UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

Report No. 3432 Revised

MEMORANDUM

To: Executive Committee of Faculty Council (September 19, 2014)
Faculty Council (October 8, 2014)

From: Dr. Graeme Norval
Chair, Undergraduate Curriculum Committee

Date: September 17, 2014

Re: **Creation of Robotics Engineering Stream in Engineering Science**

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).

PROPOSAL/MOTION

THAT the creation of a Robotics Engineering Stream within the Division of Engineering Science's undergraduate program be approved, effective September 2015.

SUMMARY

In November 2013, a working group was struck by the Division of Engineering Science to examine the idea of developing a Stream[1] in Engineering Science in the field of Robotics Engineering. A Stream in Robotics Engineering has been an area of significant interest for some time amongst students and faculty associated with the Engineering Science program. Robotics Engineering, a subset of mechatronics and an interdisciplinary field by nature, is well suited to build upon the multidisciplinary foundation curriculum offered by Engineering Science, as well as the rigorous approach to science, mathematics and design. The need to move Robotics Engineering beyond placement in a single, traditional science or engineering department has been documented by leaders in the field, including Michael Gennert and Gretar Tryggvason, the Director and Associate Director respectively of the Worcester Polytechnic Institute Robotics Engineering Program:

[1] Engineering Science streams are referred to within the Faculty as "Options", and in the undergraduate calendar and on student transcripts, as "Majors".

"Many schools currently offer robotics minor and concentrations within traditional degree programs; a few selected universities offer graduate degrees in robotics. However, it is our thesis that only a fully multidisciplinary undergraduate program consisting of a core of courses in which all these components are intertwined on a daily basis is appropriate for education of the leaders and entrepreneurs needed by this nascent industry."

IEEE Robotics & Automation Magazine, June 2009

Robotics Engineering is a rapidly evolving field in both academia and industry, and the Faculty of Applied Science and Engineering has the resources needed to support a Stream in this area, given the recently established Institute for Robotics and Mechatronics, which includes 38 faculty members (and growing) from the Edward S. Rogers Sr. Department of Electrical and Computer Engineering (ECE), the Department of Mechanical and Industrial Engineering (MIE), the Institute for Aerospace Studies (UTIAS), and the Institute for Biomaterials and Biomedical Engineering (IBBME). The Institute for Robotics and Mechatronics has already initiated a Minor and a graduate emphasis in Robotics and Mechatronics. The Department of Computer Science (DCS) has also committed to partnering on this initiative, which is essential for the development and delivery of a novel and well-rounded undergraduate program in robotics engineering. Several new faculty hires in both DCS and UTIAS will teach in the Stream, alongside established faculty members with experience teaching robotics engineering and associated subject matter.

Other leading institutions with robotics engineering programs were identified, such as Carnegie Mellon University (which offers an "Additional Major" in Robotics, requiring students to take 10 courses across robotic system sub-topics including controls, kinematics, machine perception, cognition & reasoning, and systems/integration courses), and the University of California at Santa Cruz (which offers a full Major, integrating strengths in Computer & Electrical Engineering and Computer Science), and their curriculum has influenced the design of the Robotics Engineering Stream curriculum. It should be noted, however, that while there are several institutions in Canada with programs in mechatronics, including the University of Waterloo, University of British Columbia and McMaster University, there is a gap in the Canadian landscape in undergraduate robotics engineering education which will be filled by this new program. Université de Sherbrooke is also in the process of designing a program in Robotics Engineering.

The curricular strengths of the Engineering Science foundation (years 1&2) have influenced the design of the Stream as well. Engineering Science is a demanding program with a special emphasis on learning from first principles. It has a unique 2+2 structure, beginning with two years of common curriculum covering basic maths and sciences more intensively than is normal for engineering programs, and providing additional breadth in the physical and engineering sciences. This is followed by an accelerated discipline-specific curriculum in years 3 and 4, focused in one of eight streams. The research strengths of the University of Toronto, evidenced in part by the departmental participation in the creation of the Robotics Engineering Stream, have also influenced the design of a program that is well suited to our unique strengths.

The opportunity for engineering design experience is a critical component of any Engineering Science Stream. Students will learn about the robotics systems design process through an introduction to robotics course, which will be offered in the first semester of the curriculum. The multidisciplinary curriculum will offer students an opportunity to learn about the design of the various components of a robotic system, including circuitry, algorithms and control systems. Finally, the Stream will include a capstone design course in the fourth year, along with a required thesis and laboratory-focused courses to ensure significant hands-on experience.

The Stream will be supported by existing and planned robotics facilities in the Faculty. Financial resources from the Dean's Strategic Fund have been provided to purchase new laboratory equipment, and the Stream will benefit from dedicated space in the Centre for Engineering Innovation & Entrepreneurship, a new building expected to break ground soon. Students in the Stream will benefit from existing Engineering Science spaces, including our student common room with collaborative work space, and our computer laboratory.

It is expected that the Stream will have a positive impact on the Engineering Science program, elevating the quality of the program as a whole with the inclusion of Robotics Engineering as a cutting edge and multidisciplinary field. Students and faculty have expressed great enthusiasm for the inclusion of the Stream, and the Departments offering courses will have the opportunity to engage with the high calibre of students attracted to Engineering Science, and recruit participants as potential graduate students.

NEED AND DEMAND

Students entering year 2 in September 2014 (the first group of students eligible to participate in the Stream, assuming roll-out in September 2015) were provided with the Stream proposal, and asked whether they were seriously considering participation. From a total class size of 167 (a particularly small class size for Engineering Science), 33 students indicated a strong interest in the Stream. In addition, 8 students from Engineering Science have graduated with the new Robotics Minor (out of 75 faculty-wide), and 13 are currently enrolled. Finally, Engineering Science students from across the program currently engage in fourth year thesis research on Robotics-related topics. In recent years, ~15-20 students per year have engaged in related research with Faculty members associated with the Institute for Robotics and Mechatronics, and the Department of Computer Science. However, we believe this only gives some indication of the interest in robotics. If a Stream is established in Engineering Science, we expect it to attract new, top students from across the country and internationally who are interested in a career in Robotics Engineering.

The Engineering Science program attracts top students from across Canada and around the world, with a 2014 mean entrance average of over 94%. However, once an Engineering Science student is admitted in the program, and meets the ongoing academic requirements to maintain their spot in the program, they can select any of the upper-year Streams at the end of the second year. In other words, caps are not placed on any of the Streams in the program.

Graduates of this Stream will have opportunities to pursue graduate studies in Canada, the US and overseas, benefitting from the strong reputation of the Engineering Science program, such the University of Toronto, Georgia Tech, Oxford University, ETH Zurich, MIT, Stanford and Cornell. However, there are also opportunities for direct entry to government, public or private companies, in particular through the growing number of robotics focused companies in Canada, as well as the large number of companies that utilize robotics technology.

INTERACTION WITH THE ROBOTICS MINOR

The Engineering Science Robotics Engineering Stream and the Robotics and Mechatronics Minor serve complementary purposes. The purpose of the Minor is to acknowledge and facilitate interdisciplinary (cross-departmental) training in the robotics area within the confines of a traditional engineering degree, offering breadth to the students enrolled. By awarding the student this Minor, the faculty recognizes the extra effort required for students to take courses in areas which are not within their own department or area of specialization. In contrast, the Robotics Engineering Stream offers a categorically interdisciplinary program to Engineering Science students, in which they have the opportunity to focus solely on Robotics Engineering, building on the first two foundation years in Engineering Science. This provides the students with significant depth in Robotics Engineering in years 3 and 4. The new Stream offers a comprehensive robotics education unlike anything else offered in Canada.

We foresee that the Minor and the Robotics Engineering Stream will enrich each other both in terms of content and in terms of marketing of either program. These programs draw from different pools of students and will enhance U of T's presence and visibility in the exploding robotics area. Courses currently offered in the Minor will provide a natural reservoir of elective courses for the Stream. Resources such as labs and experienced TA's can be shared across the two programs in an organic way.

LEARNING OUTCOMES

As with the existing streams in the Engineering Science program, the learning outcomes for the proposed Robotics Engineering stream match those at the program-level. These program-level learning outcomes are:

i. To produce an academically enriched program for young men and women seeking a significant academic challenge;
ii. To produce engineering science graduates who have a deep understanding of mathematics, physics, chemistry, biology and the engineering sciences, and can apply and integrate this knowledge to solve complex problems;
iii. To prepare men and women for careers in the engineering sciences within academia, industry and the public sector as well as careers in other professions;
iv. To produce engineering science graduates who have an understanding of the impact of technology on individuals, groups and society-at-large;

v. To educate men and women as global citizens and leaders of the society in which they live and work.

In addition, by the end of fourth year, the Robotics Engineering student will be able to:

i. Apply mathematics and engineering science concepts to design robots capable of perceiving, reasoning and acting.

ii. Translate the user or customer's desired action or operational outcome into a set of requirements that a robotic system must perform.

iii. Take a "systems approach" to robotics; apply engineering knowledge to the design of any aspect of a robotics system, analyze/design a robotics system in both its parts and as a whole, and integrate the various aspects of robotic systems to solve an engineering problem.

iv. Design robotic systems for a variety of applications.

v. Describe the relationship between robots and society, and the implications for the economy, human health and safety.

The degree level expectations for the Faculty's undergraduate programs, including Engineering Science, closely map to the graduate attributes (GAs) of the Canadian Engineering Accreditation Board (CEAB), which is responsible for conducting cyclical accreditation reviews of each undergraduate program. The most recent (2013) CEAB accreditation of the Engineering Science program – based on a measurement of academic units (AUs) across categories (such as engineering design and engineering science) and progress toward these graduate attributes – was for three years, from 2013 to 2016, with a report due in 2015 for a three-year extension. A mapping of the degree-level expectations with the graduate attributes is as follows:

Depth and Breadth of Knowledge:
This is tracked by the GA "knowledge base for engineering", and met by the unique 2+2 structure of the Engineering Science program, in which students gain breadth through a two year foundation in math, science, engineering science, design and social science/humanities, followed by two years of specialization, which provides depth in one of 8 upper-year Streams.

Knowledge of Methodologies:
This is tracked by the GAs "problem analysis", "investigation", "design" and "use of engineering tools", and met by the numerous design projects and laboratory experiments conducted by students in their courses.

Application of Knowledge:
This is tracked by the GAs "design" and "investigation", and met by the numerous design-oriented projects and laboratory assignments conducted by students in courses, including ESC499 (Engineering Science Thesis) and MIE443 (Mechatronics Systems: Design and Integration).

Communication Skills:
This is tracked by the GAs "communication skills" and "individual and teamwork", and emphasized in the following courses: ESC101 (Engineering Science Praxis I), ESC102 (Engineering Science Praxis II), ESC203 (Engineering, Society and Critical Thinking), ESC301 (Engineering Science Option Seminar), ESC499 (Engineering Science Thesis) and MIE443 (Mechatronics Systems: Design and Integration).

Awareness of Limits of Knowledge:
This is tracked by the GA "lifelong learning", and emphasized in particular in 400- and 500-level courses that introduce students to open questions in the subject matter of the course. This is also emphasized in ESC499 (Engineering Science Thesis).

Autonomy and Professional Capacity:
This is tracked by several GAs, including "professionalism", "impact of engineering on society and the environment", "ethics and equity", and "economics and project management". These areas are emphasized in the following courses: ESC101 (Engineering Science Praxis I), ESC102 (Engineering Science Praxis II), ESC203 (Engineering, Society and Critical Thinking), ESC301 (Engineering Science Option Seminar), and CHE374 (Engineering Economics).

Quantitative Reasoning: (an "other" DLE, as defined by the Faculty)
This is tracked by the GAs "investigation" and "problem analysis", and met by the numerous laboratory experiments and problem solving-focused assignments conducted by students in their courses.

Information Literacy: (an "other" DLE, as defined by the Faculty)
The Faculty requires all students to develop an advanced understanding of how to obtain, manipulate and evaluate information; how to bring diverse sources together to develop a comprehensive understanding of specific issues, and how to solve problems or apply the scientific method to create further knowledge in the discipline. This DLE is met by many aspects of our curriculum, but mainly emphasized in various design-oriented courses and ESC499 (Engineering Science Thesis).

An accreditation analysis, summarized in Table 1, was conducted to ensure the Robotics Engineering Stream curriculum would meet the total AU requirements, and the requirements in each category, as outlined by the CEAB. Accreditation Units are generally defined by hours of instruction in 5 different major subject areas. All categories are met without the inclusion of the two technical electives. Like all students in the Faculty, the complementary studies electives will need to be selected appropriately to meet the minimum requirements.

Table 1: Accreditation Unit Analysis

Category	Required Totals	Robotics Engineering Stream
Complementary Studies	225	153.6[1]
Math	195	292.2
Natural Science	195	251.3
Math + Natural Science	420	543.4
Engineering Science	225	1003.68
Engineering Design	225	285.8
Engineering Science + Engineering Design	900	1289.5
Total	1950	1986.5[2]

1. The Complementary Studies AU total does not include 3 complementary studies/humanities & social science electives selected by students. The average CS course value has been calculated as 29.4 according to the Faculty's 2012 accreditation report, meaning students should have no problem meeting the 225 AU requirement.
2. The Total AU count does not include 3 complementary studies/humanities & social science electives OR 2 technical electives selected by students.

All 12 of the CEAB's Engineering Graduate Attributes have been mapped to the Robotics Engineering Stream curriculum, based on a preliminary analysis, as outlined in Table 2. Upon program commencement, the Robotics Engineering Stream will join the rest of the Faculty in the regular data collection and evaluation cycle.

Table 2: Engineering Graduate Attributes Mapped to the Robotics Engineering Stream

Graduate Attribute	Relevant Courses
A knowledge base for engineering	All core technical courses
Problem analysis	Most core technical courses
Investigation	AER521; ESC499
Design	ROB3XX; AER372; ESC301; MIE342; MIE346; MIE443
Use of engineering tools	CSC263; ROB3XY; CSC411; ECE470; AER521
Individual and team work	ROB3XY; MIE443
Communication skills	ESC301; ESC499
Professionalism	ESC301; ESC499; MIE443
Impact of Engineering on Society and the Environment	ESC301; ROB3XX; MIE443
Ethics and equity	ESC301
Economics and project management	CHE374
Life-long learning	ESC301; ESC499

Once the new Stream is approved by Faculty Council, the Canadian Engineering Accreditation Board (CEAB) will be informed of the new Stream and planned rollout.

CORE CONTENT BY STREAM TOPIC AREA

i. Perception
Perception represents the identification, organization and interpretation of sensory information. If a robot is to reason correctly, it must have a reliable sense of its environment. Courses that explore perception include:
ROB5XX: Computer Vision for Robotics
AER521: Mobile Robotics and Perception

ii. Reasoning
Reasoning allows the robot to think in a logical way through the completion of a task and make the best judgments relative to the task and its components. Courses that explore reasoning include:
AER372: Control Systems
CSC263: Data Structures and Algorithms
CSC384: Introduction to Artificial Intelligence
CSC411: Machine Learning and Data Mining
ECE557: Systems Control
AER521: Mobile Robotics and Perception
ECE470: Robot Modeling and Control
MIE443: Mechatronic Systems: Design and Integration

iii. Modelling & Actuation
Robots must be able to act, to actually carry out their required tasks. Courses that explore modelling & actuation include:
AER301: Dynamics
AER521: Mobile Robotics and Perception
ECE470: Robot Modeling and Control
MIE342: Circuits with Applications to Mechanical Engineering Systems
MIE346: Analog & Digital Electronics for Mechatronics

iv. System Integration
The understanding and integration of various components of a robotic system. Courses that explore system integration include:
ROB3XX: Introduction to Robotics
AER521: Mobile Robotics and Perception
ECE470: Robot Modeling and Control
MIE443: Mechatronic Systems: Design and Integration

v. Additional Courses
Additional courses that support the development of the robotics engineer, and the engineer as a whole:
CHE374: Engineering Economics
ROB3XY: Mathematics of Robotics
ESC301: Engineering Science Option Seminar
ESC499: Thesis

PROPOSED STREAM REQUIREMENTS (TABLE 3)[1]

The following table outlines the courses that students are expected to complete in the Robotics Engineering Stream.

3F Semester (total weekly hours = 27)	**3S Semester (total weekly hours = 18 + 1 elective)**
(NEW COURSE) ROB3XX: Introduction to Robotics	HSS/CS or Technical Elective[2]
CSC263: Data Structures and Algorithms	CSC411: Machine Learning and Data Mining
AER301: Dynamics	AER372: Controls
CHE374: Engineering Economics	CSC384: Introduction to Artificial Intelligence
MIE342: Circuits with Applications to Mechanical Engineering Systems	MIE346 Analog & Digital Electronics for Mechatronics
(NEW COURSE) ROB3XY: Mathematics of Robotics	
ESC301: Engineering Science Option Seminar	ESC301: Engineering Science Option Seminar
4F Semester (total weekly hours =20 + 1 elective)	**4S Semester (total weekly hours = 17.5 + 2 electives)**
ESC499: Thesis	ESC499: Thesis
ECE557: Systems Control	AER521: Mobile Robotics and Perception
(NEW COURSE) ROB5XX: Computer Vision for Robotics	MIE443: Mechatronic Systems: Design and Integration[3]
ECE470: Robot Modeling and Control	HSS/CS or Technical Elective
HSS/CS or Technical Elective	HSS/CS or Technical Elective

1. Please see Appendix A for the core course descriptions
2. Students must take 2 HSS/CS courses and 2 Technical Electives.
3. MIE443 currently has an enrolment cap. The existing number of spaces for MIE students will remain; additional spaces will be added for Engineering Science.

TECHNICAL ELECTIVE STRUCTURE

There are two technical elective slots, giving students an opportunity to take courses related to an application of, or functional area in, Robotics Engineering.

Application Courses:
AER302: Aircraft Flight
AER307: Aerodynamics
AER407: Space Systems Design
BME350: Biomedical Systems Engineering I: Organ Systems
MIE439: Biomechanics I
MIE422: Automated Manufacturing

Functional Courses:
AER336: Scientific Computing
APM384: Partial Differential Equations
CSC321: Introduction to Neural Networks and Machine Learning
CSC401: Natural Language Computing
CSC412: Probabilistic Learning and Reasoning
CSC485: Computational Linguistics
CSC486: Knowledge Representation and Reasoning
ECE353: Systems Software
ECE358: Foundations of Computing
ECE411: Real-Time Computer Control
ECE445: Neural Electricity
ECE455: Digital Signal Processing
ECE516: Intelligent Image Processing
ECE521: Inference Algorithms
ECE532: Digital Systems Design
MAT363: Geometry of Curves and Surfaces
MAT389: Complex Analysis
MIE438: Microprocessors & Embedded Microcontrollers
MIE444: Mechatronics Principles
Other technical elective

CAPSTONE DESIGN

MIE443: Mechatronic Systems: Design and Integration is proposed as the Capstone Design course for the Stream, as it integrates the various components of designing a robotic system through team-based projects. The course is taught by the Stream co-chair, Goldie Nejat, PEng.

THESIS

All Engineering Science students are required to take a fourth year thesis. Students in the program have been pursuing thesis projects in robotics for many years, which is a demonstration of the strong interest from students in this area. Fourth year thesis students will have a variety of supervisors to choose from, including the various faculty associated with The Institute for Robotics and Mechatronics (see http://irm.utoronto.ca) and the Department of Computer Science.

PROCESS AND CONSULTATION

The interdisciplinary working group that created the proposal for a Stream in Robotics Engineering included the following membership:
Professor Tim Barfoot (UTIAS)
Professor Mireille Broucke (ECE)
Dr. Jim Davis (UTIAS/EngSci)
Professor David Johns (ECE)
Mr. Chris Jones (EngSci)
Professor Mark Kortschot (EngSci)
Professor Goldie Nejat (MIE)
Ms. Lisa Romkey (EngSci)
Professor Raquel Urtasun (DCS)

Consultation on the Robotics Engineering Stream curriculum was held with a number of individuals and groups throughout the planning process:

i. Office of the Vice-Provost, Academic Programs, University of Toronto (late August)
ii. Faculty of Applied Science and Engineering Undergraduate Curriculum Committee
iii. Division of Engineering Science Curriculum Committee
iv. Faculty of Applied Science and Engineering Chairs and Directors
v. All faculty members associated with the Institute for Robotics and Mechatronics
vi. Current students in the Engineering Science program
vii. Engineering Science Advisory Board
viii. Colleagues from other Robotics Engineering programs (Sherbrooke, Carnegie Mellon) and Industry (MDA Robotics)

The Undergraduate Curriculum Committee is composed of representatives from each undergraduate program; the Vice-Dean, Undergraduate Studies; the Chair, First Year; the Associate Dean, Cross-Disciplinary Programs; students; and the Registrar's Office. The Committee meets regularly to review changes to the curriculum, and makes recommendations to Faculty Council for approval.

Appendix A: Core Course Descriptions

[AER301H1F Dynamics]

3/0/1

Reference frames in relative translation and rotation, vector and matrix formulations. Dynamics of a single particle and of systems of particles. Lagrange's equations. D'Alembert's and Hamilton's principle. Orbital dynamics. Rigid body kinematics and dynamics, Lagrangian approach to vibrations of complex systems. Model analysis. Primary Reference: class notes. Reference Books: Greenwood, Principles of Dynamics; Goldstein, Classical Mechanics.

[AER372H1S Control Systems]

3/1.5/1

An introduction to dynamic systems and control. Models of physical systems. Stability and feedback control theory. Analysis and synthesis of linear feedback systems by "classical" and state space techniques. Introduction to nonlinear and optimal control systems. Digital computer control. Multivariable feedback system design.

[AER521H1S Mobile Robotics and Perception]

3/1.5/1

The course addresses fundamentals of mobile robotics and sensor-based perception for applications such as space exploration, search and rescue, mining, self-driving cars, unmanned aerial vehicles, autonomous underwater vehicles, etc. Topics include sensors and their principles, state estimation, computer vision, control architectures, localization, mapping, planning, path tracking, and software frameworks. Laboratories will be conducted using both simulations and hardware kits.

[CHE374H1F Economic Analysis and Decision Making]

3/0/1

Economic evaluation and justification of engineering projects and investment proposals. Cost estimation; financial and cost accounting; depreciation; inflation; equity, bond and loan financing; after tax cash flow; measures of economic merit in the private and public sectors; sensitivity and risk analysis; single and multi-attribute decisions. Introduction to micro-economic. Applications: retirement and replacement analysis; make-buy and buy-lease decisions; economic life of assets; capital budgeting; selection from alternative engineering proposals; production planning; investment selection.

[CSC263: Data Structures and Algorithms]

2/0/1

Algorithm analysis: worst-case, average-case, and amortized complexity. Expected worst-case complexity, randomized quicksort and selection. Standard abstract data types, such as graphs, dictionaries, priority queues, and disjoint sets. A variety of data structures for implementing these abstract data types, such as balanced search trees, hashing, heaps, and disjoint forests. Design and comparison of data structures. Introduction to lower bounds.

CSC384 Introduction to Artificial Intelligence
2/0/1
Theories and algorithms that capture (or approximate) some of the core elements of computational intelligence. Topics include: search; logical representations and reasoning, classical automated planning, representing and reasoning with uncertainty, learning, decision making (planning) under uncertainty. Assignments provide practical experience, both theory and programming, of the core topics.

CSC411 Machine Learning and Data Mining
2/0/1
An introduction to methods for automated learning of relationships on the basis of empirical data. Classification and regression using nearest neighbour methods, decision trees, linear models, and neural networks. Clustering algorithms. Problems of overfitting and of assessing accuracy. Problems with handling large databases.

ECE470H1S Robot Modeling and Control
3/1.5/1
Classification of robot manipulators, kinematic modeling, forward and inverse kinematics, velocity kinematics, path planning, point-to-point trajectory planning, dynamic modeling, Euler-Langrange equations, inverse dynamics, joint control, computed torque control, passivity-based control, feedback linearization.

ECE557H1F Systems Control
3/1.5/1
State-space approach to linear system theory. Mathematical background in linear algebra, state space equations vs. transfer functions, solutions of linear ODE's, state transition matrix, Jordan form, controllability, eigenvalue assignment using state feedback, observability, designing observers, separation principle, Kalman filters, tracking and the regulator problem, linear quadratic optimal control, stability. Laboratories cover the state space control design methodology.

ESC301H1Y Engineering Science Option Seminar
0/0/1
The Option seminar supports discipline specific discussions of ethics, professionalism, safety and standards and research in a seminar-based setting. Guest speakers, presentations and other activities will highlight various topics of interest, including the present and future research related to the Option. This course will be offered on a credit/no credit basis and the assessment will be through a combination of written assignments, presentations and tests.

ESC499: Thesis
3/2/0
Every student in Fourth Year Engineering Science is required to prepare a thesis on an approved subject. Instructions concerning the thesis requirements are issued during the Winter Session of Third Year and copies may be obtained in the Division office. The weight allocated to the thesis in each Option is shown in the Fourth Year curriculum. Full year

theses are graded after submission in the Winter Session and the grade included in the weighted average for that session only.

MIE342H1F: Circuits with Applications to Mechanical Engineering Systems
3/1.5/1
This course presents analysis of complex circuits and application of circuit principles to design circuits for mechanical engineering systems. Discussions will centre around circuits and instrumentation. In-depth discussions will be given on a number of topics: (1) Mechatronics design applications of circuit principles; (2) Network theorems, node-voltage, mesh-current method, Thévenin equivalents; (3) Operational amplifier circuits; (4) 1st and 2nd order circuits; (5) Laplace transform, frequency response; (6) Passive and active filter design (low- and high-pass filters, bandpass and bandreject filters); (7) Interface/readout circuits for mechanical engineering systems, sensors, instrumentation; (8) Inductance, transformers, DC/AC machines; (9) Digital circuit and data sampling introduction.

MIE346H1S: Analog and Digital Electronics For Mechatronics
3/1.5/1
A study of the fundamental behaviour of the major semiconductor devices (diodes, bipolar junction transistors and field effect transistors). Development of analysis and design methods for basic analog and digital electronic circuits and devices using analytical, computer and laboratory tools. Application of electronic circuits to instrumentation and mechatronic systems.

MIE443H1S: Mechatronic Systems: Design and Integration
2/5/0
The course aims to raise practical design awareness, provide pertinent project engineering methodology, and generate a know-how core in integration of complex automation. This course has mainly practical content, and is integral and useful in the training and education of those students who plan to be employed in areas related to intelligent automation, as well as to the breadth of knowledge of all others. Although emphasis will be on robotic-based automation (mechatronics), the learning will be useful in all domains of system integration. This course will introduce students to the basics of integration, methodology of design, tools, and team project work. The course will be monitored based on projects from a selected list of topics. The lectures will be in format of tutorials as preparation and discussions on project related issues. A main goal is to bring the methods, means and spirit of the industrial design world to the class room. Emphasis will be on understanding the elements of integration, methodology and approaches, and will involve numerous case studies. Specifically the course will provide a practical step-by-step approach to integration: specifications, conceptual design, analysis, modeling, synthesis, simulation and bread-boarding, prototyping, integration, verification, installation and testing. Issues of project management, market, and economics will be addressed as well. Limited Enrolment.

ROB3XX: Introduction to Robotics
3/1.5/1
The course is intended to provide an introduction and a very interdisciplinary experience to robotics. The structure of the course is modular and reflects the perception-control-action paradigm of robotics. The course, however, aims for breadth, covering an introduction to the key aspects of general robotic systems, rather than depth, which is available in later more advanced courses. Applications addressed include robotics in space, autonomous terrestrial exploration, biomedical applications such as surgery and assistive robots, and personal robotics. The course culminates in a hardware project centered on robot integration.

ROB3XY: Mathematics of Robotics
3/0/1
The course addresses advanced mathematical concepts particularly relevant for robotics. The mathematical tools covered in this course are fundamental for understanding, analyzing, and designing robotics algorithms that solve tasks such as robot path planning, robot vision, robot control and robot learning. Topics include complex analysis, optimization techniques, signals and filtering, advanced probability theory, and numerical methods. Concepts will be studied in a mathematically rigorous way but will be motivated with robotics examples throughout the course.

ROB5XX: Computer Vision for Robotics
3/0/1
An introduction to aspects of computer vision specifically relevant to robotics applications. Topics include the geometry of image formation, basic image processing operations, camera models and calibration methods, image feature detection and matching, stereo vision, structure from motion and 3D reconstruction. Discussion of moving object identification and tracking as time permits.

Changes to Chapter 7 - Curriculum and Programs
University of Toronto
Faculty of Applied Science and Engineering
Curriculum Change Form A
For consideration by Faculty Curriculum Committee for 2015-16

Program: AEESCBASE#	Year of Study:	3/4	Session:	Fall/Winter

Current Calendar Entry:		LEC	LAB	TUT	WGT

New/Revised Proposed Text:		LEC	LAB	TUT	WGT	Description of change
YEAR 3 ROBOTICS ENGINEERING						New Major
Fall Session - Year 3						
Dynamics	AER301H1F	3	-	1	0.50	
Economic Analysis and Decision Making	CHE374H1F	3	-	1	0.50	
Data Structures and Algorithms	CSC263H1F	2	-	1	0.50	
Circuits with Applications to Mechanical Engineering Systems	MIE342H1F	3	1.5	1	0.50	
Introduction to Robotics	ROB3XXH1F	3	1.5	1	0.50	
Mathematics of Robotics	ROB3XYH1F	3	-	1	0.50	
Engineering Science Option Seminar	ESC301H1Y	-	-	1	0.25	
Winter Session - Year 3						
Controls Systems	AER372H1S	3	1.5	1	0.50	
Introduction to Artificial Intelligence	CSC384H1S	2	-	1	0.50	
Machine Learning and Data Mining	CSC411H1S	2	-	1	0.50	
Analog and Digital Electronics for Mechatronics	MIE346H1S	3	1.5	1	0.50	
Engineering Science Option Seminar	ESC301H1Y	-	-	1	0.25	
CS/HSS or Technical Elective[1]					0.50	
YEAR 4 ROBOTICS ENGINEERING						
Fall Session - Year 4						
Thesis	ESC499Y1Y	3	2	-	1.00	
Robot Modeling and Control	ECE470H1F	3	1.5m	1m	0.50	
Systems Control	ECE557H1F	3	1.5	1	0.50	
Computer Vision for Robotics	ROB5XXH1F	3	-	1	0.50	
CS/HSS or Technical Elective[1]					0.50	
Winter Session - Year 4						
Thesis	ESC499Y1Y	3	2	-	1.00	
Mobile Robotics and Perception	AER521H1S	3	1.5	1	0.50	
Mechatronic Systems: Design and Integration	MIE443H1S	2	5	-	0.50	
CS/HSS or Technical Elective[1]					0.50	
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1. Robotics Option students must complete 1.0 credit of Technical Electives, and 1.0 credit of Complementary Studies (CS)/Humanities and Social Sciences (HSS) electives in Years 3 and 4. All students must fulfill the Faculty graduation requirement of 2.0 CS/HSS credits, at least 1.0 of which must be HSS. ESC203 is 0.5 HSS. Technical and CS/HSS Electives may be taken in any sequence.

TECHNICAL ELECTIVES
Students are required to select their technical electives from the list of approved courses below. Some courses have limited enrolment. Availability of elective courses for timetabling purposes is not guaranteed. It is the student's responsibility to ensure a conflict-free timetable. Technical Electives outside of the group of courses below must be approved in advance by the Division of Engineering Science.

Application Courses					
Aircraft Flight	AER302H1S	3	-	1	0.50
Aerodynamics	AER307H1F	3	-	1	0.50
Space Systems Design	AER407H1F	-	3	-	0.50
Biomedical Systems Engineering I: Organ Systems	BME350H1F	3	1	2	0.50
Automated Manufacturing	MIE422H1F	2	3	-	0.50
Biomechanics I	MIE439H1S	3	2	-	0.50
Functional Courses					
Scientific Computing	AER336H1S	3	-	1	0.50
Partial Differential Equations	APM384H1F	3	-	1	0.50
Introduction to Neural Networks and Machine Learning	CSC321H1S	2	-	1	0.50
Natural Language Computing	CSC401H1S	2	-	1	0.50
Probabilistic Learning and Reasoning	CSC412H1S	2	-	1	0.50
Computational Linguistics	CSC485H1F	2	-	1	0.50
Knowledge Representation and Reasoning	CSC486H1S	2	-	1	0.50
Systems Software	ECE353H1S	3	3	-	0.50
Real-Time Computer Control	ECE411H1S	3	1.5m	1m	0.50
Neural Bioelectricity	ECE445H1F	3	1.5m	1m	0.50
Digital Signal Processing	ECE455H1F	3	1.5	1	0.50
Intelligent Image Processing	ECE516H1S	3	3m	-	0.50
Inference Algorithms	ECE521H1S	3	-	2m	0.50
Digital Systems Design	ECE532H1S	3	3m	-	0.50
Geometry of Curves and Surfaces	MAT363H1S	3	-	-	0.50
Complex Analysis	MAT389H1S	3	-	1	0.50
Microprocessors and Embedded Microcontrollers	MIE438H1S	2	3	-	0.50
Mechatronics Principles	MIE444H1F	2	3	-	0.50
Other technical elective					0.50

			Signature
Submitted by:	Dept/Division:	Engineering Science	
	Affected Programs:		
Curriculum Committee Approval Date:			
Recommendations:			
Faculty Council Approval Date:			
Recommendations:			