



MEMORANDUM

To: Executive Committee (October 3, 2018)
Faculty Council (October 31, 2018)

From: Prof. Evan Bentz
Chair, Undergraduate Curriculum Committee

Date: October 31, 2018

Re: Proposed Undergraduate Artificial Intelligence Engineering Minor

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).

BACKGROUND

A minor and certificate (see Report 3599) in Artificial Intelligence (AI) Engineering are proposed to provide students in the Core-8 engineering programs and Engineering Science with expertise in machine learning (ML) and AI concepts that will allow them to access challenging and lucrative careers in the burgeoning ML/AI field. These programs will also provide students with the background to pursue advanced research in ML/AI at the master's and the PhD levels. A further impetus for the introduction of the certificate and minor is to work towards the goal of meeting the demand for ML/AI engineering talent in the Ontario and the broader Canadian technology industries.

The minor in AI is proposed to provide students in the Core-8 engineering programs and Engineering Science with substantial background and expertise in ML/AI concepts, enabling access to challenging and lucrative careers in the burgeoning ML/AI field, and to build the background for advanced research in ML/AI to be pursued at the master's and the PhD levels.

CONSULTATION

FASE professors consulted are listed in the attached proposal. The proposal has been approved by the Undergraduate Curriculum Committee, which is composed of representatives from each program, the Vice-Dean, Undergraduate, the Vice-Dean, First Year Studies, the Associate Dean,

Cross-Disciplinary Programs and the Registrar. The proposal has also been reviewed and approved by the Faculty of Arts and Science via the membership of the Joint Oversight Committee.

PROGRAMS

All undergraduate programs are involved in these changes, and the impact on students in these programs has been considered.

GOVERNANCE PROCESS

- Development and consultation within unit – November 2017-September 2018
- Approval of Undergraduate Curriculum Committee – September 2018
- Approval of FASE Council – October 2018
- Submission to Committee on Academic Policy & Programs – annually
- Report to Ontario Quality Council - annually

MOTION FOR FACULTY COUNCIL

THAT the Artificial Intelligence Engineering Minor, as described in the revised proposal attached to Report 3598 Revised, be established effective January 1, 2019, with students allowed to enroll at that time.

University of Toronto

Major Modification Proposal

New Freestanding Minor (and Certificate) Where There is No Existing Specialist or Major

What is being proposed:	Minor and Certificate in Artificial Intelligence Engineering
Department/unit (if applicable):	Cross-Disciplinary Programs Office
Faculty:	Applied Science and Engineering
Faculty contact:	Prof. Bryan Karney, Assoc. Dean, Cross-Disciplinary Programs
Department/unit contact:	Caroline Ziegler, Faculty Governance and Programs Officer Sharon Brown, Assistant Director, Cross-Disciplinary Programs Office
Version date:	October 12, 2018 (revised October 31, 2018)

Summary

A minor and certificate in Artificial Intelligence (AI) Engineering are proposed to provide students in the Core-8 engineering programs and Engineering Science with expertise in machine learning (ML) and AI concepts that will allow them to access challenging and lucrative careers in the burgeoning ML/AI field. These programs will also provide students with the background to pursue advanced research in ML/AI at the master's and the PhD levels. A further impetus for the introduction of the certificate and minor is to work towards the goal of meeting the demand for ML/AI engineering talent in the Ontario and the broader Canadian technology industries.

Effective Date

The programs will be established effective January 1, 2019 and students would be allowed to enrol in the programs starting at that date.

The programs make use of existing courses which students may have already taken or enrolled in for the fourth year. It is possible that some graduating students could complete the minor or certificate requirements prior to graduation this coming June or if not, enrolling in the program prior to graduation would allow them to return after graduation to fulfill any missing program requirements.

Academic Rationale

In the fall of 2017, FASE approved a new stream (major) for the Engineering Science BAScE degree program in machine learning. During the development of this program, it was noted that an opportunity to pursue a credential in this area would be of interest to students in the Core-8 engineering programs and also to Engineering Science students who have an interest in the field, but wish to specialize in a different area.

At a first glance, artificial intelligence (AI) and machine learning (ML) appear primarily to reside in the disciplines of computer engineering and computer science. However, the topics of AI and ML now apply to all disciplines of engineering. Consider that 1) civil engineers apply AI/ML to project future road-traffic patterns, 2) mechanical engineers apply AI/ML for industrial automation and robotic control, or 3) chemical engineers will use AI/ML in drug discovery, to name just a few examples. Indeed, the future will see AI/ML becoming ubiquitous in wide ranging aspects of applied science and engineering. Given these trends, for UofT to lead the way, both in terms of research and in the production of engineering talent with the desired AI/ML skillsets, it is essential that our undergraduate students across FASE have the option to develop a strong background in AI/ML during their studies. By the end of these programs students will be able to understand and utilize algorithms and data structures in the application of AI technologies, discuss and critique the role and implications of AI in society and apply their in-depth knowledge related to AI and ML technologies to address various engineering problems.

As the courses in this area are generally outside of the focus of many engineering disciplines, it could be challenging for students to complete six half-courses (3.0 FCE) in the area and would require extra courses for some disciplines. Thus, we are proposing a certificate of 3 courses (1.5 FCE) as an alternative which would be easier for students to complete within their degree requirements.

While the Department of Computer Science has a Focus in AI, it is only available to students pursuing a Computer Science Specialist program, so engineering students would not be eligible to complete that.

Need and Demand

Machine learning and artificial intelligence have exploded in importance in recent years and garnered attention in a wide variety of application areas, including computer vision (e.g., image recognition), game playing (e.g., AlphaGo), autonomous driving, speech recognition, customer preference elicitation, bioinformatics (e.g., gene analysis) and others. Canada has had a long-standing role at the forefront ML/AI research, particularly research conducted at the University of Toronto, and the University of Montreal. A consequence of this strength has been the establishment of industrial research and development labs with an ML/AI emphasis by major corporations in Toronto and Montreal, such as Facebook (Montreal), Uber (Toronto), and Huawei (Montreal). Both cities are also home to branches of the new Vector Institute – a public/private joint-funded research centre with the overarching objective of advancing ML research in Canada and retaining ML expertise, innovations, and associated economic benefits in Canada. Demand for ML/AI talent in the industry and in academia are extremely high. Moreover, as the scope of applications for ML broadens, it is believed that demand will exceed

supply in this field for years to come, as universities and colleges reorient program offerings to produce sufficient talent.

Admission/Eligibility Requirements

The following background is recommended preparation for either the certificate and minor:

- An introductory course in software programming, preferably Python
- Differential and integral calculus
- An introductory course in linear algebra

The above are already met by the first two years of our Core-8 programs, as well as the first two years of Engineering Science.

In addition, a number of the existing ML/AI courses in the minor and certificate require an introductory course in probability theory and/or probability and statistics. This pre-requisite is met by the following engineering courses:

- CHE223H (Chem), CME263H (CIV+MIN), ECE302H (ECE), MIE231H (Mech), MIE236H (Indy), MSE238H (MSE), STA286H (EngSci)

Requirements for the Certificate and Minor

Certificate Program

Certificates in FASE comprise three half courses (1.5 FCE), one of which may already be part of a student's degree requirements. It should be noted that meeting the requirements for a certificate is the student's responsibility, and the certificate program may not fit compactly within the student's normal workload.

The proposed curriculum for the certificate is:

- 1) APS360H Artificial Intelligence Fundamentals – a new foundational course specifically created for the certificate and minor. Its content, at least initially, will mirror the new EngSci course, MIE324H Introduction to Machine Intelligence. It will launch in winter 2019.
- 2) One of:
 - a. ECE345H Algorithms and Data Structures
 - b. ECE358H Foundations of Computing
 - c. CSC263H Data Structures and Analysis
 - d. MIE335H Algorithms & Numerical Methods

Note: pre-requisite changes will be made so students in all Core-8 programs will be permitted to take ECE345H with the permission of the director of the certificate/minor; permission will be granted provided the students have sufficient background in programming/algorithms, as demonstrated through an appropriate on-line assessment.

- 3) One of:
 - a. ROB311H Artificial Intelligence
 - b. CSC384H Introduction to Artificial Intelligence
 - c. ECE421H Introduction to Machine Learning
 - d. CSC411H Machine Learning and Data Mining
 - e. ROB313H Introduction to Learning From Data

Note: Robotics Major students in Engineering Science have two of the three required courses as part of their core curriculum (CSC263H and ROB311H and ROB313H). These students will only be able to access the certificate program with the permission of director of the certificate program or the Associate Dean, Cross-Disciplinary Programs. The permission will be based on the selection of a suitable set of alternative courses

Minor Program

Minors in FASE comprise six half courses (3.0 FCE), one of which may already be part of a student's degree requirements. It should be noted that meeting the requirements for a minor is the student's responsibility, and the minor may not fit compactly within the student's normal workload.

- 1) APS360H Artificial Intelligence Fundamentals
- 2) One of:
 - a. ECE345H Algorithms and Data Structures
 - b. ECE358H Foundations of Computing
 - c. CSC263H Data Structures and Analysis
 - d. MIE335H Algorithms & Numerical Methods
- 3) One of:
 - a. ROB311H Artificial Intelligence
 - b. CSC384H Introduction to Artificial Intelligence
- 4) One of:
 - a. ECE421H Introduction to Machine Learning
 - b. CSC411H Machine Learning and Data Mining
 - c. ROB313H Introduction to Learning From Data
- 5) One or two of (ML/AI additional emphasis):
 - ECE368H Probabilistic Reasoning
 - CSC401H Natural Language Processing
 - CSC420H Introduction to Image Understanding
 - CSC421H Neural Networks & Deep Learning
 - CSC485H Computational Linguistics
 - CSC486H Knowledge Representation and Reasoning
 - MIE451H Decision Support Systems
 - MIE457H Knowledge Modeling and Management
 - MIE565H Analytics in Action
 - MIE566H Decision Analysis
 - ROB501H Computer Vision for Robotics (EngSci only)

- AI/ML-related capstone or project or Engineering Science thesis (H or Y), with topic to be approved by the director of the ML/AI minor. This capstone/thesis would count for either one or two credits (depending on weight of the course – 0.5 FCE or 1.0 FCE)
- 6) One or zero of (students must have a minimum total of 3.0 FCE):
- ECE344H Operating Systems
 - ECE419H Distributed Systems
 - ECE431H Digital Signal Processing
 - ECE454H Computer Systems Programming
 - ECE367H Matrix Algebra and Optimization
 - ECE470H Robot Modeling and Control
 - ECE532H Digital Systems Design
 - ECE411H Real-Time Computer Control
 - ECE568H Computer Security
 - CSC444H Software Engineering
 - CSC343H Introduction to Databases
 - ROB501H Computer Vision for Robotics
 - AER336H Scientific Computing
 - CHE507H Data-based Modelling for Prediction and Control
 - ECE356H Linear Systems and Control Theory
 - ECE557H Systems Control
 - STA302H Methods of Data Analysis
 - STA410H Statistical Computation
 - MAT336H Elements of Analysis
 - MAT389H Complex Analysis
 - BME595H Medical Imaging

Note: Robotics Major students in Engineering Science have three of the three required courses as part of their core curriculum (CSC263H and ROB311H and ROB313H). These students will only be able to access the minor program with the permission of the director of the minor or the Associate Dean, Cross-Disciplinary Programs. The permission will be based on the selection of a suitable set of alternative courses.

See Appendix A for proposed calendar copy.

See Appendix B for a the course descriptions of the core courses in the program.

Program Structure, Learning Outcomes and Degree-Level Expectations (DLEs)

The Faculty of Applied Science and Engineering aims to provide all of its undergraduate students with an education that will encourage them to be leaders in society in developing solutions to its most pressing problems. In order to achieve this, each graduate will have achieved the Degree-Level Expectations for the BAsC described in Appendix C.

Engineering minors and certificates are designed to recognize students for focusing their degree-program electives in a particular area of study. They are optional structures above and

beyond a student's degree requirements and are therefore enhancements to existing rigorous degree-level expectations for engineering programs. The minors are structured to ensure further **depth and breadth** in student's area of focus that supports the learning objectives of their engineering program. Students are limited to counting one (0.5 FCE) "core course" from their degree program; the remaining courses can be electives from within or outside of their degree program.

Both the minor and the certificate in Artificial Intelligence Engineering are structured around a desire to include a broad, interdisciplinary introduction to the field (APS360H), and specific curriculum in algorithms and data structures, artificial intelligence and machine learning/data mining. These are considered by the program designers to be the fundamental concepts for a credential in artificial intelligence.

Specific learning outcomes for the programs are as follows.

Upon completion of the Certificate program, students will be able to:

- Understand and utilize algorithms and data structures in the application of artificial intelligence technologies.
- Utilize state-of-the-art machine learning technologies in addressing engineering problems.
- Discuss and critique the role and implications of artificial intelligence in society.
- Apply their in-depth knowledge to create solutions using ONE of:
 - "traditional" artificial intelligence technologies, such as search, reasoning, knowledge representation, OR:
 - machine learning technologies, such as deep neural networks, support vector machines, regression.

Upon completion of the Minor program, students will be able to:

- Understand and utilize algorithms and data structures in the application of artificial intelligence technologies.
- Utilize state-of-the-art machine learning technologies in addressing engineering problems.
- Discuss and critique the role and implications of artificial intelligence in society.
- Apply their in-depth knowledge to create solutions using:
 - "traditional" artificial intelligence technologies, such as search, reasoning, knowledge representation
 - machine learning technologies, such as deep neural networks, support vector machines, regression
 - an additional sub-discipline of AI, such as natural language understanding, automated image interpretation,
 - and/or the execution of a significant "capstone" project using state-of-the-art AI technologies to address engineering problem.
- Integrate artificial intelligence and machine learning techniques and knowledge more broadly in courses and experiences related to their engineering discipline.

Assessment of Teaching and Learning

All of the courses within the minor and certificate already exist within the Faculty of Applied Science and Engineering or the Faculty of Arts and Science. Assessment in the courses will follow the established guidelines within their respective Faculties.

The assessment of teaching and learning is regularly reviewed in the Faculty of Applied Science and Engineering through the Canadian Engineering Accreditation Board (CEAB) review process.

Consultation

The following individuals were consulted during the development of these programs:

- Professor Sonja Fidler (CS)
- Professor Scott Sanner (MIE)
- Professor Tim Chan (MIE)
- Professor Yuri Lawryshyn (Chem)
- Professor Kostas Plataniotis (ECE)
- Professor Vaughn Betz (ECE)
- Professor Natalie Enright Jerger (ECE)
- Professor Paul Chow (ECE)
- Professor Stark Draper (ECE)
- Professor Deepa Kundur (EngSci, ECE)
- Professor Ravi Adve (ECE)
- Professor Jimmy Ba (CS, future faculty member, 2018)
- Professor Ashish Khisi (ECE)
- Professor Ben Liang (ECE)
- Xavier Snelgrove, Element AI

The FASE Undergraduate Curriculum Committee and Executive Committee have approved the proposal. The proposal has also been reviewed and approved by the Faculty of Arts and Science via the membership of the Joint Oversight Committee.

Resources

Enrolment and administration of the minor and certificate will be managed through the existing resources of the Cross-Disciplinary Programs Office. Prof. Jason Anderson (ECE) has provided his expertise in developing the curriculum for the programs and will continue to provide academic leadership as the director of the minor. A wide variety of other professors teach and do research in this area as well.

The course APS360H – Artificial Intelligence Fundamentals was created and approved in support of these program in April 2018. The course will be offered for the first time in Winter 2019. Funding and administrative support for this course will come from the budget of the Cross-Disciplinary Programs Office.

All other courses already exist in other departments within their regular budgets. Core courses will be included in the interdepartmental teaching budget allocations, as is done with other minors.

The minor's CSC courses are already present in the list of courses for the Interdivisional Teaching Agreement (IDT). We do not expect to require an increase in the number of seats already negotiated for engineering students in these courses. There are sufficient options for engineering students within the Faculty to meet the program requirements without enrolling in DCS courses. In addition, the Division of Engineering Science anticipates that they will not utilize as many of these IDT spaces because they have also created new courses for their students in this area. Therefore, we are expecting the engineering enrollment numbers in DCS courses to remain consistent with previous years.

There are no anticipated space or infrastructure requirements for these programs beyond those already in place for the existing courses.

Oversight and Accountability: Review

Minors and certificates in the Faculty of Applied Science and Engineering are subject to periodic review in conjunction with the review of the Cross-Disciplinary Programs Office.

Governance Pathway

Steps	Date
Development/consultation with the units	November 2017-September 2018
FASE Undergraduate Curriculum Committee	Approved September 10, 2018
Consultation with FASE Deans' offices, FAS Deans' Office, and VPAP's Office	September-October 2018
FASE Faculty Council approval	October 31, 2018
Submission to Provost's Office	November 2018
Submission to Committee on Academic Programs & Policy for approval	Per 2018-2019 schedule
Report to Ontario Quality Council for information	Per 2018-2019 schedule

Appendix A: Proposed Calendar Descriptions

Course Requirements for the Certificate in Artificial Intelligence Engineering

Artificial Intelligence (AI) and Machine learning (ML) have exploded in importance in recent years and garnered attention in a wide variety of application areas, including computer vision (e.g. image recognition), game playing (e.g. AlphaGo), autonomous driving, speech recognition, customer preference elicitation, bioinformatics (e.g. gene analysis) and others. While the topics may appear primarily to reside in the disciplines of computer engineering and computer science, the topics of AI and ML now apply to all disciplines of engineering, such as projection of future road-traffic patterns, applications in industrial automation and robotic control, or the

All undergraduate Engineering students except students in the Engineering Science Machine Learning Major are eligible to participate in this certificate. Note that Engineering Science Students in the Robotics Major will have to take additional courses due to the number of core courses overlapping with their degree program.

The requirements for the Certificate in Artificial Intelligence Engineering in the Faculty of Applied Science and Engineering are the successful completion of the following courses:

- 1) APS360H Artificial Intelligence Fundamentals
- 2) One of:
 - a. ECE345H Algorithms and Data Structures
 - b. ECE358H Foundations of Computing
 - c. CSC263H Data Structures and Analysis
 - d. MIE335H Algorithms & Numerical Methods
- 3) One of:
 - a. ROB311H Artificial Intelligence
 - b. CSC384H Introduction to Artificial Intelligence
 - c. ECE421H Introduction to Machine Learning
 - d. CSC411H Machine Learning and Data Mining
 - e. ROB313H Introduction to Learning From Data

Note: Robotics Major students in Engineering Science have two of the three required courses as part of their core curriculum (CSC263H and ROB311H and ROB313H). These students will only be able to access the certificate program with the permission of director of the certificate program or the Associate Dean, Cross-Disciplinary Programs. The permission will be based on the selection of a suitable set of alternative courses

Completion of the certificate is subject to the following constraints:

- a) Availability of the courses (including the foundational courses) for timetabling purposes is not guaranteed; the onus is on the student to ensure compatibility with their timetable.
- b) Students must secure approval from their home department before selecting any elective outside their departmental approved list.

Course Requirements for the Minor in Artificial Intelligence Engineering

Artificial Intelligence (AI) and Machine learning (ML) have exploded in importance in recent years and garnered attention in a wide variety of application areas, including computer vision (e.g. image recognition), game playing (e.g. AlphaGo), autonomous driving, speech recognition, customer preference elicitation, bioinformatics (e.g. gene analysis) and others. While the topics may appear primarily to reside in the disciplines of computer engineering and computer science, the topics of AI and ML now apply to all disciplines of engineering, such as projection of future road-traffic patterns, applications in industrial automation and robotic control, or the use of AI/ML drug discovery, to name just a few examples.

All undergraduate Engineering students except students in the Engineering Science Machine Learning Major are eligible to participate in this minor course of study. Note that Engineering Science Students in the Robotics Major will have to take additional courses due to the number of core courses overlapping with their degree program.

The requirements for the Minor in Artificial Intelligence Engineering in the Faculty of Applied Science and Engineering are the successful completion of the following courses:

- 1) APS360H Artificial Intelligence Fundamentals
- 2) One of:
 - a. ECE345H1 Algorithms and Data Structures
 - b. ECE358H1 Foundations of Computing
 - c. CSC263H1 Data Structures and Analysis
 - d. MIE335H1 Algorithms & Numerical Methods
- 3) One of:
 - a. ROB311H1 Artificial Intelligence
 - b. CSC384H1 Introduction to Artificial Intelligence
- 4) One of:
 - a. ECE421H1 Introduction to Machine Learning
 - b. CSC411H1 Machine Learning and Data Mining
 - c. ROB313H1 Introduction to Learning From Data
- 5) One or two of (ML/AI additional emphasis):
 - ECE368H Probabilistic Reasoning
 - CSC401H Natural Language Processing
 - CSC420H Introduction to Image Understanding
 - CSC421H Neural Networks & Deep Learning
 - CSC485H Computational Linguistics
 - CSC486H Knowledge Representation and Reasoning
 - MIE451H Decision Support Systems
 - MIE457H Knowledge Modeling and Management
 - MIE565H Analytics in Action

- MIE566H Decision Analysis
 - ROB501H Computer Vision for Robotics (EngSci only)
 - AI/ML-related capstone or project or Engineering Science thesis (H or Y), with topic to be approved by the director of the minor. This capstone/thesis would count for either one or two credits (depending on weight of the course – 0.5 FCE or 1.0 FCE)
- 6) If needed, one of the courses in the table below to bring the complement of courses to the minimum total of 3.0 FCE:

- ECE344H Operating Systems
- ECE419H Distributed Systems
- ECE431H Digital Signal Processing
- ECE454H Computer Systems Programming
- ECE367H Matrix Algebra and Optimization
- ECE470H Robot Modeling and Control
- ECE532H Digital Systems Design
- ECE411H Real-Time Computer Control
- ECE568H Computer Security
- CSC444H Software Engineering
- CSC343H Introduction to Databases
- ROB501H Computer Vision for Robotics
- AER336H Scientific Computing
- CHE507H Data-based Modelling for Prediction and Control
- ECE356H Linear Systems and Control Theory
- ECE557H Systems Control
- STA302H Methods of Data Analysis
- STA410H Statistical Computation
- MAT336H Elements of Analysis
- MAT389H Complex Analysis
- BME595H Medical Imaging

Note: Robotics Major students in Engineering Science have three of the three required courses as part of their core curriculum (CSC263H and ROB311H and ROB313H). These students will only be able to access the minor program with the permission of the director of the minor or the Associate Dean, Cross-Disciplinary Programs. The permission will be based on the selection of a suitable set of alternative courses.

Completion of the minor is subject to the following constraints:

- a) Of the 6 (half year) courses required, one (half year) course can also be a core course in a student's Program, if applicable.
- b) Either a Thesis or Design course can count for up to two elective in Requirement #5 IF the Thesis or Design course is strongly related to artificial intelligence. This requires approval by the director of the minor.
- c) Some departments may require students select their electives from a pre-approved subset. Please contact your departmental academic advisor for details.
- d) Arts and Science Courses listed below may be considered eligible electives for students taking the minor, subject to the student meeting any prerequisite requirements. Students must also seek the approval of their home program to ensure that they meet their degree requirements. In situations where these courses don't meet those of their home program, students can elect to take these as extra courses.

Appendix B: Course Descriptions for Core Courses

APS360H: Artificial Intelligence Fundamentals (3/0/1/0.5) – A new broad-based, foundational course specifically created for the Artificial Intelligence Certificate and Minor programs which we intend to introduce in winter 2019. Its content will provide a basic introduction to the history, technology, programming and applications of artificial intelligence, with emphasis on fast evolving field of machine learning. Topics to be covered may include linear regression, logistic regression, support vector machines, and neural networks. An applied approach will be taken, where students get hands-on exposure to AI techniques through the use of state-of-the-art machine learning software frameworks. In assignments, students will apply the AI techniques taught to contemporary computing challenges, for example, by applying AI to improve computer decision making, prediction, image/speech recognition, image/speech synthesis, game playing or other tasks.

CSC263H: Data Structures and Analysis (2/-/1/0.50) - 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.

CSC384H: Introduction to Artificial Intelligence (2/-/1/0.50) – 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, in both theory and programming, of the core topics.

CSC411H: Machine Learning and Data Mining (2/-/1/0.50) – 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. Emphasis on statistical approaches.

ECE345H: Algorithms and Data Structures (3/-/2m/0.50) - Design and analysis of algorithms and data structures that are essential to engineers in every aspect of the computer hardware and software industry. Recurrences, asymptotics, summations, trees and graphs. Sorting, search trees and balanced search trees, amortized analysis, hash functions, dynamic programming, greedy algorithms, basic graph algorithms, minimum spanning trees, shortest paths, introduction to NP completeness and new trends in algorithms and data structures.

ECE358H: Foundations of Computing (3/-/1/0.50) - Fundamentals of algorithm design and computational complexity, including: analysis of algorithms, graph algorithms, greedy algorithms, divide-and-conquer, dynamic programming, network flow, approximation algorithms, the theory of NP-completeness, and various NP-complete problems.

ECE421H: Introduction to Machine Learning (3/-/2m/0.50) – An Introduction to the basic theory, the fundamental algorithms, and the computational toolboxes of machine learning. The focus is on a balanced treatment of the practical and theoretical approaches, along with hands on experience with relevant software packages. Supervised learning methods covered in the course will include: the study of linear models for classification and regression, neural networks and support vector machines. Unsupervised learning methods covered in the course will include: principal component analysis, k-means clustering, and Gaussian mixture models. Theoretical topics will include: bounds on the generalization error, bias-variance trade-offs and the Vapnik-Chervonenkis (VC) dimension. Techniques to control overfitting, including regularization and validation, will be covered.

MIE335H: Algorithms & Numerical Methods (3/1/1/0.50) - Algorithmic analysis, big-O asymptotic analysis; numerical linear algebra, solution techniques for linear and non-linear systems of equations; matrix factorization, LU and Cholesky factorization, factorization in the revised simplex method; Newton's method, Gale-Shapley method, greedy methods for combinatorial optimization, branch-and-bound search methods; graph theory and graph theoretic algorithms; design and implementation of algorithms to optimize mathematical models.

ROB311H: Artificial Intelligence (3/-/1/0.50) – An introduction to fundamental principles of artificial intelligence, and will explore the subject matter in rigorous mathematical terms. Topics include the history and philosophy of AI, search methods in problem solving, knowledge and reasoning, probabilistic reasoning, decision trees, Markov decision processes, natural language processing and elements of machine learning such as neural-network paradigms.

ROB313H: Introduction to Learning from Data (3/-/2/0.50) – An introduction to the topic of machine learning, which is key to the design of intelligent systems and gaining actionable insights from datasets that arise in computational science and engineering. The course will cover the theoretical foundations of this topic as well as computational aspects of algorithms for unsupervised and supervised learning. The topics to be covered include: The learning problem, clustering and k-means, principal component analysis, linear regression and classification, generalized linear models, bias-variance trade-off, regularization methods, maximum likelihood estimation, kernel methods, the representer theorem, radial basis functions, support vector machines for regression and classification, an introduction to the theory of generalization, feedforward neural networks, stochastic gradient descent, ensemble learning, model selection and validation.

Appendix C: Undergraduate Degree-Level Expectations

Degree Level Expectations for Graduates Receiving the Degree of Bachelor of Applied Science

Faculty of Applied Science and Engineering University of Toronto

1 Degree Learning Objectives and Requirements

1.1 Overall Learning Objectives

The Faculty of Applied Science and Engineering aims to provide all of its undergraduate students with an education that will allow them to be leaders in society in developing solutions to its most pressing problems. Our graduates will be able and inspired to:

- be leading practitioners of engineering and engineering design
- be known for their technical literacy as well as their knowledge of mathematics and the basic sciences and the role of technology in society
- be able to formulate and solve problems in complex systems independently and in teams
- pursue independent lifelong learning within their field of study and more broadly
- be prepared for careers, including graduate programs, that build upon their advanced technical knowledge
- participate meaningfully as leaders in society

In order to achieve this, each graduate will have achieved the following general learning objectives:

- a. Depth of knowledge that cultivates critical understanding and intellectual rigour in at least one engineering discipline.
- b. Competencies in learning and applying knowledge to solve problems facing society and that are fundamental to responsible and effective participation in the workplace, in the community, in scholarly activity, and in personal life:
 - i. Critical and Creative Thinking
 - ii. Oral and Written Communication
 - iii. Quantitative Reasoning
 - iv. Teamwork
 - v. Information Literacy
 - vi. Ethical Thinking and Decision-Making
- c. Breadth of knowledge across mathematics, basic sciences, engineering sciences, engineering economics and engineering design that cut across the engineering disciplines and across a range of nontechnical areas including the humanities and social sciences and an awareness of the impact of technology on society.
- d. Integration of skills and knowledge developed in a student's course of study through a capstone experience in the upper years.

1.2 Requirements to Graduate

In order to graduate with a B.A.Sc. degree, each student in the Faculty of Applied Science and Engineering will have completed a full undergraduate program as outlined in the Faculty Calendar within nine calendar years of first registration, exclusive of mandatory absences from his/her program. Current programs include: Chemical, Civil, Computer, Electrical, Industrial, Mineral, Materials and Mechanical Engineering.

The practice of engineering is regulated, by statute, in all Canadian provinces and territories. To become a Professional Engineer, an individual must satisfy the requirements of the licensing bodies.

These requirements include a degree from an accredited program, successful completion of a professional practice examination in engineering law and ethics, and suitable experience. At present, all programs in the Faculty of Applied Science and Engineering are accredited and evaluated regularly by the Canadian Engineering Accreditation Board (CEAB) of the Canadian Council of Professional Engineers. Therefore, graduation from the Faculty may lead to registration in the provincial Associations of Professional Engineers, in accordance with individual policies. No student will be permitted to graduate who does not meet these requirements.

The criteria set out by the CEAB are designed to ensure that each graduate has a foundation in Mathematics and Basic Sciences, a broad preparation in Engineering Sciences and Engineering Design and an exposure to non-technical subjects (Complementary Studies) that complement the technical aspects of the curriculum. Basic Sciences must include physics and chemistry and also may include elements of life sciences and earth sciences; they impart an understanding of natural phenomena. Engineering Sciences normally involve mathematics and Basic Sciences but carry knowledge further to creative applications. Complementary studies include the humanities, social sciences, arts, management, engineering economics and communication skills.

Each program in the Faculty consists of a technical component and complementary studies component. The curriculum for students in their early years forms a basis in the fundamental subjects prior to subsequent specialization in the various engineering disciplines. Students are able to choose from a range of technical electives in their senior years. In the senior years, all programs contain a Capstone experience through a design project, which integrates their skills and knowledge and provides students with the opportunity to carry out original work in their chosen fields of study.

There are a set of common requirements, described below, that cut across all programs in the following categories: Coursework; Promotion; English Proficiency; and Practical Experience. In this context, a course is defined as one half-course equivalent, which may consist of a half course ("S", "F" or "H") or half of a full-year "Y" course.

1. **Coursework:** Each program will have courses that provide the following:
 - a. Complementary Studies Electives
 - b. A basic knowledge of Engineering Economics
 - c. Technical Electives
 - d. Courses with substantial design content in Years 1, 2 and/or 3

- e. Capstone course(s) in Years 3 and/or 4 with strong integrative, design and independent work elements
 - f. Across all four years, programs will provide sufficient opportunities for the development of professional awareness and practice.
2. **Promotion:** All undergraduate programs will consist of eight Fall and Winter Sessions taken in order.
- a. To gain credit for a session a student must:
 - i. satisfy the academic regulations to proceed to the succeeding session as described in the calendar and
 - ii. not be subsequently required to repeat the session for which credit is to be gained, and
 - iii. achieve a course mark of 50% or greater in every course taken as part of the academic load in a session, and
 - iv. not have any outstanding designations of 'standing deferred', 'incomplete' or 'No Grade Available' for any course in any session.
 - b. To be eligible to graduate, each student must attain a weighted Session Average of 60% or greater in the final session of their program. Any student who does not achieve a weighted Session Average of 60% in their final session (4W), but has attained a weighted Session Average that allows them to proceed to the next session on probation, shall repeat the final session and achieve a weighted Session Average of 60% or greater to graduate.
3. **English Proficiency:** Each student must show an ability to write English coherently and correctly. Every student will also take at least one course that includes a written communication component within their curriculum. Satisfactory completion of the course or courses is required for graduation.
4. **Practical Experience:** The Faculty requires that all students complete a minimum of 600 hours of practical work before graduation.

2 Degree Level Expectations for the Bachelor of Applied Science

2.1 Depth and Breadth of Knowledge

The Faculty ensures that a student has mastered a body of knowledge with appropriate depth by requiring that each student completes the requirements of one of the degree Programs of Study (POST) as described in the Faculty Calendar. The curriculum for students in First Year forms a common basis in the fundamental subjects, including the natural sciences and mathematics, prior to a subsequent specialization in the various engineering disciplines. Each program consists of a technical component and a complementary studies component.

Critical analysis and thinking and analytical skills are emphasized through the student's exposure to an increasingly sophisticated understanding of their program of study. Specialization within the discipline is developed through technical electives taken in the 3rd and 4th years of study. A detailed knowledge of and experience in design is ensured through the Design Course requirements, beginning with courses in the first three years as well as the

Capstone course(s) in each program. Opportunity to further develop these skills is provided through a research thesis that is available in most POSTs.

The Faculty assures that students have breadth of knowledge in a number of ways. Breadth across engineering is assured through a First Year of study that prepares a student for any of the programs of study. Breadth beyond engineering is developed through the Complementary Studies Electives as well as the Engineering Economics requirement.

2.2 Knowledge of Methodologies

Every POST has requirements which demonstrates a student's understanding of the methods of engineering design. Students in all engineering programs must successfully complete courses with substantial design in their first three years and a Capstone design course in their senior years. These courses require students to evaluate the appropriateness of various approaches to analyze and solve the design problem and also to devise and sustain arguments for their design. In most POSTs, students have the opportunity to participate in a research thesis course that familiarizes them with the specific methodologies currently in use in the development of knowledge in their discipline.

2.3 Application of Knowledge

The application of science and mathematics to solve problems is fundamental to all programs in Engineering and therefore is required in many of the courses within all POST. A minimum level of instruction in Engineering Science and Engineering Design is required, both of which directly involve the application of knowledge.

2.4 Communication Skills

The Faculty requires students to communicate information, arguments and analysis accurately and reliably, orally and in writing, to specialist and non-specialists audiences. The requirement for courses with substantial engineering design that are required across all programs require a series of technical reports and presentations with direct involvement with our Engineering Communication Program. In addition, our Capstone Design Courses and research theses all involve a written report and most involve oral presentations. The course requirements for instruction in Complementary Studies also adds to the education our students receive in communication skills. Also, the English Proficiency requirement insures a minimum level of writing ability for all graduates.

2.5 Awareness of Limits of Knowledge

Each POST develops, through a sequence of courses starting at the 100-series or 200-series and culminating at the 300-series or 400-series or 500-series of courses, an understanding of a discipline as it is currently appreciated by educators who are at the same time involved in original scholarship in the subject area. The course content at the upper series level is designed, in part, to provide students with an appreciation of the uncertainties, ambiguities and limitations of knowledge in the specific area.

2.6 Autonomy and Professional Capacity

The development of an awareness and understanding of professional practice is required for all POSt. The required design courses require students to work in teams and also accept responsibility for their own contributions. Students are required to make their own decisions for their own learning through selection of their technical and nontechnical electives. Finally, in completing their course requirements, the Faculty expects strict adherence by students to the Code of Behaviour on Academic Matters, which requires students to not tolerate or encourage the creation of an environment of cheating, misrepresentation or unfairness.

2.7 Other Degree Level Expectations

The Faculty requires all students to have developed competency in several areas of learning and applying knowledge not identified explicitly in the previous sections. In particular, the Faculty requires students to have developed competencies in quantitative reasoning and in information literacy.

Quantitative reasoning is considered the ability to identify, assemble and interpret quantitative information and make and test hypotheses based on such data. Development of this competency is an explicit part of all POSTs offered by the Faculty.

The Faculty requires all students to develop an advanced understanding of how to obtain information, manipulate and evaluate it and bring diverse sources together to develop a comprehensive understanding of specific issues, solve problems or apply the scientific method to create further knowledge in the discipline. These advanced information literacy skills are developed through the studies in their concentration(s) and are demonstrated in the advanced courses required in each POST.