medical devices prevents thrombosis and biofouling. Leslie DC, Waterhouse A, Berthet JB, Valentin TM, Watters AL, Jain A, Kim P, Hatton BD, Nedder A, Donovan K, Super EH, Howell C, Johnson CP, Vu TL, Bolgen DE, Rifai S, Hansen AR, Aizenberg M, Super M, Aizenberg J, Ingber DE. Nat Biotechnol. 2014.
- Drug self-assembly for synthesis of highly-loaded antimicrobial drug-silica particles. Stewart CA, Finer Y, Hatton BD. Sci Rep. 2018.

Department of Chemical Engineering & Applied Chemistry

Molly Shoichet

- *In vitro* Evaluation of ASCs and HUVECs Co-cultures in 3D Biodegradable Hydrogels on Neurite Outgrowth and Vascular Organization. Rocha LA, Gomes ED, Afonso JL, Granja S, Baltazar F, Silva NA, Shoichet MS, Sousa RA, Learmonth DA, Salgado A Front Cell Dev Biol. 2020.
- Injectable hydrogel enables local and sustained co-delivery to the brain: Two clinically approved biomolecules, cyclosporine and erythropoietin, accelerate functional recovery in rat model of stroke. Tuladhar A, Obermeyer JM, Payne SL, Siu RCW, Zand S, Morshead CM, Shoichet MS. Biomaterials. 2020.

Milica Radisic

- Biodegradable scaffold with built-in vasculature for organ-on-a-chip engineering and direct surgical anastomosis. Zhang B, Montgomery M, Chamberlain MD, Ogawa S, Korolj A, Pahnke A, Wells LA, Massé S, Kim J, Reis L, Momen A, Nunes SS, Wheeler AR, Nanthakumar K, Keller G, Sefton MV, Radisic M:, Nature Protoc. 2018 Aug;13(8):1793-1813.
- Modifications of biomaterials with immobilized growth factors or peptides for tissue engineering applications. Xiao Y, Reis L, Zhao Y, Radisic M: Methods, 2S1046-2023(15)00172-3, 2015.

Eugenia Kumacheva

- Structurally Anisotropic Hydrogels for Tissue Engineering. Khuu, N.; Kheiri, S.; Kumacheva, E. *Trends in Chemistry* 3, 1002–1026 (2021).
- Self-Driving Platform for Metal Nanoparticle Synthesis: Combining Microfluidics and Machine Learning. Tao, H.; Wu, T.; Kheiri, S.; Aldeghi, M. Aspuru-Guzik, A., Kumacheva, E. *Adv. Funct. Mater.* https://doi.org/10.1002/adfm.202106725.

Helen Tran

- Integrating Emerging Polymer Chemistries for the Advancement of Recyclable, Biodegradable, and Biocompatible Electronics. Chiong JA, Tran H, Lin Y, Zheng Y, Bao Z.Adv Sci (Weinh). 2021 Jul;8(14):e2101233.
- Mechanically tunable conductive interpenetrating network hydrogels that mimic the elastic moduli of biological tissue. Feig VR, et al. Among authors: tran h. Nat Commun. 2018.

Alison P. McGuigan

- Applications of Omics Technologies for 3D In Vitro Disease Models. Pieters V, Co I, Wu N, McGuigan AP. Tissue Engineering Part C. 2021 Jan.
- Development of a bioprinting approach for automated manufacturing of multi-cell type biocomposite TRACER strips using contact capillary-wicking. Li NT, Rodenhizer D, Mou J, Shahaj A, Samardzic K, McGuigan AP. Biofabrication, 2019 Oct.

Institute of Medical Science

Taufik Valiante

- Volitional control of individual neurons in the human brain. Patel K, Katz CN, Kalia SK, Popovic MR, Valiante TA. Brain. 2021 Dec 31;144(12):3651-3663.
- Implantable photonic neural probes for light-sheet fluorescence brain imaging. Sacher WD, Chen FD, Moradi-Chameh H, Luo X, Fomenko A, Shah PT, Lordello T, Liu X, Almog IF, Straguzzi JN, Fowler TM, Jung Y, Hu T, Jeong J, Lozano AM, Lo PG, Valiante TA, Moreaux LC, Poon JKS, Roukes ML. Neurophotonics. 2021 Apr;8(2):025003.

Robert Chen

- Induction of Human Motor Cortex Plasticity by Theta Burst Transcranial Ultrasound Stimulation. Zeng K, Darmani G, Fomenko A, Xia X, Tran S, Nankoo JF, Oghli YS, Wang Y, Lozano AM, Chen R. Ann Neurol. 2021.
- Exploring the connections between basal ganglia and cortex revealed by transcranial magnetic stimulation, evoked potential and deep brain stimulation in dystonia. Udupa K, Bhattacharya A, Chen R. Eur J Paediatr Neurol. 2021.

Anthony Lang

- Contribution of rare variant associations to neurodegenerative disease presentation. Dilliott AA, et al. NPJ Genom Med. 2021.
- Safety and efficacy of anti-tau monoclonal antibody gosuranemab in progressive supranuclear palsy: a phase 2, randomized, placebo-controlled trial. Dam T, et al. Nat Med. 2021.

Cindi Morsehead

- Metformin pretreatment rescues subependymal zone neurogenesis and long-term olfactory memory in a juvenile model of cranial irradiation. Derkach D, Kehtari T, Renaud M, Heidari M, Morshead CM. Cell Reports Medicine. 2021.
- Constraint-induced movement therapy promotes motor recovery after neonatal stroke in the absence of neural precursor activation. Adams KV, Mahmud N, Green-Holland M, Vonderwalde I, Umebayashi D, Sachewsky N, Coles BL, van der Kooy D, Morshead CM. Eur J Neurosci. Feb. 2021.

Gelareh Zadeh

- Paediatric atypical choroid plexus papilloma: is adjuvant therapy necessary? Browne-Farmer C, Hazrati LN, Mamatjan Y, Zadeh G, Dirks P, Rutka J, Malkin D, Bouffet E, Huang A, Tabori U, Ramaswamy V, Bartels U. J Neurooncol. 2021.
- Liquid Biomarkers for Improved Diagnosis and Classification of CNS Tumors. Bunda S, Zuccato JA, Voisin MR, Wang JZ, Nassiri F, Patil V, Mansouri S, Zadeh G. Int J Mol Sci. 2021.

Liang Zhang

- Diversity amongst human cortical pyramidal neurons revealed via their sag currents and frequency preferences. Moradi Chameh H, Rich S, Wang L, Chen FD, Zhang L, Carlen PL, Tripathy SJ, Valiante TA. Nat Commun. 2021.
- Sexually dimorphic patterns in electroencephalography power spectrum and autism-related behaviors in a rat model of fragile X syndrome. Wong H, Hooper AWM, Niibori Y, Lee SJ, Hategan LA, Zhang L, Karumuthil-Melethil S, Till SM, Kind PC, Danos O, Bruder JT, Hampson DR. Neurobiol Dis. 2020.

Julio Furlan

- Effects of age on survival and neurological recovery of individuals following acute traumatic spinal cord injury. Furlan JC. Spinal Cord. 2022.
- Age as a determinant of inflammatory response and survival of glia and axons after human traumatic spinal cord injury. Furlan JC, et al. Exp Neurol. 2020.

Karen Davis

- Exploring sex differences in alpha brain activity as a potential neuromarker associated with neuropathic pain. auchon C, Kim JA, El-Sayed R, Osborne NR, Rogachov A, Cheng JC, Hemington KS, Bosma RL, Dunkley BT, Oh J, Bhatia A, Inman RD, Davis KD. Pain. 2021.
- Neurofilament-light in former athletes: a potential biomarker of neurodegeneration and progression. Taghdiri F, Multani N, Ozzoude M, Tarazi A, Khodadadi M, Wennberg R, Mikulis D, Green R, Colella B, Davis KD, Blennow K, Zetterberg H, Tator C, Tartaglia MC. Eur J Neurol. 2020.

John Griffiths

- Yao HK, Guet-McCreight A, Mazza F, Moradi Chameh H, Prevot TD, Griffiths JD, Tripathy SJ, Valiante TA, Sibille E, Hay E. Reduced inhibition in depression impairs stimulus processing in human cortical microcircuits. Cell Rep. 2022 Jan 11;38(2):110232. doi: 10.1016/j.celrep.2021.110232. PMID: 35021088.
- Wang KZ, Bani-Fatemi A, Adanty C, Harripaul R, Griffiths J, Kolla N, Gerretsen P, Graff A, De Luca V. Prediction of physical violence in schizophrenia with machine learning algorithms. Psychiatry Res. 2020 Jul;289:112960. doi: 10.1016/j.psychres.2020.112960. Epub 2020 Apr 13. PMID: 32361562.

Alfonso Fasano

- Sasikumar S, Cohn M, Harmsen IE, Loh A, Cho SS, Sáenz-Farret M, Maciel R, Soh D, Boutet A, Germann J, Elias G, Youm A, Duncan K, Rowland NC, Strafella AP, Kalia SK, Lozano AM, Fasano A. Single-Trajectory Multiple-Target Deep Brain Stimulation for Parkinsonian Mobility and Cognition. Mov Disord. 2022 Mar;37(3):635-640. doi: 10.1002/mds.28870. Epub 2021 Nov 22. PMID: 34806782.
- Fasano A, Eliashiv D, Herman ST, Lundstrom BN, Polnerow D, Henderson JM, Fisher RS. Experience and consensus on stimulation of the anterior nucleus of thalamus for epilepsy. Epilepsia. 2021 Dec;62(12):2883-2898. doi: 10.1111/epi.17094. Epub 2021 Oct 26. PMID: 34697794.