FOR APPROVAL | **PUBLIC** | **OPEN SESSION**

TO:	Committee on Academic Policy and Programs
SPONSOR: **CONTACT INFO:**	Mark Schmuckler, Acting Vice-Provost, Academic Programs (416) 978-0490, vp.academicprograms@utoronto.ca
PRESENTER: **CONTACT INFO:**	See Sponsor
DATE:	December 14, 2020 for January 12, 2021
AGENDA ITEM:	4

ITEM IDENTIFICATION:

New Program: Major in Quantitative Biology in an existing undergraduate degree (HBSc), Faculty of Arts & Science.

JURISDICTIONAL INFORMATION:

The Committee on Academic Policy and Programs approves new undergraduate programs within an existing degree, as defined by the University of Toronto Quality Assurance Process. *(AP&P Terms of Reference, Section 4.4.b.i.)*

GOVERNANCE PATH:

1. **Committee on Academic Policy and Programs [for approval] (January 12, 2021)**

PREVIOUS ACTION TAKEN:

The proposal for the Major in Quantitative Biology received approval from the Faculty of Arts & Science Faculty Council on December 9, 2020.

HIGHLIGHTS:

This is a proposal for a new Major in Quantitative Biology that will lead to an Honours Bachelor of Science degree. It will be offered by the Department of Ecology & Evolutionary Biology in the Faculty of Arts & Science (FAS). The Major will consist of 8.0 full-course equivalents (FCEs).

The proposed new Major in Quantitative Biology responds to the growing demand for quantitative methods competency as students in the biological sciences enter graduate school or the workforce. It also aligns with one of the Faculty's strategic priorities of expanding innovations in academic programming for undergraduate students. It is designed for students with a deep interest in biology who wish to gain a strong grounding in quantitative methods and their application to biological questions. More than ever, advancements in biology, from the molecular through the organismal to the ecosystem level, require quantitative thinking and skills along with a strong understanding of biological processes. Interdisciplinary research that draws from the natural sciences, mathematics, statistics and computer science is an important aspect of modern biology. This Major provides foundations in biology and quantitative approaches used to test and advance biological knowledge, and is appropriate for students who wish to pursue a career or graduate studies in a broad range of life sciences, ranging from biomedical to conservation to epidemiology.

The program consists of existing courses that are delivered through a mixture of classroom learning and applied laboratory teaching, with an emphasis on understanding how quantitative methods inform our understanding of biology and how they can be applied to test and develop new hypotheses. Students also have access to independent research opportunities that enhance professional skills, science communication and the development and application of knowledge in quantitative biology.

The program will appeal to students hoping to study statistical and computer sciences with a biological context, or biologists who would like to be equipped with quantitative tools to help pursue graduate studies in the future. It will be a limited-enrolment program. To enrol, students must have completed 4.0 FCEs; achieved a minimum grade of 70% in one of the stated introductory biology courses; and achieved a minimum grade of 70% in an introductory quantitative course specified. It is anticipated that 30 to 35 students will enrol in the program each year for a total of 100 students in the Major each year.

Consultation outside the Faculty of Arts & Science occurred with the Temerty Faculty of Medicine, which was supportive of the proposal. The proposal was discussed at the June 11, 2020 meeting of the Tri-campus Deans, and feedback was uniformly positive.

The program was subject to external appraisal on October 6, 2020 by Professors Simon A. Levin, Department of Ecology and Evolutionary Biology, Princeton University; and Gregor Fussmann, Department of Biology, McGill University. The external appraisers made a number of suggestions that resulted in changes to the program, as reflected in the Dean’s response to the appraisal report.

FINANCIAL IMPLICATIONS:

The new financial obligations resulting from this program will be met at the divisional level.

RECOMMENDATION:

Be it Resolved,

THAT the proposed Major in Quantitative Biology, which will confer the existing degree HBSc, as described in the proposal from the Faculty of Arts & Science dated November 9, 2020, be approved effective, September 1, 2021.

DOCUMENTATION PROVIDED:

- *Proposal for a Major in Quantitative Biology, FAS*

University of Toronto
New Undergraduate Program Proposal

The program proposal must address the purpose and content of the new program and the capacity of the unit to deliver a high-quality program.

This template (last updated by the Office of the Vice-Provost, Academic Programs on September 6, 2019) is for all proposals for new undergraduate programs. It aligns with UTQAP requirements and will help to ensure that all evaluation criteria established by the Quality Council are addressed in bringing forward a proposal for a new program. Separate templates have been developed for other types of proposals.
Please note that all proposed new programs are subject to external appraisal.

Name of proposed program:	**Major in Quantitative Biology**, Hons. BSc
Degree conferred:	Hons. BSc
Department/unit (if applicable) where the program will be housed:	Department of Ecology and Evolutionary Biology (EEB)
Faculty/academic division:	Faculty of Arts & Science
Dean's office contact:	Virginia Maclaren, Acting Vice-Dean, Academic Planning
Proponent:	Professor Benjamin Gilbert Professor Stephen Wright
Direct entry or selection of POSt at end of 1st year:	Selection at end of first year
Version date:	November 9, 2020

Development & Approval Steps	Date (e.g., of external appraisal site visit, final sign

	off, governance meeting, quality council submission, ministry submission)
New Program Consultation Meeting	November 4, 2019
Consultation Proponents/Dean's Office/Provost's Office	
Provost's Advisory Group	June 17, 2020
External Appraisal	October 6, 2020
Decanal signoff In signing off I confirm that I have ensured appropriate: ✓ compliance with the evaluation criteria listed in UTQAP section 2.3 ✓ consultation with the Office of the Vice-Provost, Academic Programs early in the process of proposal development ✓ Consultation with faculty and students, other University divisions and external institutions	Melanie Woodin, Dean, Faculty of Arts & Science September 2, 2020
Provostial signoff In signing off I confirm that the new program proposal: ✓ Is complete ✓ Includes information on all the evaluation criteria listed in UTQAP section 2.3	Susan McCahan, Vice-Provost, Academic Programs September 9, 2020
Unit-level approval (if required)	N/A
Faculty/divisional governance	Sciences Curriculum Committee Nov 20, 2020 Arts & Science Council Dec 9, 2020
Submission to Provost's Office	
AP&P	Jan 12, 2021
Academic Board (if a new degree)	N/A
Executive Committee of Governing Council (if a new degree)	N/A
The program may begin advertising as long as any material includes the clear statement that, "No offer of admissions will be made to the program pending final approval by the Quality Council and the Ministry of Training, Colleges and Universities (where the latter is required)."	
Ontario Quality Council	Feb 20, 2021
Submitted to the Ministry (in case of a new degree)	N/A

New Undergraduate Program Proposal

Quantitative Biology Major (QBio)
Department of Ecology and Evolutionary Biology
Faculty of Arts & Science

Table of Contents

Instructions: Please include all sections with page numbers and a full list of appendices in the table of contents. The Table of Contents will update automatically when you right-clicking on it and select "Update Field" and then "Update Entire Table."

1 Executive Summary

Please provide a brief overview of the proposed program summarizing the key points from each section of the proposal. (You may wish to complete this section last.) This may need to be used on a stand-alone basis:

The Department of Ecology and Evolutionary Biology (EEB), in the Faculty of Arts & Science, is proposing a new major in Quantitative Biology (QBio) that will lead to an Honours Bachelor of Science. Ecology and evolutionary biology, and many other fields within biology, have seen a rapid increase in quantitative methods that are increasingly in demand both academically and in the workplace. The rapid increase in quantitative methods in biology is matched by expertise of EEB faculty and student demand for training in QBio. The proposed major is designed to draw on existing resources in EEB and other relevant departments (including Cell & Systems Biology, Mathematics, Statistical Sciences, and Computer Science) to formalize and further develop options for students.

The proposed major is designed to couple a biology program with three complementary quantitative methodologies: mathematics, statistics, and programming. This coupling reflects a range of academic and professional routes in QBio, from predictive disease modeling (mathematics), to biological image analysis (statistics) to genome mapping (programming). By allowing a range of courses on biological and quantitative topics, the major is designed for flexibility and student choice while maintaining a backbone of common learning objectives. Students who complete the major will have:

- A wide breadth and depth of knowledge in biology and the quantitative methods used to predict and model biological processes and patterns
- Practical skills at developing biological hypotheses, quantitatively testing these hypotheses, and knowledge of how to apply these skills in professional settings
- An awareness of the limits to current methodologies and approaches to life-long learning essential for maintaining expertise in the rapidly developing field of quantitative biology.

The proposed major is expected to attract students who show interests in biology and quantitative methods and will have a limited enrollment to keep the program to 100 students. It will draw on junior and intermediate courses with specific topics in quantitative fields in biology or quantitative methods and includes a number of final year courses with

research project components that act as capstones to synthesize and apply knowledge and tools from lower-level courses.

The proposed major is expected to support the Faculty of Arts & Science's goals of providing for the increasing student demand for quantitative sciences while developing new student opportunities that bridge disciplines. This new major will also be well-placed to contribute to, and benefit from, future developments in A&S that address these goals, including enhanced pedagogical support for computational and data studies. QBio will benefit from recent faculty recruitments in EEB, who engage in cutting-edge research in quantitative biology and will soon be exploring new courses to further contribute to the major.

2 Effective Date & Date of First Review

Anticipated start date: September 2021

First date degree program will undergo a UTQAP review and with which unit[1]: 2024-2025 in Ecology and Evolutionary Biology, Faculty of Arts & Science.

3 Academic Rationale

Please use the headings below:

- Identify what is being proposed and provide an academic rationale for the proposed program (what is being created and why?).
- Explain the appropriateness of the program name and degree nomenclature.
- If relevant, describe the mode of delivery (including blended or online; placement, etc.) and how it is appropriate to support students in achieving the learning outcomes of the program.
- Context
  - Discuss how the program addresses the current state of the discipline or area of study. (Identify pedagogical and other issues giving rise to the creation of this program. Where appropriate, speak to changes in the area of study or student needs that may have given rise to this development.)

[1] Programs that are inter-and multidisciplinary must identify a permanent lead administrative division and identify a commissioning officer for future cyclical program reviews.

- Describe the consistency of the program with the University's mission as specified within the Statement of Institutional Purpose and unit/divisional academic plan and priorities.
- Distinctiveness
  - Identify any unique curriculum or program innovations or creative components.

Proposed program and academic rationale:
A new undergraduate Major program, Quantitative Biology (QBio), is proposed by the Department of Ecology & Evolutionary Biology (EEB) within the Faculty of Arts & Science (A&S). The new program is proposed within the existing degree of Honours Bachelor of Science (Hons. BSc).

Biology is the scientific study of all living things. The modern study of biology depends crucially on application of quantitative methods from mathematics, statistics, and computer science. This integration of natural and formal science is critical for properly modeling natural systems in a predictive way, for understanding complex biological systems, and for appropriate analysis of big data in genomics, ecology, and medicine. Technological advances in biology from the levels of molecules to organisms to ecosystems require quantitative thinking and approaches to make sense of all the information. Society needs to make informed decisions that require a breadth of quantitative approaches in life sciences, from the ecological consequences of global change to the control of emerging infectious diseases to genomic interpretation for personalized medicine. Recognizing these societal needs, reviews of the Faculty of Arts & Science and units within A&S have identified both the faculty expertise required and the academic need for quantitative skills to be enhanced across A&S. The goal of this program is distinct from other related programs such as Bioinformatics & Computational Biology in its focus on broad quantitative training spanning statistics, mathematical modelling, and computational approaches. Rather than a program that is aimed at training the next generation of, for example, computational biologists, this program aims to provide the quantitative literacy for future careers that require a range of knowledge in both biology and quantitative fields, such as public health and conservation policy. EEB is at the forefront of teaching and research into the factors governing biodiversity, from genomes to ecosystems, which utilizes quantitative methods in all aspects of the discipline. EEB faculty members' integration of both basic and applied perspectives into their research and teaching means their activities are making major impacts on both the fundamental understanding of the natural world, as well as on policy and practice for minimizing and managing human impacts on biodiversity. The Department has the unique depth and breadth of expertise in quantitative biology to launch this program.

Appropriateness of program name and degree nomenclature:
The Quantitative Biology major will encompass a number of potential areas of focus both on the biological front (cell and systems biology, ecology and evolutionary biology), and from a quantitative viewpoint (mathematical modeling, statistical modeling, and computer programming and simulation). The inclusive program name captures this diversity of topics for life science students more than other related names, such as "mathematical biology" or "computational biology." The program is designed as a major, encompassing biological and quantitative fields that lead to honours bachelor of science.

Context:
Quantitative analysis is crucial in modern life science disciplines. Both academic and industry settings often require mathematical, statistical, and computational skills to solve biological problems and manage big data. However, existing life science major programs at U of T require minimal quantitative skills for completion (usually 1.5 FCE [full-course equivalent] or less), creating a clear gap in life science students' undergraduate training opportunities to prepare for careers and advanced study after graduation. Shifts in enrolments within Arts & Science toward quantitative disciplines reinforces the value, real and perceived, for students. The 2018-19 Faculty of Arts and Science (A&S) self-study and external review clearly identified that computational and quantitative approaches should be "distributed across the entire knowledge landscape," rather than being concentrated exclusively within individual departments (e.g. Statistical Sciences or Computer Science). Dovetailing with this view, EEB's 2017-18 UTQAP self-study and external review pointed to strengthening EEB's commitment to quantitative biology at the level of faculty complement. Thus, the time is right to strengthen undergraduate training with a Quantitative Biology (QBio) Major program.

Based on this rationale, we believe that offering a QBio Major will give a clear signpost to students about the merits of quantitative training in life sciences and a pathway to pursue it. We suspect that this major will appeal to the practical inclinations of students and their families as they chart their undergraduate program choices, as quantitative skills will give them valuable assets in pursuing diverse career options after graduation.

Delivery:
The intent of the new QBio program is to provide broad-based training in diverse quantitative areas (mathematics, statistics, computing) that integrates in a general way with all of life sciences (genetics/genomics, evolution, ecology/conservation, epidemiology, molecular and

cellular biology, physiology, and systems biology). Quantitative courses that touch on life sciences are dispersed across many units at U of T, but their inter-related nature is currently opaque to students. The QBio major will provide students with a curated package of required and elective courses to help them explore, and benefit from, the broad range of existing expertise in multiple units. The QBio Major program requires “fundamentals” courses at the 100- and 200-level in each of these four broader disciplines (biology, mathematics, statistics, and computer science). Course options at the 300- and 400-level consist of biology courses that explicitly incorporate quantitative approaches or quantitative courses that are applied to biological topics. These courses are notable both for their distribution across quantitative and biological departments, and for the diverse methods of teaching and evaluating the knowledge and skills necessary for QBio. In particular, they range from exam-based knowledge courses, to courses with applied methods that are largely assessed through practical assignments, to courses that use group debate and individual research projects to foster professional development and communication skills.

Relevant expertise and courses exist across a large number of units, ranging from the Departments of Geography & Planning to Psychology to Cell & Systems Biology, and these will be integrated into the program. EEB is well-positioned to administer this program, as the greatest fraction of biology courses at U of T that incorporate a large quantitative component are taught by EEB faculty. This concentration of courses reflects the quantitative core of the discipline of ecology and evolutionary biology, which is unique among the life science and related departments. The nature of the ecological dynamics of populations and communities (ecology), and the evolutionary dynamics of adaptive traits and their genetic underpinnings (evolution) are inherently quantitative. EEB faculty’s strength in quantitative biology is reflected in the teaching and research of a diverse group of 13 faculty members (Professors Agrawal, Chang, Cutter, Fortin, Gilbert, Jackson, Krkosek, Mahler, Mideo, Sztepanacz, Stinchcombe, and Wright; plus a new hire starting in January 2021 as a result of a successful Fall 2018 search). See sections 12.1: *Faculty* and 13: *Quality and Other Indicators* for further details about this decorated group of faculty. These faculty members have discussed and voiced strong support for creation of the QBio program and lending their expertise in mathematical modeling, statistical modeling, and high-performance computing to solve biological problems in undergraduate courses. EEB faculty also discussed and approved the QBio plan during faculty meetings and at a summer 2017 departmental retreat. Additionally, a new teaching-stream hire (Professor Riskin) has initiated a departmental working group to review quantitative teaching methods in the department to establish best practices, tools for assignments, and a common “R handbook” for use by all EEB courses using quantitative methods.

This mandate to enhance quantitative biology generally is reflected in the EEB 2017-18 UTQAP self-study and external review recommendations. In addition, the proposed QBio major is specifically highlighted in the 2020-2025 A&S Academic Plan as an example of “innovations in academic programming,” which the Faculty will prioritize over the next five years: “A new major in Quantitative Biology will provide students with an opportunity to focus on building skills in state-of-the-art analytics relevant to the life sciences.”

More broadly, the QBio major is in line with the mission of the University, as indicated in the Statement of Institutional Purpose, which states, “The University of Toronto is committed to being an internationally significant research university, with undergraduate, graduate and professional programs of excellent quality.” The program will assist students in the “realization of their educational goals,” including “career development,” by preparing them for contemporary career opportunities that require quantitative and computational skills. The QBio major will also provide a new forum in which faculty members can “draw on their research to enrich their teaching” of undergraduate students. Ultimately, this will be a program drawing on the top-tier research, and teaching experience, of over a dozen EEB faculty members (see Section 12.1) who are dedicated to delivering programs of excellent quality.

To bolster the commitment to implementing and administering this new program, EEB has implemented two new courses (EEB313H1: Quantitative Methods in R for Biology and EEB462H1: Phylogenetic Systematics) and re-introduced an older course, making changes that include a broader title, description, and scope to better mesh with the aims of the QBio program (EEB430H1: Modeling in Ecology and Evolution). EEB also has dedicated a faculty member to teach in a biostatistics course that in recent years had relied on sessional lecturers (EEB225: Biostatistics for Biologists). It is expected that the two newest faculty hires will also contribute new courses in the future that will further enhance the breadth and depth of course options available to QBio Majors.

Distinctiveness:
The QBio Major program is broader in scope and distinct from the few existing undergraduate programs at U of T that connect parts of biology and quantitative disciplines, all of which are Specialist programs (*Note*. Specialists require more course credits [e.g., 12-

14.0 FCE], and students do not need to complete another program in order to graduate. Majors, on the other hand, require fewer courses [e.g. 8.0 FCE] and must be combined with other programs of study for students to graduate). The Department of Cell & Systems Biology (CSB) offers a Bioinformatics and Computational Biology Specialist (B&CB), co-sponsored by EEB and the Department of Biochemistry (BCH); the Department of Statistical Sciences (STA) offers a Specialist in Statistical Sciences Methods and Practice with streams in biological disciplines; and the Department of Physics (PHY) offers four Biological Physics Specialist streams. The B&CB program emphasizes computational methods and molecular applications, whereas the QBio Major emphasizes the application of diverse quantitative approaches to diverse biological subdisciplines. The STA and PHY programs are not life science programs, but they offer extensive quantitative training. Major programs in the life sciences, on the other hand, require at most 1.5 FCE of quantitative training in mathematics, statistics, or computer science (including the Genome Biology Major offered jointly by CSB, EEB, and Molecular Genetics [MGY]). The QBio Major aims to achieve the goal of providing rigorous quantitative training in a life science program by requiring 3.0 FCE in quantitative courses and by only incorporating biology courses that include a substantial quantitative component at the 300+ level (2.0 FCE required). We aim for this quantitative training to be broad-based, with roughly equal emphasis on analytical mathematic, statistical, and computational perspectives both in the core coursework and in the application of quantitative approaches to biological topics.

Distinguishing features:

A novel feature of the proposed program is that it aims to bring together the rich diversity of quantitative biology courses from across A&S under a common umbrella of student academic experience. This includes drawing course options from 10 departments (Cell & Systems Biology (CSB), Computer Science (CSC), Ecology & Evolutionary Biology (EEB), Geography & Planning (GGR), Mathematics (MAT), Physics (PHY), Psychology (PSY), and Statistical Sciences (STA) in Arts & Science, as well as A&S courses in Biochemistry (BCH) and Molecular Genetics (MGY) administered through the Faculty of Medicine). Some of these course options will only be accessible to students with appropriate pre-requisite courses and would therefore be most suitable for students choosing QBio as a major in combination with a second major offered by one of those units. Despite what superficially seems like a constraint on course selection, the program completion requirements are structured in a flexible way to provide students multiple pathway options to successfully complete the QBio Major in combination with any one of these other complementary programs. This low-overhead promotion of cross-disciplinarity is a unique feature, and a strength of the program.

4 Streams

- Description of streams, if any.

The QBio major does not have distinct streams. However, a number of potential "pathways" have been developed for students to demonstrate how it can be coupled with another major according to students' chosen areas of focus (see Appendix F).

5 Need and Demand

- Provide a brief description of the need and demand for the proposed program focusing, as appropriate, on:
  - student interest
  - societal need
  - employment opportunities for prospective graduates
  - interest expressed by potential employers
  - professional associations
  - government agencies or policy bodies and how this has been determined.
  - How is the program distinct from other programs at U of T? (Address, if relevant, how this program might affect enrolment in other related programs offered here.)
  - With specific reference to the impact on need and demand, describe how the proposed program relates to (is similar to or different from) existing programs offered by other universities in North America and Internationally (with specific reference to Canadian and Ontario examples). In doing this you may wish to append a table showing other programs.

Student interest:

We foresee the QBio Major as an important and attractive program for students, both independently and as a bridge between disciplines. It will provide a superb complement to students with a second major in other life science programs (e.g. EEB, HMB [Human Biology], CSB, BCH, MGY, PSY) as well as for students whose primary major is in heavily quantitative disciplines (MAT, STA, CSC, PHY). In a Spring 2017 online survey of undergraduates enrolled in at least one program administered by EEB, conducted as part of a departmental UTQAP self-study, 51% of 193 respondents indicated that they would be "possibly" or "definitely" interested in a Quantitative Biology Major program. This same survey found that over 70% of students would "possibly" or "definitely" be interested in "quantitative skills" courses. In-person responses in a student focus group suggested that students perceived that a QBio major could prepare them for diverse career options and/or post-graduate training. Importantly, QBio would provide a clear and fruitful path for students who enter life sciences aiming for medical school, but who do not find themselves on a realistic trajectory for acceptance into medical school.

Societal need:
Recent technological advances in the acquisition and analysis of biological data, ranging from the genomes of emerging pathogens to global forest depletion, require quantitative thinking and analytical approaches. Moreover, decision-makers require inferences from these data and analyses to address many of society's most pressing needs, ranging from the ecological consequences of global change to the control of emerging infectious diseases to genomic interpretation for personalized medicine.

Career opportunities for prospective graduates:
Graduates of this program will understand how the biological underpinnings of life present a host of scientific problems that are both intellectually challenging and critical to our future, and how to solve them with quantitative reasoning. Their studies will include a broad array of approaches – including molecular studies, laboratory experiments, computer and mathematical modeling, and statistical analysis – as well as opportunities to conduct independent research projects. They will be well-positioned to pursue careers in medicine, universities, colleges, consulting firms, hospitals, government and non-governmental agencies, private industry, clinical and non-clinical research labs, information technology, biotechnology, bioinformatics, pharmaceutical industries, and public utilities. With emerging tech sector job shortages, graduates with quantitative skills will be especially competitive in the job market. This program also provides a strong foundation for graduate studies and professional programs in medicine, dentistry, nursing and other health sciences, veterinary medicine, and forensic science. We anticipate that students graduating with an Hons. BSc in Quantitative Biology would be very attractive to post-graduate programs including medical school, public health, and graduate programs (including the MGY computational biology PhD, EEB, and CSB).

Similar programs at other universities:
McGill offers a "Quantitative Biology Major" as well as joint major programs between Biology and either Mathematics or Computer Science. Based on the number of required credits (73 credits), the McGill Quantitative Biology Major appears to be most analogous to a "Specialist"

program at U of T. As such, the McGill program requires a greater number of courses in each of the constituent disciplines. The McGill program currently appears to be unique within Canada.

Other examples of Quantitative Biology Majors are offered by the University of Southern California (USC, started in 2017), University of North Carolina – Chapel Hill (UNC), and Australian National University (ANU), and a "Quantitative and Computational Biology Major" is offered at Stanford. Other schools that offer QBio programs appear to emphasize individual quantitative subdisciplines (e.g., bio-math at McMaster, York, University of Delaware, and University of Pennsylvania; or on computational biology at U of T's existing B&CB program as well as MIT and Cornell).

Distinctiveness and relationship to other programs at U of T:
The proposed QBio Major program shares the theme of integrating quantitative and biological disciplines as in the **Bioinformatics & Computational Biology (B&CB) Specialist** limited-enrolment program administered by CSB (and for which EEB is a co-sponsor). However, the mission and learning outcomes of the QBio and B&CB programs are distinct, in addition to their differentiation as major (8.0 FCE) versus specialist (12.5 FCE) programs of study and tuition fees (B&CB is a deregulated fee program). Specifically, the B&CB program emphasizes the molecular-level of life sciences to (per its program description) "balance[e] computer-science and life-science courses…designed to prepare students for graduate studies in the field." In contrast, the QBio program is less specialized, being designed to infuse students with diverse life science concepts across levels of biological organization, from genomes to ecosystems, coupled to broad-based quantitative thinking and approaches from applied mathematics, statistics, as well as computer science. Thus, while QBio will prepare students for graduate studies in quantitative biology, it is suited to a broader range of research topics and careers. The course requirements and options also clearly differentiate these programs in terms of statistics, computer science, and biology courses (see Table 1). In total, 5.5 FCE of required courses are unique to one program or the other, and there are more than 20 FCE worth of course options which differ between the programs. EEB continues to support the success of the B&CB Specialist program and we feel confident that students will recognize the distinct aims and requirements of the two programs, from the program descriptions, course requirements, and the mentorship strategies operated by CSB and EEB. University of Toronto Mississauga (UTM) also offers a Bioinformatics Specialist program, similar in scope to B&CB. We identified no similar program offered by University of Toronto Scarborough (UTSC).

Table 1: Course requirements of B&CB Specialist vs. proposed QBio Major

	B&CB Specialist	QBio Major
Statistics	0.5+ FCE	1.0+ FCE
Computer Science	3.5+ FCE	0.5+ FCE
Biology	2.0+ FCE	3.0+ FCE

The **Biological Physics Specialist (BPS)** program offered by the Department of Physics, within A&S, also shares the theme of interdisciplinarity with life sciences, with three biological streams available (biochemistry, immunology, and physiology). The course requirements are very distinct from QBio, although they share some introductory biology and mathematics courses. Some upper-year course options also overlap, including a Physics course and several Mathematics courses. No courses from Statistics or Computer Science or EEB are part of the BPS programs. Therefore, the QBio program should not exert any impact on course enrolments for BPS. UTM also offers a Biomedical Physics program similar in scope to BPS. Given that UTSG and UTM draw from different pools of undergraduate students, enrolments in QBio will have no impact on those at UTM.

The **Specialist in Statistical Science: Methods and Practice (SSS)**, offered by the Department of Statistical Sciences within A&S, is a limited-enrolment program that has several life science “focuses,” including in EEB. The SSS program with a focus in Ecology or in Evolutionary Biology places primary emphasis on statistical training, with a secondary application to these particular life sciences (analogous to the CSB B&CB Specialist’s extra emphasis on computing and genome informatics). The distinction of specialist (SSS) versus major (QBio) program also clearly distinguishes these programs; students taking the QBio major will need to combine it with at least one other program in order to graduate. UTM also offers an Applied Statistics Specialist program that is similar in scope to SSS. The Department of Statistical Sciences signalled their strong support for the QBio Major program.

The **Genome Biology Major** program (administered by the Department of Cell & Systems Biology and co-sponsored by EEB) also incorporates some quantitative training into its requirements. However, it is distinct from QBio in that Genome Biology requires just 1.5 FCE of quantitative courses (1.0 FCE math plus 0.5 FCE stats vs. 2.5 FCE math/statistics/computer science plus 0.5 FCE upper-year requirement), and Genome Biology includes no upper-year course options in Mathematics, Statistics, or Computer Science. Its emphasis on genomics also means that upper-year courses primarily fall within the molecular biological subdisciplines (courses through CSB, MGY, and some EEB), though it shares with QBio some course options in bioinformatics (e.g., CSB352H1 andCSB472H1). Consequently, we do not anticipate any impact on course or program enrolments in Genome Biology induced by creation of the QBio Major. The Department of Cell & Systems Biology also voiced strong support for the QBio Major program. We identified no similar program at UTM or UTSC.

6 Enrolment

- Provide details regarding the anticipated yearly in-take and projected steady-state enrolment target including a timeline for achieving it. Include approximate domestic/international mix. (Please adjust the table as necessary.)
- Please provide an explanation of the numbers shown and their relation to the Faculty/division's enrolment plan. Please be specific where this may differ from approved enrolment plans.

Anticipated yearly in-take and projected steady-state enrolment:
We anticipate a steady-state enrolment of ~100 students in the QBio Major (see Table 2). For comparison, the EEB Major has ~200 students, Biology Major has ~300 students, Genome Biology Major has ~120 students, Fundamental Genetics Major has ~250 students, and Human Biology Major has ~750 students. The Bioinformatics & Computational Biology Specialist has ~100 students, Applied Statistics Specialist has ~180 students, Biological Physics Specialist has ~75 students.

The key limiting factor on enrolment capacity for the proposed QBio Major would be the program requirement of 0.5 FCE of 15 possible 400-level courses. The 400-level courses tend to have small class sizes and, in some cases, depend on students having appropriate pre-requisites from their second major. The inclusion of 15 possible courses, with many options in EEB where students will have priority enrollment, is comparable to offerings in specialist programs and will be more than sufficient to accommodate the approximately 35 4^{th} year students in the QBio Major.

Relation to Faculty and Division Enrolment plan:
Anticipated enrolment is within the current capacity of EEB. Given the large numbers of students and high demand in many quantitative departments in A&S (e.g., the Department of Statistical Sciences administers >3,000 students), we expect our modest enrollment projections to have a minimal impact. Enrolment has been discussed with the A&S Dean's

office and is accounted for in the overall plan for the Faculty. We expect the QBio program to appeal to both domestic and international students.

Table 2: Anticipated enrolment by academic year, 2021-22 to 2027-28 (steady state is expected to be reached by approximately 2025-26).

Level of Study	2021-22	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28
1st year	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2nd year	15	25	30	30	30	30	30
3rd year	10	20	30	35	35	35	35
4th year	0	10	25	30	35	35	35
Total enrolment	25	55	85	95	100	100	100

7 Admission Requirements

- Provide formal admission requirements as they will appear in the undergraduate calendar or other official admissions materials.
- Explain how the program's admission requirements are appropriate for the learning outcomes established for completion of the program.
  - How will they help to ensure students are successful?
  - Provide sufficient explanation of any additional requirements for admission to the program such as minimum grade point average, special language, portfolio, etc. (and how the program recognizes prior work or learning experience, if applicable).
- Is this a direct-entry or indirect-entry program; please explain.

QBio will be a limited-enrolment program to ensure that course capacity will enable all students enrolled in the program to complete the program requirements. Initially, entry requirements will be a minimum grade of 70% (B-) in an introductory biology course (BIO120/ BIO130) and in an introductory quantitative course (CSC108H1/ CSC120H1/CSC148H1/CS110Y1/MAT135H1/MAT136H1/MAT137Y1/MAT157Y1). Should capacity or student demand differ from projections, then future adjustments to entry requirements or to an open-enrolment program could be addressed through Curriculum

Committee governance. Completion requirements include 2.5 FCE in the first year of studies in Biology, Computer Science, and Mathematics. We therefore expect that many QBio students would come from the life sciences, physical and mathematical sciences, and computer science admission streams.

The entry requirements are designed to 1) ensure students have the background and interest in biology and quantitative disciplines to pursue QBio, and 2) assess that they have had sufficient academic success (minimum B-) in biology and at least one quantitative course to ensure that they can be successful in courses specializing in both areas.

8 Program Requirements, Learning Outcomes, Degree-Level Expectations (DLEs) & Program Structure

- In a curriculum map, or in the table below, or in another format appropriate for the discipline, state the program learning outcomes and program requirements, and show how the program learning outcomes are appropriate for the degree-level expectations.
- Discuss how the design, structure, requirements and delivery of the program are appropriate for the program learning outcomes and degree-level expectations.
  - The sequencing of required courses or other learning activities, etc.
  - The mode of delivery of the program (face-to-face; blended or online; placement, etc.) and how it is appropriate to support students in achieving the learning outcomes of the program and the degree-level expectations.
  - Describe how the specific elements of the curriculum (e.g., Internships, etc.) will be administered.
  - A clear indication of how faculty “scholarship and research is brought to bear on the achievement of Degree-Level Expectations” (UTQAP 1.1).

  Describe how the program structure and delivery methods reflect universal design principles and/or how the potential need to provide mental or physical health accommodations has been considered in the development of this program.

The QBio Program has been designed with the philosophy that the integration of biological principles and quantitative methods are inseparable for students to become proficient in the field. For a biology-statistics QBio route, for example, students should not be learning biological hypotheses and facts without thinking critically about the statistical approaches used to test them and, similarly, they should be learning statistical techniques with specific ideas of how and when they can be applied in a biological context. The subset of EEB courses that we consider in our proposal (about ¼ of all EEB courses) were selected because they address the PLOs of QBio, with all courses specifically designed for PLOs 1 and 8 (Demonstrate Knowledge in QBio and Apply QBio Approaches to Represent Biological Phenomena; all PLOs defined below). We use a similar scaffolding for many of our PLOs, so that students integrate their biological knowledge with the societal implications of this knowledge (PLOs 7 and 9); build communication skills and team work simultaneously (PLOs 4 and 5); and build capacity in evaluating biological hypotheses and quantitative approaches used for this evaluation concurrently (PLOs 2 and 10). This integration of biological, quantitative, and methodological knowledge is a key strength of the QBio program.

The Degree-level expectations, program learning outcomes, and delivery are outlined in Table 3. The curriculum map (see Tables 4a and 4b) provides course-level details and evaluation methods.

The Program Learning Outcomes (PLOs) are:

- PLO1: Demonstrate advanced knowledge and practice of scientific methodology and biological techniques
- PLO2: Critically evaluate biological information and hypotheses
- PLO3: Apply the process of scientific inquiry through hypothesis generation and testing in laboratory or field settings
- PLO4: Communicate scientific principles clearly and concisely through oral presentation, writing, or in graphical representations of biological information
- PLO5: Solve biological problems as part of a team or with collaborators
- PLO6:Demonstrate knowledge of cellular, ecological, and evolutionary processes governing the diversity of life
- PLO7: Demonstrate knowledge of the levels of biological organization and their interconnection from molecules to organisms to populations to ecosystems
- PLO8: Apply mathematical, statistical, or computational approaches to solve biological problems and to represent ecological and evolutionary ideas
- PLO9: Demonstrate knowledge of the relevance and importance of ecological and evolutionary principles in society
- PLO10: Critically evaluate quantitative approaches for testing scientific hypotheses.

Table 3: DLEs, Program Learning Outcomes & Requirements

Degree-Level Expectations	Program Learning Outcomes*	How the Program Design/Structure of the required courses and other learning activities supports the achievement of Program Learning Outcomes
1. **Depth and Breadth of Knowledge** **Depth of Knowledge:** Students will achieve mastery of a topic which is characterized by several of the following traits: understanding of advanced subject material as determined by those in the discipline or interdisciplinary area of study; command of increasingly advanced material that progressively probes (an aspect of) the subject more thoroughly; competence in using the scholarly materials and research tools relevant to the discipline or interdisciplinary areas of study; ability to produce a substantial research or inquiry-based work; and capacity to draw together a broad range of prior learning and apply it to a challenging problem or topic. **Breadth of Knowledge:**	**In Quantitative Biology, Depth and Breadth of Knowledge is understood as:** • Recognizing that all life has evolved and that an understanding of the central question of the origin and maintenance of diversity – from cells to genomes to ecosystems – underlies all life sciences and is critical to our stewardship of life on this planet. • Understanding that the diversity of life at all levels of organization is structured through common processes that occur at each level, from cellular processes and their resulting functions, to evolution of populations and species, to species interactions with the environment and each other. • Obtaining an in-depth understanding of the quantitative methods used to model patterns of diversity, the processes that create them and their functions.	The program design and requirement elements that ensure these student outcomes for depth and breadth of knowledge are: In the first two years, to support depth and breadth of knowledge, students are exposed to diverse courses in math, biology, and statistics. In keeping with QBio methods, these introductory courses expose students to lab work, classical assessment of knowledge through tests and exams, and to written assignments designed to familiarize students with scientific literature and introduce critical thinking. At the intermediate level (typically 2nd and 3rd year courses with more specialized topics), students delve into specific knowledge and topics in QBio. These range from intermediate stats, programming, and math courses to QBio courses that have greater emphasis on either the biological or quantitative aspects of the field. Each of these courses focuses on a specific area of expertise, with methods introduced and evaluation targeted for the expertise.

Students will gain an appreciation of the variety of modes of thinking, methods of inquiry and analysis, and ways of understanding that underpin different intellectual fields. They will further develop an understanding of how various areas of study intersect and allow for complementary insights on common issues or problems.	• Attaining in-depth knowledge of scientific and biological methodologies used to generate and evaluate biological information. **This is reflected in students who are able to:** • Demonstrate advanced knowledge and practice of scientific methodology and biological techniques (PLO1); • Critically evaluate biological information and hypotheses (PLO2); • Demonstrate knowledge of cellular, ecological, and evolutionary processes governing the diversity of life (PLO6); • Demonstrate knowledge of the levels of biological organization and their interconnection from molecules to organisms to populations to ecosystems (PLO7) • Apply mathematical, statistical, or computational approaches to solve biological problems and to represent ecological and evolutionary ideas (PLO8)	At the senior level, students are required to take an integrated quantitative biology or research experience course. Examples of the types of activities in these courses include designing and analysing mathematical models of biological processes, designing and implementing an experiment and appropriate statistical method to test a biological hypothesis, and writing a scientific paper that characterizes the state of knowledge of the published literature and how their research add to this knowledge.
2. **Knowledge of Methodologies** Students will have a working knowledge of different methodologies	**In Quantitative Biology, Knowledge of Methodologies is understood as:**	The program design and requirement elements that ensure these student outcomes for knowledge of methodologies are:

and approaches relevant to their studies, and will be able to justify their choices among them when addressing questions that arise in their area of study.	Having been exposed to a broad array of scientific approaches used in modeling biological patterns and processes, from statistical to mathematical modeling, and having the opportunity to develop an in-depth understanding of statistical or mathematical modeling of a biological pattern and process, through advanced courses and independent research projects. Also having been exposed to a broad array of scientific approaches used in gathering data, from lab to field techniques. **This is reflected in students who:** Apply the process of scientific inquiry through hypothesis generation and testing in laboratory or field settings (PLO3); Apply mathematical, statistical, or computational approaches to solve biological problems and to represent ecological and evolutionary ideas (PLO8); and critically evaluate quantitative approaches for testing scientific hypotheses (PLO10).	In the first two years, broad exposure to laboratory techniques, mathematical models, and statistical methods for testing hypotheses. Examples of introductory-level elements include labs in which students apply simple statistical tests, distinguish between statistical and biological hypotheses, and apply classic mathematical models. At the intermediate level, students gain exposure to more developed statistical and mathematical tools, as these tools are important components of quatitative biology. Similarly, students have the option of programming courses, including through EEB, which provides the link between biological hypothesis testing, data manipulation, data visualization, and statistical hypothesis testing. Upper-year courses focus on quantitative methods with a biological application, as well as research courses or quantitative biology courses in which students develop the ability to formulate quantitative methods specific to a biological problem or hypothesis. Evaluation at each level is typically performed with lab/practical assignments that include mathematical solutions, programming, and so on, as well as exam-based assessments of knowledge. At upper levels, evaluation typically focuses on project-based assignments that assess knowledge of the field, as well as choice of method and success at its implementation.

3. **Application of Knowledge** Students will be able to apply their knowledge and understanding in such activities as: analyzing and evaluating material in their areas of study; developing effective arguments or interpretive approaches; forming hypotheses and posing questions relevant to their fields; crafting solutions to problems, collecting appropriate data, or interpreting novel situations and materials.	**In Quantitative Biology, Application of Knowledge is understood as:** Having the opportunity to apply QBio knowledge and methods to current and classic questions in biology, and having the opportunity to apply statistical or mathematical modeling of a biological pattern and process, through advanced courses and independent research projects. **This is reflected in students who:** Apply the process of scientific inquiry through hypothesis generation and testing in laboratory or field settings (PLO3); solve biological problems as part of a team or with collaborators (PLO5); and apply mathematical, statistical, or computational approaches to solve biological problems and to represent ecological and evolutionary ideas (PLO8).	The program design and requirement elements that ensure these student outcomes are: In the first two years, introductory courses expose students to exercises designed to apply knowledge learned in class, develop biological hypotheses, and apply basic mathematical and statistical models. These are designed for individual student projects as well as group projects in which students develop and present their approaches and findings as a team. At the intermediate level (typically 2nd and 3rd year courses with more specialized topics), students delve into specific knowledge and topics in QBio. These range from intermediate stats and math courses to QBio courses that have greater emphasis on integrating the biological or quantitative aspects of the field. Each of these courses focus on a specific area of expertise, with methods introduced and evaluation targeted for the expertise. A typical example would involve using mathematical modeling to test a classic hypothesis in evolutionary biology and to further propose new hypotheses. Many intermediate courses use labs and larger course projects to teach students to craft solutions to biological problems, including through analysis of student-collected data and publicly-available datasets, construction of mathematical and statistical models to

		biological data, and application of statistical and computational algorithms. These projects are frequently team-based. At the mastery level in 4th year courses, this application process may include self-directed projects and independent-research projects. At this level, hypothesis development and testing is undertaken through mentorship with a supervisor, and typically involves a careful reading of recent literature and one-on-one discussion. Integration of team-based learning is formally accomplished through course work that teaches and practices techniques like peer review, as well as through informal learning that occurs when students interact with the lab group of their supervisor. The specific quantitative approach used in this research varies by supervisor and student, but always involves mathematical, statistical, or computational methods and frequently integrates multiple approaches.
4. **Communication Skills** Students will be able to: organize ideas into coherent arguments supported by appropriate kinds of evidence; structure their communications for varying audiences and contexts; produce effective written work; present their work orally or visually where appropriate to the area of study.	**In Quantitative Biology, Communication Skills is understood as:** Opportunities for students to develop their oral and written communication skills, including data visualization and presentation skills. In addition, opportunities for students to critically and constructively evaluate their own work as well as the work of peers.	The program design and requirement elements that ensure these student outcomes are: Communication skills are integrated into student learning and evaluation at all levels. In QBio, it is not possible to develop professional written and oral skills without first teaching skills in graphical representation of data (representation is the core around which the written and oral communication is built). Even the

	This is reflected in students who: Communicate scientific principles clearly and concisely through oral presentation, writing, and graphical representations of biological information (PLO4); and solve biological problems as part of a team or with collaborators (PLO5)	separation of oral and written communication is nuanced in that the scientific standard for structuring communication is identical in both cases. These skills, and the knowledge of how they apply to QBio, are taught through role modeling and presentation of data, concepts, and hypotheses in all courses. For example, presentation of statistical tests and summary data (central tendencies and measures of spread) are integral to DLE 1, 2 and 5. The courses listed for PLOs 4 and 5 (see Table 4b) focus on student communication skills, rather than the role modeling of communication norms for QBio that are typical of all courses. For junior students, this includes written assignments in standard scientific formats that are evaluated on both content and clarity, with feedback designed to allow students to revise and resubmit assignments. In mid- and upper-year courses, scientific debates and presentations are used in several courses, with the latter typically following the protocols of scientific conferences in biology (15-20 minute presentations with PowerPoint visuals of graphics, etc.). In several courses, presentations follow individual or group-focused presentation development, a process that provides structured feedback to students on the components of their presentations. Courses that integrate projects incorporate activities to build learning through clear data visualization, including summary graphs, data plots,

		appropriate representation of summary statistics (mean, median, error bars), and infographics. Evaluation of Communication Skills provides specific feedback on elements of communication and how student work meets, or fails to meet, high standards of communication. Group skills follow a similar approach, where communication and coordination among team members may include within-team presentations (e.g., walking a team through a mathematical solution) or formalized sharing approach (e.g., using GitHub to share and co-edit computer code). Upper-level research courses typically teach and require three formats of scientific communication: formal written presentations (scientific paper format), visual and oral one-on-one presentations (poster fair presentations), and group visual and oral presentations (PowerPoint presentations). These communication skills are taught formally in upper-level research courses through instructor and peer evaluation, and also informally through participation in the activities of a supervisor's lab group, where students are evaluated by their peers and graduate students and observe role models (graduate student and supervisor).
5. **Awareness of Limits of Knowledge** Students will gain an understanding of the limits to their own knowledge and to the knowledge within their areas of	**In Quantitative Biology, Awareness of Limits of Knowledge is understood as:** • Critically evaluating biological scientific information and the quantitative	The program design and requirement elements that ensure these student outcomes for awareness of limits of knowledge are:

study. They will also gain an appreciation of how uncertainty and ambiguity might influence analyses and interpretations.	(methodological) approaches used to obtain this information. Students should be able to use this information to generate hypotheses, assess whether evidence supports their conclusions and the conclusions of others, and to solve problems. • Appreciating that knowledge about mechanisms of change in biological systems requires theoretical and empirical approaches and the application of scientific hypothesis testing across a range of phenomena in the biological hierarchy; and that the identification of recurrent patterns of variation across different spatial and temporal scales is more likely to lead to general conclusions than the ad hoc collection of facts from individual case histories. • Understanding that ecological and evolutionary change in biological systems requires a multidisciplinary approach and the integration of information from different levels in the hierarchy of life, from cells to genes, organisms, and ecosystems; and that a focus on any one level will often fail to provide	In junior and mid-level courses, awareness of limits of knowledge are taught through three approaches. First, students are taught critical thinking and critical assessment of the scientific literature, which is a necessary step to understanding how knowledge develops, is challenged, and ultimately grows. This critical thinking is encouraged through debate-style interactive learning, as well as through hypothesis development and testing. Second, many courses use an historical approach to explain subject-specific development of ideas and knowledge, with an emphasis on current knowledge and how it is likely to change. Examples of this historical approach include several developments that have come to light through new laboratory and quantitative approaches, such as new understanding of macroevolutionary relationships. Third, intermediate courses expose students to topics not covered in the course but that nonetheless provide more in-depth understanding of topics. Examples include providing overviews of more advanced mathematical or statistical approaches, exposure to advanced mathematical or simulation models that provide different or more nuanced understanding of the subject matter, and introductions to associated fields of research that are not covered within courses. Upper-level courses, such as research courses and quantitative biology courses, integrate these

	comprehensive insight. Similarly, multidisciplinary quantitative approaches, from mathematical modeling and prediction to statistical modeling and pattern detection, provide distinct and important understanding of biological processes and patterns that are all necessary to provide comprehensive insight. **This is reflected in students who:** Critically evaluate biological information and hypotheses (PLO2); Critically evaluate quantitative approaches for testing scientific hypotheses (PLO10); Demonstrate knowledge of the relevance and importance of ecological and evolutionary principles in society (PLO9).	approaches by 1) requiring students to place their research or topic of study in the broader scientific literature, 2) requiring that students clearly explain the advances and limits of their research projects/topics of study, and 3) requiring that students communicate their research projects/topics of study in accessible language that clarifies the broader importance to society.
6. **Autonomy and Professional Capacity** Students will develop competencies critical to their pursuit of further study, employment, community involvement, and other activities that require life-long learning, decision-making, and personal and social responsibility.	**In Quantitative Biology, Autonomy and Professional Capacity is understood as:** • Possessing a comprehensive understanding of fundamental biological principles so that they can make informed decisions on pressing societal issues that include gene therapy and genetic testing, reproductive	The program design and requirement elements that ensure these student outcomes for autonomy and professional capacity are: Key courses in quantitative biology develop competencies for employment, life-long learning, and social responsibility. Junior and intermediate courses focus on building the skill and knowledge base required

	technologies, genetic engineering, stem cell research, population growth, emerging diseases, global environmental change, and the conservation of biological diversity. • Understanding the link between the Quantitative Biological knowledge and its application. Students should have the background necessary to continue expanding their biological and quantitative knowledge and be able to apply this knowledge to novel questions and problems. **This is reflected in students who:** Solve biological problems as part of a team or with collaborators (PLO5); and Demonstrate knowledge of the relevance and importance of ecological and evolutionary principles in society (PLO9).	for employment, including basic biological knowledge and quantitative skills. These courses also introduce personal and social responsibility by exploring the relevance of this basic knowledge to current and emerging societal issues, such as species conservation and biodiversity loss, emerging diseases, genetic testing, and gene therapy. Upper-level courses focus more strongly on employment skills, life-long learning, and decision-making by providing students with opportunities to develop research projects and synthesize research topics. These opportunities emphasize many working relationships: independent research, idea and research development with the support of mentors (peer-to-peer and research supervisors), and through formal (structured) and informal (lab group) discussions and collaborations. The emphasis is threefold. First, students learn to develop the skills necessary for accomplishing the task at hand and, through this example, build an employable skillset and create a blueprint for life-long learning. Second, they learn the challenges and benefits of social working conditions and relationships, which allows them to better understand their strengths and preferences, and develop an understanding of when different approaches (e.g., independent versus group work) are most useful. Third, advanced topics and research in quantitative biology frequently deals with

		social and ethical issues. The many working relationships involved in upper-level courses serve to develop personal and social responsibility by ensuring discussion of these issues with mentors and peer groups through structured and casual interactions.

* PLO numbering is consistent with the list above and the QBio Curriculum Map (Table 4b).

Table 4a: Program Learning Objectives with examples of activities and methods of evaluation

PLO 1 Demonstrate knowledge and practice of scientific methodology and biological techniques	**PLO 2** Critically evaluate biological information and hypotheses	**PLO 3** Apply the process of scientific inquiry through hypothesis generation and testing in laboratory or field settings	**PLO 4** Communicate scientific principles clearly and concisely through oral presentation, writing, or in graphical representations of biological information	**PLO 5** Solve biological problems as part of a team or with collaborators	**PLO 6** Demonstrate knowledge of cellular, ecological, and evolutionary processes governing the diversity of life	**PLO 7** Demonstrate knowledge of the levels of biological organization and their interconnection from molecules to organisms to populations to ecosystems	**PLO 8** Apply mathematical, statistical, or computational approaches to solve biological problems and to represent ecological and evolutionary ideas	**PLO 9** Demonstrate knowledge of the relevance and importance of ecological and evolutionary principles in society	**PLO10** Critically evaluate quantitative approaches for testing scientific hypotheses
Activities: Coverage in lectures or lab practicals of the methods used to extract scientific information about biological systems	**Activities:** Thoughtful and critical discussions during tutorial, class time, or lab practical of original scientific literature	**Activities:** Application in lab or field practicals of the scientific method to set hypotheses and gather data to test them	**Activities:** Student oral presentations, essay-length writing assignments, data presentation in slides or poster or reports	**Activities:** Group or team assignments, collaboration with grad student mentor, inverted classroom participation	**Activities:** Coverage of cellular, ecological, and evolutionary processes that contribute to the origin and maintenance of biodiversity, and its functions	**Activities:** Coverage in lectures or lab practicals: biodiversity, genetic variation, organismal biology, molecular biology	**Activities:** Application of math/ stats/ computing techniques in lab or field practicals, or detailed coverage of quantitative topics in lecture	**Activities:** Detailed coverage in lectures or lab practicals of the interconnection between science and human society	**Activities:** Thoughtful and critical discussions of original scientific literature. Use of theory, simulation, or comparative analysis to evaluate effectiveness of different approaches.

PLO 1 Demonstrate knowledge and practice of scientific methodology and biological techniques	**PLO 2** Critically evaluate biological information and hypotheses	**PLO 3** Apply the process of scientific inquiry through hypothesis generation and testing in laboratory or field settings	**PLO 4** Communicate scientific principles clearly and concisely through oral presentation, writing, or in graphical representations of biological information	**PLO 5** Solve biological problems as part of a team or with collaborators	**PLO 6** Demonstrate knowledge of cellular, ecological, and evolutionary processes governing the diversity of life	**PLO 7** Demonstrate knowledge of the levels of biological organization and their interconnection from molecules to organisms to populations to ecosystems	**PLO 8** Apply mathematical, statistical, or computational approaches to solve biological problems and to represent ecological and evolutionary ideas	**PLO 9** Demonstrate knowledge of the relevance and importance of ecological and evolutionary principles in society	**PLO10** Critically evaluate quantitative approaches for testing scientific hypotheses
Methods of Assessment: Practical exercises, including laboratory and computer assignments. Exam questions testing knowledge of methodology.	**Methods of Assessment:** Oral presentations and discussion-based evaluation. Written critiques of literature. Oral and written presentation of students' research.	**Methods of Assessment:** Written assignments specifying hypothesis and testing methods. Exam questions linking hypotheses to specific tests. Laboratory exercises and lab reports of specific hypotheses and empirical tests.	**Methods of Assessment:** Oral presentations and discussion-based evaluation. Written critiques of literature. Oral, written and poster presentation of students' research.	**Methods of Assessment:** Group-based laboratory, analytic, or computer-based assignments typically involving independent group meetings and discussion, group presentations, and individual written reports.	**Methods of Assessment:** Written assignments requiring demonstration of knowledge. Exam questions testing knowledge of cellular, ecological, or evolutionary processes and their consequences.	**Methods of Assessment:** Written assignments requiring synthesis of knowledge across levels of organization. Exam questions testing knowledge of cellular, ecological, or evolutionary processes and their consequences.	**Methods of Assessment:** Practical assignments, including analytic and computer assignments. Exam questions testing knowledge of methodologies and their applications.	**Methods of Assessment:** Oral presentations, discussion-based evaluation, and written critiques of literature that evaluate the ability to link course materials and primary literature to current social issues.	**Methods of Assessment:** Practical assignments, including analytic and computer assignments, aimed at comparing quantitative approaches. Oral presentations and discussion-based evaluation. Written critiques of

PLO 1 Demonstrate knowledge and practice of scientific methodology and biological techniques	**PLO 2** Critically evaluate biological information and hypotheses	**PLO 3** Apply the process of scientific inquiry through hypothesis generation and testing in laboratory or field settings	**PLO 4** Communicate scientific principles clearly and concisely through oral presentation, writing, or in graphical representations of biological information	**PLO 5** Solve biological problems as part of a team or with collaborators	**PLO 6** Demonstrate knowledge of cellular, ecological, and evolutionary processes governing the diversity of life	**PLO 7** Demonstrate knowledge of the levels of biological organization and their interconnection from molecules to organisms to populations to ecosystems	**PLO 8** Apply mathematical, statistical, or computational approaches to solve biological problems and to represent ecological and evolutionary ideas	**PLO 9** Demonstrate knowledge of the relevance and importance of ecological and evolutionary principles in society	**PLO10** Critically evaluate quantitative approaches for testing scientific hypotheses
									literature. Oral and written presentation of students' research.

Table 4b: Curriculum map detailing QBio courses offered by EEB and the Program Learning Objectives they meet.

EEB Course	Course Title	PLO 1	PLO 2	PLO 3	PLO 4	PLO 5	PLO 6	PLO 7	PLO 8	PLO 9	PLO10
Levels of Mastery: 1 = Introduce 2 = Develop 3 = Master		Demonstrate knowledge and practice of scientific methodology and biological techniques	Critically evaluate biological information and hypotheses	Apply the process of scientific inquiry through hypothesis generation and testing in laboratory or field settings	Communicate scientific principles clearly and concisely through oral presentation, writing, or in graphical representations of biological information	Solve biological problems as part of a team or with collaborators	Demonstrate knowledge of cellular, ecological, and evolutionary processes governing the diversity of life	Demonstrate knowledge of the levels of biological organization and their interconnection from molecules to organisms to populations to ecosystems	Apply mathematical, statistical, or computational approaches to solve biological problems and to represent ecological and evolutionary ideas	Demonstrate knowledge of the relevance and importance of ecological and evolutionary principles in society	Critically evaluate quantitative approaches for testing scientific hypotheses
Introductory biology/EEB/genetics and statistics[1]											
BIO120H1	Adaptation & Biodiversity	1	1	1	1	1	1	1	1		1
BIO220H1	Genomes to Ecosystems in a Changing World	1	1	1	1	1	1	1	1	1	1
EEB225H1	Biostatistics for Biological Sciences	2	1	1	2				1		1
Intermediate to advanced biology with quantitative component[2]											
EEB319H1	Population Ecology	2	2	2		2	2	3	2	2	2
EEB321H1	Community Ecology	2	2	2	2		2	3	2	2	2
EEB323H1	Evolutionary Genetics	2					2	3	2		2
EEB324H1	Evolutionary Ecology	2	2		2		2	2	2		2

EEB Course	Course Title	PLO 1	PLO 2	PLO 3	PLO 4	PLO 5	PLO 6	PLO 7	PLO 8	PLO 9	PLO10
EEB362H1	Macroevolution	2					2	3	2		2
Quantitative methods in biology or advanced quantitative biology[3]											
EEB313H1	Quantitative Methods in R for Biology	2			2	2			3		3
EEB430H1	Theoretical Ecology	3	3	3	3	3	3	3	3	3	3
EEB459H1	Population Genetics	3					3	3	3		3
EEB460H1	Molecular Evolution & Genomics	3	3	3	3	3	3	3	3	3	3
EEB498Y1	Advanced Research Project in EEB	3	3	3	3	3	3	3	3	3	3
EEB499Y1	Advanced Research Project in EEB	3	3	3	3	3	3	3	3	3	3

1. Required courses. EEB225 (introductory statistics) may be replaced by another introductory statistics course
2. Students require 1.0 FCE. Each course listed is 0.5 FCE
3. Students require 1.5 FCE, of which at least 0.5 FCE must be at the 400 level

9 Assessment of Learning

- Appropriateness of the proposed methods for the assessment of student achievement of the intended program learning outcomes and degree-level expectations.
- Describe plans for documenting and demonstrating the level of performance of students consistent with the DLEs. (Assessment of Teaching and Learning examples in Guide to Quality Assurance Processes)

Appropriateness of the proposed methods for the assessment of student achievement of the intended program learning outcomes and degree-level expectations.
A summary of how methods of assessment are tailored to our Program Learning Outcomes are provided in the curriculum map (see Table 4a). Below, we provide further explanation, context, and examples of assessment methods.

Student assessment at all levels is tailored to the specific skills and knowledge being evaluated. In junior and intermediate courses, communication skills and critical thinking are generally assessed through written and oral presentations. In the mandatory BIO120 (Adaptation and Biodiversity), for example, students write a research proposal that is designed to teach critical thinking and limits of knowledge, knowledge of methodologies, and communication skills (DLEs 2, 4, and 5). Students receive specific training on scientific writing, citing sources, and so on, and receive feedback on a ”pre-proposal” that they can then use to improve their final submission (DLE 4). Lab projects in the same course focus on knowledge of methodologies and application of knowledge (DLEs 2 and 3), whereas depth and breadth of knowledge (DLE 1) is largely assessed through tests and exams.

Intermediate courses in quantitative biology mainly rely on computer tutorials to assess knowledge of methodologies and application of knowledge (DLEs 2 and 3), with several courses using written and oral presentations to assess communication skills (DLE 4). As with BIO120, students in these courses have access to assistance with communication skills through EEB writing TAs, who are TAs trained specifically to work with instructors to build student writing skills. In addition, beginning in autumn 2020, these courses will contribute to and use an EEB R guidebook — a resource for students who are searching for R programming background and examples for quantitative biology.

Upper-level courses in quantitative biology are a mix of research courses and applied quantitative biology. These are capstone courses that synthesize all DLEs (DLEs 1–6) but give greater emphasis to Autonomy and Professional Capacity (research courses) or Breadth of Knowledge and Application of Knowledge (applied quantitative biology).

An EEB498 research course (Advanced Research Project in Ecology and Evolutionary Biology), for example, places a large onus on the student to develop their research, test their hypotheses, and present their results. Research supervisors (and usually research labs with graduate students as well) guide students through all stages of these courses, from choosing topics that are appropriate for quantitative biology and amenable to an undergraduate study, to analysis, interpretation, and presentation of ideas. Students are assessed by research supervisors on their breadth and depth of knowledge and their ability to explain the limits of their knowledge (DLEs 1 and 5), and their knowledge and application of methodologies (DLEs 2 and 3). These are mainly assessed through their communication skills in formal oral presentations, poster presentations, and a research proposal and paper (DLE 4). The combination of these requirements, along with the emphasis on student responsibility for accomplishing them, teach autonomy and professional capacity (DLE 6).

Upper-level quantitative biology (non-research project) courses often cover a greater breadth of information but, by nature, have less autonomy. For example, EEB430 (Modeling in Ecology and Evolution) begins by introducing several approaches and questions addressed through mathematical modeling, from population modeling to stage-structured models to multi-species models and evolutionary invasion analysis. This breadth of topics, along with laboratory applications, shows a greater focus on breadth of knowledge, knowledge of methods, application of knowledge, and understanding limits of knowledge (DLEs 1, 2, 3, and 5), which are assessed through labs and a formal exam. The second portion of the course focuses on and is evaluated through 1) presenting and critiquing scientific papers on models in ecology and evolutionary biology, and 2) a small group project developing and presenting a mathematical model. The emphasis for the second half is on communication, autonomy, and professional capacity (DLEs 4 and 6). Assessment is through written papers (formal scientific paper format), ability to identify and discuss the strengths and weaknesses of published papers, their own research and the research of their peers, and through oral presentations of their research (formal scientific PowerPoint or chalkboard presentations).

Plans for documenting and demonstrating the level of performance of students consistent with the DLEs.

The level of performance of students will be assessed and documented at several levels. First, upper-level quantitative biology courses and research courses assess the contributions of lower-level courses to student performance through evaluation of pre-course knowledge and skills. This assessment by faculty is complemented by informal student assessments of "learning gaps." For example, students and faculty were recently concerned that the level of statistical programming in EEB was below that necessary for a student wishing to specialize in quantitative biology. This concern led to the creation and recent implementation of EEB313 (Quantitative Methods in R for Biology), which in turn has resulted in many students entering research courses with a strong skillset in statistical programming and data visualization.

The QBio capstone courses, including research courses and quantitative biology courses like EEB430 (Modeling in Ecology and Evolution) culminate in "end products" that are evaluated each year by faculty and are directly comparable to similar end products from other universities. For example, PowerPoint and poster presentations of research projects are discussed and compared across years, and compared to undergraduate projects presented at national and international conferences (in EEB, comparable posters would be at the Ontario Ecology, Ethology and Evolution Colloquium, and meetings held by the Canadian Society for Ecology and Evolution, the Ecological Society of America, and the American Society of Naturalists). These end products provide a direct and synthetic assessment of performance consistent with the DLEs outlined in Table 3.

The assessments described above are overseen and formally processed by the EEB department's Undergraduate Affairs Committee (UAC). The UAC meets regularly and discusses "holes" and "opportunities" in our EEB program offerings. These holes and opportunities are raised through one of five mechanisms: 1) Faculty or students can approach the EEB chair or associate chair (undergraduate) to raise issues; 2) the EEB chair and associate chair undergraduate review course evaluations to examine qualitative statements on the strengths and weaknesses of current courses and any concerns about insufficient background to take them; 3) the associate chair undergraduate reviews trends in course enrollment and shifts in course content as course instructors change; 4) the associate chair undergraduate conducts meetings with key faculty in each program to identify when and how courses can better integrate content and methodologies across courses, and to identify emerging norms in the field that should be filled with course changes or new courses; and 5) the EEB department has retreats every 1–2 years in which goals for undergraduate education are reviewed and updated, and appropriate changes to course offerings are considered. Regardless of the mechanism used to identify a need for program change or re-evaluation, the UAC develops and debates proposals for course and program modifications and these proposals are then discussed at faculty meetings. Minutes from UAC meetings, meetings of key faculty, departmental retreats, and faculty meetings (along with formal documents presented to support or refute concerns raised) are kept as documentation to evaluate success in meeting DLEs.

10 Program Description & Calendar Copy

- Provide a description of the program (audiences: prospective and current students, staff, and employers) that can be used for external and internal posting that includes the key features of the program:
  - Program's purpose (who is it for, what are the outcomes)
  - Nature of learning environment (including mode of delivery)
  - Approaches to teaching/learning/assessment
  - Basic information (e.g., FCE count, program length, etc.)
- Provide, as an appendix, a clear and full calendar copy including:
  - The program description; the program requirements including all required courses and recommended electives and their prerequisites, including for any streams.
- Provide as an appendix:
  - A full list of the all courses included in the program including course numbers, titles, and descriptions.

Please indicate clearly whether they are new/existing. (Please note that all new courses should be proposed and approved independently in line with established academic change procedures. Where possible, append full course proposals as an appendix).

Program Description:
The Quantitative Biology Major program (8.0 FCEs) is designed for students with a deep interest in biology who wish to gain a strong grounding in quantitative methods and their application to biological questions. More than ever, advancements in biology, from the molecular through the organismal to the ecosystem level, require quantitative thinking and skills along with a strong understanding of biological processes. Interdisciplinary research that draws from the natural sciences, mathematics, statistics, and computer science, is an important aspect of modern biology. This major provides foundations in biology and quantitative approaches used to test and advance biological knowledge and is appropriate

for students who wish to pursue a career or graduate studies in a broad range of life sciences, ranging from biomedical to conservation to epidemiology.

The program is delivered through a mixture of classroom-learning and applied laboratory teaching, with an emphasis on understanding how quantitative methods inform our understanding of biology, and how they can be applied to test and develop new hypotheses. Students also have access to independent research opportunities that enhance professional skills, science communication, and the development and application of knowledge in quantitative biology.

Appendix A includes a full list of the course numbers and titles. Note that only existing courses are included in the proposed calendar copy and course listings.
Appendix B includes the full Undergraduate Calendar Copy of the program description and requirements.

11 Consultation

- Describe the expected impact of what is being proposed on the nature and quality of other programs delivered by the unit/division.
- Describe the expected impact of what is being proposed on programs being offered by other units/divisions.
- Describe any consultation with the Deans of Faculties/divisions that will be implicated or affected by the creation of the proposed program as per UTQAP 2.4.2: "The Dean ensures that appropriate consultation is conducted with faculty and students, other university divisions and external institutions."

The expected impact of what is being proposed on the nature and quality of other programs delivered by EEB:
Within the home unit (EEB), the Quantitative Biology Major will have little direct impact on other programs being offered. The restricted size of the QBio Major will restrict it to approximately 1/9 of the total enrollments in specialist and major programs run by EEB. We expect that, just as QBio may draw students from some of our other majors, it is likely to add students who are intent on adding a biological emphasis to an otherwise solely quantitative (mathematical/statistical/computer science) major.
The QBio Major will likely have positive indirect effects on other EEB programs. Other EEB specialists and majors have several courses that teach quantitative approaches, from

conservation planning to population genetics, environmental footprint budgets, and genome analysis. Participation in these courses by QBio majors will broaden student exposure to the range of skills and questions addressed by quantitative biologists. Similarly, their participation in the EEB poster fair (for independent study students) will increase exposure of students in other majors and specialist programs to quantitative biology, including those that can be paired with the QBio Major.

The expected impact of what is being proposed on programs being offered by other units/divisions:

Most of the first-year prerequisite courses are standard for students in other life science programs, and so should not impact them greatly. Required course options at the 200 level also are generally large classes, and similarly should be able to easily accommodate QBio students without a great impact on other units. As a limited enrolment program, the QBio Major is expected to reach a steady state of ~100 students enrolled (with an enrolment limit of 200 students). This aim corresponds to ~30 students per year. Given the diverse course options at the 300- and 400- levels, we do not anticipate that any single course should experience undue burden of elevated enrollment pressure. There are multiple course paths to fulfill program requirements without upper-year courses from these units (e.g., CSC, PHY, STA), but their inclusion enhances student awareness about options for studying quantitative biology at U of T and provides additional flexibility to students in fulfilling their requirements, especially for students with a second major in these other units.

Given the large number of students already handled by these units (e.g., STA administers >3000 students in its Major and Specialist programs) and the modest enrollment projections for QBio, we do not anticipate great shifts in student numbers out of programs from other units. This is especially true given that we expect students typically to already have their second Major in one of these other programs. One might superficially suspect overlap in student interest between QBio and the CSB Bioinformatics & Computational Biology Specialist, but the emphasis of CSB on molecular biology and computer science, and its more extensive course Specialist requirements and deregulated fees clearly differentiate it from the QBio Major.

Consultation with the Deans of Faculties/divisions:

To date, we have consulted with 11 units outside of EEB with course listings in the proposed QBio Major or in related disciplines that hail from A&S, including collaborative programs administered through the Faculty of Medicine. We received confirmation of the acceptability of required course inclusion from the Departments of Cell & Systems Biology, Computer

Science, Mathematics (as well as from Chemistry for non-inclusion of introductory CHM courses). We also received the acceptance for course inclusion as electives from the Departments/units of Biochemistry, Cell & Systems Biology, Computer Science, Geography & Planning, Human Biology, Mathematics, Molecular Genetics, Physics, and Psychology. To enhance the connections between departments, EEB has coordinated with the Departments of Statistical Sciences and Cell & Systems Biology; these units voiced strong support for the Quantitative Biology Major program, and EEB expects to engage these units in ongoing consultation for the life of the QBio program. All consultations with these departments took place in Fall 2017 and Winter 2018, and follow-up consultations with departments that have several electives listed (e.g., Computer Science, Cell & Systems Biology, Statistical Sciences) were conducted in early 2020.

On June 10, 2020, the draft proposal was taken to a meeting of the Executive Committee for Molecular Genetics. The committee was in favour of QBio as an opportunity for undergraduate students to gain more quantitative training in preparation for graduate programs, and they were supportive of the creation of this program.

The proposal was also discussed at the June 11, 2020, meeting of the Tri-campus Deans group. Feedback was uniformly positive, with members from both UTM and UTSC noting that such a program would likely be of significant interest to undergraduate students.

On June 9, 2020, a copy of the proposal was provided to the Faculty of Medicine’s Dean; Vice Dean, Graduate and Academic Affairs; Vice Dean, Post MD Education; and the Director of the Office of the Dean. Feedback from the Vice Dean, Graduate and Academic Affairs was supportive of this program’s creation.

12 Resources

12.1 Faculty

- Complete Table 3 below
- Brief commentary, including:
  - Evidence of the participation of a sufficient number and quality of faculty who will actively participate in the delivery of (teach and/or supervise) the program
  - Evidence of and planning for adequate numbers and quality of faculty and staff to achieve the goals of the program

- The role of any adjunct or contractual (e.g., stipendiary) faculty.
- The provision of supervision of experiential learning opportunities, as appropriate.
- If relevant, plans and commitment to provide additional faculty resources to support the program.
- Planned/anticipated class sizes (connect this to delivery method, Section 8 and assessment methods, Section 9).
- Provide the shalls of all faculty who appear in Table 3, as evidence substantiating the above. The appendix should form a separate document with a table of contents and all CVs in alphabetical order. CVs should be submitted in a consistent format.

The faculty listed (Table 5) make up the core group of EEB professors who will teach and supervise QBio students. Additional faculty from partner departments (e.g., CSB) may also supervise independent research projects (see Courses, Appendix A) if they meet the PLOs of the QBio program (Tables 3 and 4). The program consists of existing courses, so it is anticipated that there will be no additional workload for the faculty complement. In addition to the faculty listed in Table 5, the Department of EEB has two upcoming additions to its faculty complement who will contribute to the QBio program. First, Dr. Matthew Osmond is a mathematical biologist who has accepted an Assistant Professor position in the department and will be officially starting in January 2021. It is anticipated that Dr. Osmond will begin developing quantitative courses for the September 2022 semester. Second, as of November 2020, the Department of EEB is undergoing a search for an Assistant Professor position in "computational ecology and evolutionary biology." The arrival of Dr. Osmond and the current search are expected to increase the number of faculty who could contribute to the QBio program within the next academic year. However, the QBio program has sufficient faculty teaching and supervisory capacity with the current faculty listed in Table 5.

Table 5: Detailed Listing of Committed Faculty

Name	Unit of Primary Budgetary App't and % (Unit = EEB unless otherwise noted)	Unit of Other Budgetary App't and % (if applicable)	Commitment to Other Programs[2]	Nature of Contribution to this Program (course instructor [CI], Research Supervisor [RS])
Tenure Stream: Professor				
Agrawal, Aneil	100			CI, RS
Chang, Belinda	51	CSB 49%	51% EEB and 49% CSB programs	CI, RS
Cutter, Asher	100			CI, RS
Fortin, Marie-Josée	100			CI, RS
Jackson, Donald	100			CI, RS
Stinchcombe, John	100			CI, RS
Wright, Stephen	100			CI, RS
Tenure Stream: Associate Professor				
Gilbert, Benjamin	100			CI, RS
Krkosek, Martin	100			CI, RS
Mideo, Nicole	100			CI, RS
Tenure Stream: Assistant Professor				
Mahler, Donald Luke	100			CI, RS
Sztepanacz, Jacqueline	100			CI, RS
Teaching Stream: Assistant Professor				
Riskin, Shelby	100			Resource development (R book)

[2] Unless otherwise indicated, all faculty teaching workload is assigned to EEB in support of EEB programs: EEB major and specialist; Biology major and specialist; Biodiversity and Conservation Biology major; Environmental Biology major

12.2 TA Support

- Give details regarding the nature and level of TA support required by the program.

TA support is already in place for the courses offered in the QBio program. In addition, EEB devotes TA hours to course/lab development in summer months; these hours will be used to update courses on a continual basis and to aid in the development of labs for new courses.

12.3 Learning Resources

- Evidence that there are adequate resources to sustain the quality of scholarship and research activities of undergraduate and graduate students, including library support.

We anticipate that existing resources are adequate to support this program. The committed faculty identified in Table 5 typically support twenty-five undergraduate research projects (4^{th} year) per year, as well as several NSERC USRAs and other research opportunities. These faculty are active researchers in quantitative biology, having published over 200 papers in the last three years in top disciplinary journals as well as popular science journals like Science, Nature, and PNAS, and frequently publish with undergraduate as well as graduate students. They support approximately 35-45 graduate students and 3-8 postdocs, who will be directly involved in the QBio program as TAs and sometimes as course instructors, and indirectly by providing feedback and support for undergraduate students' independent research. The resources provided by the committed faculty and their labs are considerable and include online resources and access to open-source programming and emerging large-data and big-data databases that are frequently unavailable at libraries. In short, the committed faculty will ensure that cutting-edge intellectual resources will be available to students and integrated into their education. In addition, EEB regularly funds "course development TAships," which are summer TA positions designed to ensure that new or updated teaching and technical tools are integrated into courses and practicals.

Please see the following appendices:
Appendix C: Library statement confirming the adequacy of library holdings and support for student learning.
Appendix D: Statement concerning student support services on St. George campus.

12.4 Space/Infrastructure

- Evidence that there are adequate resources to sustain the quality of scholarship and research activities of undergraduate and graduate students, including information technology support and laboratory access; address any unique requirements including renovations to existing space, new space, equipment, etc.

- Note: The requirements for physical facilities should be identified by providing information on the change in the number of people to be accommodated by type (i.e., faculty, students, administrative staff, etc.) as well as information on changes in equipment and activities requiring accommodation. The division/Faculty should state whether it plans to bring forward proposals for additional space; the renovation of existing space; or whether the current space allocation to the academic program will accommodate the new initiative.

We anticipate that existing space and infrastructure within the University are adequate to support the needs of this program. The infrastructure resources required for teaching, such as computer labs and computer software, are already present in the required and elective courses in QBio (see Appendix A). Additional and new courses, as they are added to the program, will undergo individual assessments of resources, but we do not foresee increasing resource needs beyond those already in place for current courses.

Courses used to fulfil this program make use of computer teaching labs located around the St. George campus that are managed centrally by ACE (Academic and Campus Events office), as are standard classrooms to support lecture teaching, flipped pedagogical designs, and seminar discussion courses. The Information & Instructional Technology (IIT) office manages personnel to assist in installation of teaching software in computing labs. In addition to the Associate Chair (Undergraduate), the EEB Department is home to space for 2 undergraduate program staff to conduct responsibilities that include advising undergraduate students on program requirements, hosting informational workshops and events, and managing a peer-to-peer mentorship program. Wet-lab courses are supported by 5 teaching lab technicians to support learning outcomes in dedicated biological teaching laboratories for courses with lab practical components. The depth of tenure-stream faculty in the EEB Department (see Table 5) oversee leading-edge research lab facilities in which QBio program students have the option of conducting research project courses.

12.5 Other Resource Implications

- For example,
  - Are there interdivisional teaching implications?
  - Will the new program affect any existing agreements with other institutions, or will require the creation of a new agreement to facilitate the new program (e.g.,

Memorandum of Understanding, Memorandum of Agreement, etc.). (Existing joint programs are offered with Centennial, Sheridan and Michener.)
- If this is a new joint program, please indicate how future reviews of the program will be conducted in accordance with UTQAP 2.1: "Where a program is held jointly with an Ontario institution that does not have an IQAP that has been ratified by the Quality Council, the UTQAP will serve as the guiding document and University of Toronto will be the lead institution. Where a program is held jointly with an Ontario institution that does have an IQAP that has been ratified by the Quality Council, a lead institution will be selected. Program proposals specify how future reviews will be conducted."

- Please consult with the Provost's office (vp.academicprograms@utoronto.ca) early regarding any resource implications described in this section.

The proposed major does not change teaching obligations within or across units.

13 Quality & Other Indicators

- Please describe the appropriateness of the faculty's collective expertise and how it contributes substantively to the proposed program. Define and use indicators to provide evidence of the quality of the faculty (e.g., qualifications, research, innovation and scholarly record)
- Please explain how the program structure and faculty research will ensure the intellectual quality of the student experience.
- Please describe any elements that enhance the program's diversity.

The faculty's collective expertise and how it contributes substantively to the proposed program: The faculty has broad expertise in quantitative biology, ranging from molecular genetics and genomics (Professors Chang, Cutter, and Wright) to population and quantitative genetics (Professors Agrawal, Sztepanacz, and Stinchcombe) to population and disease modeling (Professors Krkosek, Mideo, and Fortin) to biodiversity structure and change across evolutionary and spatial scales (Professors Gilbert, Jackson, and Mahler). Within these subfields, they employ quantitative methods that span several statistical approaches (machine learning, frequentist and Bayesian approaches) and employ diverse mathematical tools, often using computationally intensive methods.

The quality of the research and teaching conducted by these faculty is widely acknowledged. The group includes multiple Steacie Award winners, Sloan Fellows, FRSC, members of the Royal Society's College of New Scholars, and U of T Teaching Award recipients. This expertise is accessible to undergraduate students through course offerings, research opportunities within labs, and thesis-level independent projects.

How the program structure and faculty research will ensure the intellectual quality of the student experience:
The structure of the QBio program will ensure the intellectual quality of the student experience through two mechanisms. First, QBio has a close matching of tenure-stream professors with their areas of expertise. For example, upper-level courses are taught by scientists recognized in that subject area, as is the case for *Population Genetics* (Professor Agrawal), *Population Ecology* (Professor Krkosek), *Macroevolution* (Professor Mahler), and *Evolutionary Genomics* (Professor Chang). For several upper-year courses, two or more faculty collaborate to bring distinct expertise and experience. Examples of this type of collaborative teaching include *Principles of Evolution* (Professors Stinchcombe and Cutter), *Models in Ecology and Evolution* (Professors Gilbert and Krkosek), and *Evolutionary Genetics* (Professors Agrawal and Cutter).

In addition to this careful matching of research expertise and teaching for upper-year courses, foundation courses in EEB are also taught by active researchers to provide an early link between course-based learning and research. For example, the main first year EEB course (*Adaptation and Biodiversity*), has been taught by Professors Stinchcombe and Wright, and the second year EEB statistics course (*Biostatistics for Biological Sciences*) is currently taught by Professor Sztepanacz.

The second mechanism to ensure the intellectual quality of the student experience is access to independent research opportunities in EEB. A recent survey of EEB major and specialist students showed that all students seeking independent research opportunities were given the opportunity to work directly with a faculty mentor in an independent research course. These research experiences are defining for many students, providing first-hand experience in professional responsibility, science communication, independent data analysis, and so on. The success of independent research experiences is gauged through an annual poster fair at the University of Toronto, as well as through the successes of the students and their projects. For example, undergraduate thesis students regularly publish in international journals with many of the core QBio professors, illustrating that the quality of education at the international level.

Elements that enhance the program's diversity:
Quantitative Biology is a STEM discipline. The host department (EEB) is actively engaged in encouraging diversity and removing barriers that have traditionally limited the diversity in STEM fields. For example, EEB has developed a Wellness committee, with representation from undergraduate and graduate students, staff and faculty, with the aim of building an inclusive and supportive environment for all members of the EEB community. Similarly, the EEB undergraduate program is developing tools to quantify the diversity of EEB undergraduate programs and to identify and remove barriers to participation by (in)visible minorities. These broad, departmental approaches to enhancing diversity are matched with programs designed to support students through building networks and role models. For example, EEB has an active peer-to-peer mentoring group that the department supports administratively and through planned events (EEB-hosted lunches, etc.). For events with a strong faculty presence, such as EEB backpack-to-briefcase evenings and open workshops on accessing research experience, EEB is careful to choose a diversity of professors in an attempt to ensure that students have a diversity of role models within the department. Currently available statistics on gender show that, unlike many STEM disciplines, EEB has more female than male students at the undergraduate level. The QBio Major may increase involvement of women in the more quantitative STEM disciplines (math, statistics, computer science), in which women are often under-represented.

Appendix A: Courses

All of the below are existing courses. EEB313H1 (Quantitative Methods in R for Biology) and EEB430H1 (Modeling in Ecology and Evolution) were recently developed as new courses during the development of the Quantitative Biology Major proposal to enhance the program upon its launch. Any appropriate additional courses, such as upcoming courses in artificial intelligence, will be considered for inclusion to fulfill program requirements through the existing curriculum change process as they are identified. Note that course options for program completion will prevent undue impact on any particular course.

BIO120H1: Adaptation and Biodiversity
Hours: 24L/15P
Principles and concepts of evolution and ecology related to origins of adaptation and biodiversity. Mechanisms and processes driving biological diversification illustrated from various perspectives using empirical and theoretical approaches. Topics include: genetic diversity, natural selection, speciation, physiological, population, and community ecology, maintenance of species diversity, conservation, species extinction, global environmental change, and invasion biology. A lab coat is required and the cost is approximately $16 if students wish to purchase it through the Department. (Lab Materials Fee: $25)
Prerequisite: Grade 12 Biology or equivalent. Students without high school Biology must consult the BIO120 Office (bio120@utoronto.ca)
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology, Biology

BIO130H1: Molecular and Cell Biology
Hours: 36L/15P
One of the goals of modern biology is to understand how the basic building blocks of life give rise to biological form and function. This course provides students with a common lexicon to understand the key principles and concepts in molecular and cell biology, with a focus on how the building blocks of life lead to functioning cells. (Lab Materials Fee: $10). Lab coat and safety glasses are required for use in laboratories; students are responsible for purchasing these items (approximate cost is $25).
Prerequisite: SBI4U and SCH4U (Grade 12 University Preparation Biology and Chemistry) or permission of department. Please contact bio130@utoronto.ca for more information.
Distribution Requirements: Science

Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology, Biology

CSC108H1: Introduction to Computer Programming
Hours: 36L
Programming in a language such as Python. Elementary data types, lists, maps. Program structure: control flow, functions, classes, objects, methods. Algorithms and problem solving. Searching, sorting, and complexity. Unit testing. No prior programming experience required. NOTE: You may not take this course concurrently with CSC120H1/CSC148H1, but you may take CSC148H1 after CSC108H1.
Exclusion: CSC120H1, CSC121H1, CSC148H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC120H1: Computer Science for the Sciences
Hours: 36L/12P
An introduction to computer science for students in other sciences, with an emphasis on gaining practical skills. Introduction to programming with examples and exercises appropriate to the sciences; web programming; software tools. Topics from: database design, considerations in numerical calculation, using UNIX/LINUX systems. At the end of this course you will be able to develop computer tools for scientific applications, such as the structuring and analysis of experimental data. With some additional preparation, you will also be ready to go on to CSC148H1. Practical (P) sections consist of supervised work in the computer laboratory. No programming experience is necessary.
Exclusion: Any CSC course, with the exception of CSC104H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC121H1: Computer Science for Statistics
Hours: 36L/12P
An introduction to computer science for students planning to use computers for statistical analysis and research. Using a statistical programming environment, fundamental programming concepts, and computational topics relevant to statistics, such as issues with numerical calculation, random number generation, and management of data. Practicals consist of supervised work in the computer laboratory to reinforce concepts and develop programming

skills. No previous programming experience is necessary. Please consult with the CS Undergraduate office if you intend to continue on to CSC148H1.
Exclusion: Any CSC course, with the exception of CSC104H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC148H1: Introduction to Computer Science
Hours: 36L/24P
Abstract data types and data structures for implementing them. Linked data structures. Encapsulation and information-hiding. Object-oriented programming. Specifications. Analyzing the efficiency of programs. Recursion. This course assumes programming experience as provided by CSC108H1. Students who already have this background may consult the Computer Science Undergraduate Office for advice about skipping CSC108H1. Practical (P) sections consist of supervised work in the computing laboratory. These sections are offered when facilities are available, and attendance is required. NOTE: Students may go to their college to drop down from CSC148H1 to CSC108H1. See above for the drop down deadline.
Prerequisite: CSC108H1/(equivalent programming experience)
Exclusion: CSC207H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

MAT135H1: Calculus 1(A)
Hours: 36L/12T
Review of trigonometric functions, trigonometric identities and trigonometric limits. Functions, limits, continuity. Derivatives, rules of differentiation and implicit differentiation, related rates, higher derivatives, logarithms, exponentials. Trigonometric and inverse trigonometric functions, linear approximations. Mean value theorem, graphing, min-max problems, l'Hôpital's rule; anti-derivatives. Examples from life science and physical science applications.
Prerequisite: High school level calculus
Exclusion: MAT133Y1, MAT136H1, MAT137Y1, MAT157Y1, MATA30H3, MATA31H3, MATA32H3, MATA33H3, MATA35H3, MATA36H3, MATA37H3, MAT133Y5, MAT134Y5, MAT135Y5, MAT137Y5, MAT138Y5, MAT186H, MAT187H, MAT194H, MAT195H, MAT196H & MAT197H
Distribution Requirements: Science

Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT136H1: Calculus 1(B)
Hours: 36L/12T
Definite Integrals, Fundamental theorem of Calculus, Areas, Averages, Volumes. Techniques: Substitutions, integration by parts, partial fractions, improper integrals. Differential Equations: Solutions and applications. Sequences, Series, Taylor Series. Examples from life science and physical science applications.
Prerequisite: MAT135H1
Exclusion: MAT133Y1, MAT137Y1, MAT157Y1, MATA32H3, MATA33H3, MATA36H3, MATA37H3, MAT133Y5, MAT134Y5, MAT135Y5, MAT137Y5, MAT138Y5, MAT186H, MAT187H, MAT194H, MAT195H, MAT196H & MAT197H
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT137Y1: Calculus
Hours: 72L/24T
A conceptual approach for students with a serious interest in mathematics. Attention is given to computational aspects as well as theoretical foundations and problem solving techniques. Review of Trigonometry. Limits and continuity, mean value theorem, inverse function theorem, differentiation, integration, fundamental theorem of calculus, elementary transcendental functions, Taylor's theorem, sequence and series, power series. Applications.
Prerequisite: High school level calculus
Exclusion: MAT135H1, MAT136H1, MAT157Y1, MATA35H3, MATA36H3, MATA37H3, MAT135Y5, MAT137Y5, MAT138Y5, MAT187H, MAT194H, MAT195H, MAT196H & MAT197H
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT157Y1: Analysis I
Hours: 72L/48T
A theoretical course in calculus; emphasizing proofs and techniques, as well as geometric and physical understanding. Trigonometric identities. Limits and continuity; least upper bounds, intermediate and extreme value theorems. Derivatives, mean value and inverse function

theorems. Integrals; fundamental theorem; elementary transcendental functions. Techniques of integration. Taylor's theorem; sequences and series; uniform convergence and power series.
Prerequisite:
High school level calculus
Exclusion: MAT137Y1, MATA37H3, MAT137Y5, MAT157Y5, MAT195H1, & MAT197H1
Recommended Preparation: Students should consider taking the Preparing for University Math Level II in order to prepare in advance for MAT157Y1. Students may also take MAT138H1 concurrently with MAT157Y1. Students will receive credit for both MAT157Y1 and MAT138H1 if MAT138H1 is taken before or along with MAT157Y1.
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT221H1: Applied Linear Algebra
Hours: 36L/12T
An application-oriented approach to linear algebra, based on calculations in standard Euclidean space. Systems of linear equations, matrices, Gauss-Jordan elimination, subspaces, bases, orthogonal vectors and projections. Matrix inverses, kernel and range, rank-nullity theorem. Determinants, eigenvalues and eigenvectors, Cramer's rule, diagonalization. This course has strong emphasis on building computational skills in the area of algebra. Applications to curve fitting, economics, Markov chains and cryptography.
Prerequisite: High school level calculus
Exclusion: MAT223H1, MATA23H3, MAT223H5, MAT224H1, MAT240H1, MAT240H5, MAT247H1, MAT247H5
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT223H1: Linear Algebra I
Hours: 36L/12T
Systems of linear equations, matrix algebra, real vector spaces, subspaces, span, linear dependence and independence, bases, rank, inner products, orthogonality, orthogonal complements, Gram-Schmidt, linear transformations, determinants, Cramer's rule, eigenvalues, eigenvectors, eigenspaces, diagonalization.
Prerequisite: High school level calculus
Exclusion: MATA23H3, MAT223H5, MAT224H1, MAT240H1, MAT240H5, MAT247H1, MAT247H5

Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

BIO220H1: From Genomes to Ecosystems in a Changing World
Hours: 24L/15P
Dynamics of genetic and ecological change in biological systems, from genomes to ecosystems. Evolutionary genetic and ecological perspectives on wide-ranging topics including disease, aging, sexual conflict, genetics of human differences, conservation, and global climate change. Applications of evolutionary, ecological, and molecular-genetic principles and processes. Responsibilities of human societies in a changing world. (Lab Materials Fee: $25).
Prerequisite: BIO120H1
Recommended Preparation: BIO130H1, BIO230H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology, Biology

BIO230H1: From Genes to Organisms
Hours: 36L/15P
The genome is the "book of life," providing instructions to construct an organism. This course introduces genome biology and explores how the building blocks of life are networked into functioning organisms. We will investigate how cells perceive internal and external cues, how gene expression is shaped by this perception, and how these events give rise to tissues, organs, and whole organisms. (Lab Materials Fee: $20). Lab coat and safety glasses are required for use in laboratories; students are responsible for purchasing these items (approximate cost is $25).
Prerequisite: BIO130H1, (CHM135H1, CHM136H1)/(CHM138H1, CHM139H1)/ CHM151Y1
Exclusion: BIO255H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology, Biology

BIO255H1: From Genes to Organisms with Advanced Laboratory
Hours: 36L/33P
The genome is the "book of life," providing instructions to construct an organism. This course introduces genome biology and explores how the building blocks of life are networked into functioning organisms. We will investigate how cells perceive internal and external cues, how gene expression is shaped by this perception, and how these events give rise to tissues, organs,

and whole organisms. The Enhanced Laboratory provides the opportunity for greater laboratory skill development in modern investigative techniques and is intended for students interested in conducting their own laboratory research. (Lab Materials Fee: $50). Lab coat and safety glasses are required for use in laboratories; students are responsible for purchasing these items (approximate cost is $25).
Prerequisite: BIO130H1, (CHM135H1, CHM136H1)/(CHM138H1, CHM139H1)/ CHM151Y1, cGPA 3.0
Exclusion: BIO230H1
Recommended Preparation: BCH210H1 (taken concurrently or previously)
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology, Biology

BIO260H1: Concepts in Genetics
Hours: 48L/12T
This is a problem based course which discusses classical, molecular, developmental, and population genetics and genomics with emphasis on model organisms for genetic analysis.
Prerequisite: BIO230H1/ BIO255H1
Exclusion: HMB265H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology, Biology

HMB265H1: General & Human Genetics
Hours: 24L/12T
An introduction to classical and modern methods of genetic analysis. Topics include Mendelian genetics, the genetics of human population and disease, genomics, and applications of genetics to human society.
Prerequisite: BIO120H1, BIO130H1, (CHM135H1/ CHM139H1, CHM136H1/ CHM138H1)/ CHM151Y1
Exclusion: BIO260H1/ BIO207H5
Recommended Preparation: Recommended Co-requisite: BIO230H1/ BIO255H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Human Biology

EEB225H1: Biostatistics for Biological Sciences

Hours: 36L/12P
A statistics course designed especially for life science students, using examples from ecology and evolution where appropriate. Students learn to choose and use statistics that are appropriate to address relevant biological questions and hypotheses. Lectures and computer labs will be used to cover the following methods: sampling and experimental design, data exploration, correlation, regression, ANOVA, Chi-square, and non-parametric tests.
Prerequisite: BIO120H1
Exclusion: BIO225H1/ ECO220Y1/ ECO227Y1/ GGR270H1/ HMB325H1/ PCL376H1/ PSY201H1/ SOC300Y1/ STA220H1/ STA250H1/ STA288H1
Distribution Requirements: Science
Program Area Section: Ecology and Evolutionary Biology

GGR270H1: Introductory Analytical Methods
Hours: 24L/12T
Theory and practical application of elementary quantitative techniques in geography emphasizing descriptive, inferential and spatial statistical analysis, probability, and sampling.
Exclusion: ECO220Y1/ ECO227Y1/ EEB225H1/ GGR270Y1/ LIN305H1/ POL222H1/ POL242Y1/ PSY201H1/ SOC202H1/ STA220H1/ STA248H1/ STA250H1/ STA261H1
Recommended Preparation: 0.5 FCE in Geography
Distribution Requirements: Social Science, Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Geography and Planning

PSY201H1: Statistics I
Hours: 36L
Fundamentals of descriptive and inferential statistics, including population and sampling distributions, simple association, probability, estimation, and hypothesis testing.
Prerequisite: PSY100H1
Exclusion: ECO220Y1/ ECO227Y1/ EEB225H1/ GGR270H1/ HMB325H1/ POL232H1/ POL242Y1/ SOC202H1/ STA220H1/ STA248H1/ STA288H1
Recommended Preparation: Grade 12 Calculus
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Psychology

STA220H1: The Practice of Statistics I
Hours: 36L

An introductory course in statistical concepts and methods, emphasizing exploratory data analysis for univariate and bivariate data, sampling and experimental designs, basic probability models, estimation and tests of hypothesis in one-sample and comparative two-sample studies. A statistical computing package is used but no prior computing experience is assumed. Note: STA220H1does not count as a distribution requirement course.
Prerequisite: Grade 12 Mathematics and one University course in the physical, social, or life sciences
Exclusion: ECO220Y1/ ECO227Y1/ GGR270H1/ PSY201H1/ SOC300Y1/ STA250H1/ STA261H1/ STA248H1/ STA288H1/ EEB225H1/ STAB22H3/ STAB57H3/ STA215H5/ STA220H5/ ECO220Y5/ ECO227Y5/ STA258H5/ STA260H5
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA237H1: Probability, Statistics and Data Analysis I
Hours: 36L/12T
An introduction to probability using simulation and mathematical frameworks, with emphasis on the probability needed for more advanced study in statistical practice. Topics covered include probability spaces, random variables, discrete and continuous probability distributions, probability mass, density, and distribution functions, expectation and variance, independence, conditional probability, the law of large numbers, the central limit theorem, sampling distributions. Computer simulation will be taught and used extensively for calculations and to guide the theoretical development.
Prerequisite: (MAT135H1, MAT136H1)/MAT137Y1/MAT157Y1/(MATA30H3, MATA36H3)/(MATA31H3, MATA37H3)/MAT135Y5/MAT137Y5/MAT157Y5
Exclusion: STA247H1, STA255H1, STA257H1, ECO227Y1, STAB52H3, STA256H5, ECO227Y5
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA238H1: Probability, Statistics and Data Analysis II
Hours: 36L/12T
An introduction to statistical inference and practice. Statistical models and parameters, estimators of parameters and their statistical properties, methods of estimation, confidence intervals, hypothesis testing, likelihood function, the linear model. Use of statistical computation for data analysis and simulation.
Prerequisite: STA237H1/STA247H1/STA257H1/STAB52H3/STA256H5

Exclusion: ECO220Y1/ ECO227Y1/ GGR270H1/ PSY201H1/ SOC300H1/ SOC202H1/ SOC252H1/ STA220H1/ STA221H1/ STA255H1/ STA248H1/STA261H1/ STA288H1/ EEB225H1/ STAB22H3/ STAB27H3/ STAB57H3/ STA220H5/ STA221H5/ STA258H5/ STA260H5/ ECO220Y5/ ECO227Y5
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA247H1: Probability with Computer Applications
Hours: 36L/12T
Introduction to the theory of probability, with emphasis on applications in computer science. The topics covered include random variables, discrete and continuous probability distributions, expectation and variance, independence, conditional probability, normal, exponential, binomial, and Poisson distributions, the central limit theorem, sampling distributions, estimation and testing, applications to the analysis of algorithms, and simulating systems such as queues (Note: STA247H1 does not count as a distribution requirement course).
Prerequisite: (MAT135H1, MAT136H1)/ MAT137Y1/ MAT157Y1/(MATA30H3, MATA36H3)/(MATA31H3, MATA37H3)/MAT135Y5/MAT137Y5/MAT157Y5; CSC108H1/ CSC148H1/CSCA08H3/CSCA48H3/ CSC108H5/CSC148H5
Exclusion: ECO227Y1/ STA255H1/ STA257H1/STAB52H3/STA256H5/ECO227Y5
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA257H1: Probability and Statistics I
Hours: 36L/12T
A mathematically rigorous introduction to probability, with applications chosen to introduce concepts of statistical inference. Probability and expectation, discrete and continuous random variables and vectors, distribution and density functions, the law of large numbers. The binomial, geometric, Poisson, and normal distributions. The Central Limit Theorem. (Note: STA257H1 does not count as a distribution requirement course).
Prerequisite: (MAT135H1 (70%), MAT136H1(70%))/ MAT137Y1/ MAT157Y1 (MAT137Y1/ MAT157Y1 is strongly recommended)/MATA36H3(70%)/MATA37H3/MAT135Y5(70%)/MAT137Y5/MAT157Y5
Corequisite: MAT235Y1/ MAT237Y1/ MAT257Y1 (MAT237Y1/ MAT257Y1 is strongly recommended)/MATB41H3/MAT232H5/MAT233H5; MAT223H1/ MAT240H1/ MATA23H3/MAT223H5/MAT240H5
Exclusion: ECO227Y1, STA247H1, MAT377H1, STAB52H3, STA256H5, ECO227Y5
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA288H1: Statistics and Scientific Inquiry in the Life Sciences
Hours: 36L/18P
Introduction to statistics and its connection to all stages of the scientific inquiry process. Issues around data collection, analysis and interpretation are emphasized to inform study design and critical assessment of published research. Statistical software is used to conduct descriptive and inferential statistics to address basic life sciences research questions.
Prerequisite: BIO230H1/ BIO255H1
Exclusion: STA220H1, PSY201H1, GGR270H1, ECO220Y1, ECO227Y1, SOC202H1, EEB225H1, HMB325H1, STA248H1, STA261H1, PCL376H1, STA215H5, STA220H5, STAB22H3
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

PSY202H1: Statistics II
Hours: 36L
Fundamentals of statistical analysis of experimental and observational data including linear models, the analysis of variance, a priori contrasts, post-hoc tests, power analysis and effect size calculations.
Prerequisite: PSY201H1 (or exclusion)
Exclusion: ECO220Y1/ ECO227Y1/ STA221H1/ SOC252H1/ SOC300H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Psychology
STA221H1: The Practice of Statistics II
Hours: 36L/12T
Continuation of STA220H1 (or similar course), emphasizing major methods of data analysis such as analysis of variance for one factor and multiple factor designs, regression models, categorical and non-parametric methods (Note: STA221H1 does not count as a distribution requirement course).
Prerequisite: STA220H1/ STA288H1/ PSY201H1/ GGR270H1/ EEB225H1/STAB22H3/STA220H5
Exclusion: ECO220Y1/ ECO227Y1/ GGR270Y1/ PSY202H1/ SOC300H1/ SOC202H1/ SOC252H1/ STA261H1/ STA248H1/ STAB27H3/ STA221H5/ ECO220Y5/ ECO227Y5/ STAB57H3/ STA258H5/ STA260H5
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA255H1: Statistical Theory

Hours: 36L/12T

This courses deals with the mathematical aspects of some of the topics discussed in STA250H1. Topics include discrete and continuous probability distributions, conditional probability, expectation, sampling distributions, estimation and testing, the linear model (Note: STA255H1 does not count as a distribution requirement course).

Prerequisite: STA220H1/ STA221H1/ ECO220Y1 (note: ECO220Y1 may be taken as a co-requisite)/STAB22H3/STA220H5/ECO220Y5; MAT133Y1 (70%)/(MAT135H1, MAT136H1)/ MAT137Y1/ MAT157Y1/(MATA32H3 (70%), MATA33H3 (70%))/(MATA30H3, MATA36H3)/(MATA31H3, MATA37H3)/MAT133Y5 (70%)/MAT135Y5/MAT137Y5/MAT157Y5

Exclusion: ECO227Y1/ STA257H1/ STA261H1/ STA247H1/ STA248H1/ STAB52H3/STAB57H3/STA256H5/STA260H5/ECO220Y5

Breadth Requirements: The Physical and Mathematical Universes (5)

Program Area Section: Statistical Sciences

STA257H1: Probability and Statistics I

Hours: 36L/12T

A mathematically rigorous introduction to probability, with applications chosen to introduce concepts of statistical inference. Probability and expectation, discrete and continuous random variables and vectors, distribution and density functions, the law of large numbers. The binomial, geometric, Poisson, and normal distributions. The Central Limit Theorem. (Note: STA257H1 does not count as a distribution requirement course).

Prerequisite: (MAT135H1 (70%), MAT136H1(70%))/ MAT137Y1/ MAT157Y1 (MAT137Y1/ MAT157Y1 is strongly recommended)/MATA36H3(70%)/MATA37H3/MAT135Y5(70%)/MAT137Y5/MAT157Y5

Corequisite: MAT235Y1/ MAT237Y1/ MAT257Y1 (MAT237Y1/ MAT257Y1 is strongly recommended)/MATB41H3/MAT232H5/MAT233H5; MAT223H1/ MAT240H1/ MATA23H3/MAT223H5/MAT240H5

Exclusion: ECO227Y1, STA247H1, MAT377H1, STAB52H3, STA256H5, ECO227Y5

Breadth Requirements: The Physical and Mathematical Universes (5)

Program Area Section: Statistical Sciences

STA248H1: Statistics for Computer Scientists

Hours: 36L/12T

A survey of statistical methodology with emphasis on data analysis and applications. The topics covered include descriptive statistics, data collection and the design of experiments, univariate and multivariate design, tests of significance and confidence intervals, power, multiple regression and the analysis of variance, and count data. Students learn to use a statistical

computer package as part of the course (Note: STA248H1 does not count as a distribution requirement course).
Prerequisite: STA247H1/ STA257H1/STA256H5/STAB52H3; CSC108H1/ CSC148H1/ CSCA08H3/CSCA48H3/CSC108H5/CSC148H5
Exclusion: ECO220Y1/ ECO227Y1/ GGR270Y1/ PSY201H1/ SOC300H1/ SOC202H1/ SOC252H1/ STA220H1/ STA221H1/ STA250H1/ STA255H1/ STA261H1/ STA288H1/ EEB225H1/ STAB22H3/ STAB27H3/ STAB57H3/ STA220H5/ STA221H5/ STA258H5/ STA260H5/ ECO220Y5/ ECO227Y5
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA261H1: Probability and Statistics II
Hours: 36L/12T
A rigourous introduction to the theory of statistical inference and to statistical practice. Statistical models, parameters, and samples. Estimators for parameters, sampling distributions for estimators, and the properties of consistency, bias, and variance. The likelihood function and the maximum likelihood estimator. Hypothesis tests and confidence regions. Examples illustrating statistical theory and its limitations. Introduction to the use of a computer environment for statistical analysis. (Note: STA261H1 does not count as a distribution requirement course).
Prerequisite: STA257H1/STAB52H3/STA256H5
Corequisite: MAT235Y1/ MAT237Y1/ MAT257Y1/MATB42H3/MAT236H5; MAT223H1/ MAT240H1/MATA23H3/MAT223H5/MAT240H5
Exclusion: ECO227Y1/ STA248H1/ STA255H1/STAB57H3/STA260H5/ECO227Y5
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

APM236H1: Applications of Linear Programming
Hours: 36L
Introduction to linear programming including a rapid review of linear algebra (row reduction, matrix inversion, linear independence), the simplex method with applications, the duality theorem, complementary slackness, the dual simplex method and the revised simplex method.
Prerequisite: MAT221H1/ MAT223H1/ MAT240H1 (Note: no waivers of prerequisites will be granted)
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT221H1: Applied Linear Algebra

Hours: 36L/12T

An application-oriented approach to linear algebra, based on calculations in standard Euclidean space. Systems of linear equations, matrices, Gauss-Jordan elimination, subspaces, bases, orthogonal vectors and projections. Matrix inverses, kernel and range, rank-nullity theorem. Determinants, eigenvalues and eigenvectors, Cramer's rule, diagonalization. This course has strong emphasis on building computational skills in the area of algebra. Applications to curve fitting, economics, Markov chains and cryptography.

Prerequisite: High school level calculus

Exclusion: MAT223H1, MATA23H3, MAT223H5, MAT224H1, MAT240H1, MAT240H5, MAT247H1, MAT247H5

Distribution Requirements: Science

Breadth Requirements: The Physical and Mathematical Universes (5)

Program Area Section: Mathematics

MAT223H1: Linear Algebra I

Hours: 36L/12T

Systems of linear equations, matrix algebra, real vector spaces, subspaces, span, linear dependence and independence, bases, rank, inner products, orthogonality, orthogonal complements, Gram-Schmidt, linear transformations, determinants, Cramer's rule, eigenvalues, eigenvectors, eigenspaces, diagonalization.

Prerequisite: High school level calculus

Exclusion: MATA23H3, MAT223H5, MAT224H1, MAT240H1, MAT240H5, MAT247H1, MAT247H5

Distribution Requirements: Science

Breadth Requirements: The Physical and Mathematical Universes (5)

Program Area Section: Mathematics

MAT224H1: Linear Algebra II

Hours: 36L/12T

Fields, complex numbers, vector spaces over a field, linear transformations, matrix of a linear transfromation, kernel, range, dimension theorem, isomorphisms, change of basis, eigenvalues, eigenvectors, diagonalizability, real and complex inner products, spectral theorem, adjoint/self-adjoint/normal linear operators, triangular form, nilpotent mappings, Jordan canonical form.

Prerequisite: MAT221H1(80%)/ MAT223H1/ MAT240H1

Exclusion: MAT247H1

Distribution Requirements: Science

Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT240H1: Algebra I
Hours: 36L/24T
A theoretical approach to: vector spaces over arbitrary fields, including C and Z_p. Subspaces, bases and dimension. Linear transformations, matrices, change of basis, similarity, determinants. Polynomials over a field (including unique factorization, resultants). Eigenvalues, eigenvectors, characteristic polynomial, diagonalization. Minimal polynomial, Cayley-Hamilton theorem.
Prerequisite: High school level calculus
Corequisite: MAT157Y1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT237Y1: Multivariable Calculus
Hours: 72L
Sequences and series. Uniform convergence. Convergence of integrals. Elements of topology in R^2 and R^3. Differential and integral calculus of vector valued functions of a vector variable, with emphasis on vectors in two and three dimensional euclidean space. Extremal problems, Lagrange multipliers, line and surface integrals, vector analysis, Stokes' theorem, Fourier series, calculus of variations.
Prerequisite: MAT137Y1/ MAT157Y1/(MAT135H1, MAT136H1(90%))/(MAT136H1(70%), MAT138H1(70%)), MAT223H1/ MAT240H1
Exclusion: MAT235Y1, MAT257Y1, MATB41H3, MATB42H3, MATB43H3 & MAT368H5

Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics
MAT247H1: Algebra II
Hours: 36L
A theoretical approach to real and complex inner product spaces, isometries, orthogonal and unitary matrices and transformations. The adjoint. Hermitian and symmetric transformations. Spectral theorem for symmetric and normal transformations. Polar representation theorem. Primary decomposition theorem. Rational and Jordan canonical forms. Additional topics including dual spaces, quotient spaces, bilinear forms, quadratic surfaces, multilinear algebra.

Prerequisite: MAT240H1/MAT240H5
Corequisite: MAT157Y1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

CSB352H1: Bioinformatic Methods
Hours: 6L/18P
Use of available programs for analyzing biological data. This is an introductory course with a strong emphasis on hands-on methods. Some theory is introduced, but the main focus is on using extant bioinformatics tools to analyze data and generate biological hypotheses.
Prerequisite: BIO230H1/ BIO255H1, BIO260H1/ HMB265H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology

EEB319H1: Population Ecology
Hours: 24L/36P
Abundance and distribution of populations; population growth and regulation; fluctuations, stochasticity and chaos; meta-population persistence and extinction; age and stage-structured populations; interactions within and between species; optimal harvesting; spread of infectious diseases. Labs include experiments and computer simulations. (Lab materials fee: $25)
Prerequisite: BIO220H1; (MAT135H1, MAT136H1)/ MAT137Y1/ MAT157Y1; and a course in statistics from EEB225H1 (recommended), PSY201H1, STA220H1/ STA250H1/ STA257H1, STA288H1/ GGR270H1, HMB325H1
Recommended Preparation: ENV234H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology

EEB323H1: Evolutionary Genetics
Hours: 36L/12T
Evolutionary biology rests on a foundation of evolutionary genetics. This course focuses on the core ideas in population genetics and extends to evolutionary genomics. Students are exposed to the mathematical theory underlying evolutionary genetics and will learn the mathematical foundations underlying these ideas. Topics include the population genetics of mutation,

migration, drift, and selection, analysis of sequence variation, and the evolution of sexual reproduction.

Prerequisite: BIO220H1, BIO260H1/ HMB265H1
Recommended Preparation: (MAT135H1, MAT136H1)/ MAT137Y1/ MAT157Y1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology

EEB324H1: Evolutionary Ecology
Hours: 36L/12T
Empirical and theoretical approaches to key areas of research including natural selection, sexual selection, and life histories. Other topics may include phenotypic plasticity, speciation, co-evolution, and quantitative genetics.
Prerequisite: EEB318H1/ EEB323H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology

EEB362H1: Macroevolution
Hours: 24L/12T
Explores patterns and processes of large-scale evolutionary change, played out over large geographic expanses and extended periods of time. Integrates information from paleontology, phylogenetics, field studies, functional biology, and experiments to link emergent evolutionary patterns to underlying evolutionary processes. Topics include: speciation, phylogenetic inference, adaptive vs. non-adaptive evolution, evolutionary constraints, diversification and extinction, evolutionary innovations, historical biogeography, and the relationship between evolutionary history and ecology. Tutorials will illustrate common analytical approaches to macroevolutionary investigation and provide in-depth exploration of landmark studies in macroevolution.
Prerequisite: BIO220H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology

GGR337H1: Environmental Remote Sensing
Hours: 24L/24P

Principles of optical, active and passive microwave remote sensing; satellite orbit and sensor characteristics; image processing and analysis techniques and software; and environmental remote sensing applications.
Exclusion: GGR337H5
Recommended Preparation: JEG100H1/ GGR100H1, GGR272H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Geography and Planning

GGR372H1: GIS for Public Health
Hours: 24L/12P
The goal of this course is to leave students with appreciation of the power of Geographic Information Systems (GIS) to explore and analyze spatial health and medical data. The course will focus on organizing health data in a GIS, clustering detection methods, and basic spatial statistics. Other topics like agent-based models and visualization techniques will be touched upon. Lab work will provide hands on experience with example data, leaving students with a firm grasp of contemporary health and medical problems and a skill set of spatial analytical methods that can be used to solve them.
Prerequisite: 8.0 FCEs
Exclusion: GGR300H1(2015-2016), GGR335H5
Recommended Preparation: GGR270H1, GGR272H1
Distribution Requirements: Science; Social Science
Breadth Requirements: Society and its Institutions (3)
Program Area Section: Geography and Planning

GGR373H1: Advanced Geographic Information Systems
Hours: 24L/24P
Advanced theory, techniques, and applications in geographic information systems (GIS), including interpolation, geostatistics, modeling, and raster and vector analysis. GIS project design and implementation.
Prerequisite: GGR273H1
Distribution Requirements: Science
Social ScienceBreadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Geography and Planning

PHY331H1: Introduction to Biological Physics
Hours: 24L/18P

A course for students interested in a deeper understanding of physical phenomena occurring in biological systems. Thermodynamics, diffusion, entropic forces, fluids, biological applications.
Prerequisite: PHY252H1/ CHM222H1/ CHM225Y1, PHY231H1/ PHY250H1/ PHY254H1/ PHY256H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Physics

APM346H1: Partial Differential Equations
Hours: 36L
Sturm-Liouville problems, Green's functions, special functions (Bessel, Legendre), partial differential equations of second order, separation of variables, integral equations, Fourier transform, stationary phase method.
Prerequisite: MAT235Y1/MAT235Y5/(MATB41H3, MATB42H3)/ MAT237Y1/(MATB41H3, MATB42H3, MATB43H3)/MAT237Y5/ MAT257Y1, MAT244H1/MAT244H5/ MAT267H1
Exclusion: MAT351Y1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

APM446H1: Applied Nonlinear Equations
Hours: 36L
Partial differential equations appearing in physics, material sciences, biology, geometry, and engineering. Nonlinear evolution equations. Existence and long-time behaviour of solutions. Existence of static, traveling wave, self-similar, topological and localized solutions. Stability. Formation of singularities and pattern formation. Fixed point theorems, spectral analysis, bifurcation theory. Equations considered in this course may include: Allen-Cahn equation (material science), Ginzburg-Landau equation (condensed matter physics), Cahn-Hilliard (material science, biology), nonlinear Schroedinger equation (quantum and plasma physics, water waves, etc). mean curvature flow (geometry, material sciences), Fisher-Kolmogorov-Petrovskii-Piskunov (combustion theory, biology), Keller-Segel equations (biology), and Chern-Simmons equations (particle and condensed matter physics).
Prerequisite: APM346H1/ MAT351Y1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

APM461H1: Combinatorial Methods
Hours: 36L
A selection of topics from such areas as graph theory, combinatorial algorithms, enumeration, construction of combinatorial identities.
Prerequisite: MAT224H1/ MAT247H1, MAT137Y1/ MAT157Y1, MAT301H1/ MAT347Y1
Recommended Preparation: MAT344H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

APM462H1: Nonlinear Optimization
Hours: 36L
An introduction to first and second order conditions for finite and infinite dimensional optimization problems with mention of available software. Topics include Lagrange multipliers, Kuhn-Tucker conditions, convexity and calculus variations. Basic numerical search methods and software packages which implement them will be discussed.
Prerequisite: MAT223H1, MAT224H1, MAT235Y1,
Recommended Preparation: MAT336H1/ MAT337H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

BCH441H1: Bioinformatics
Hours: 24L/12T
This course is an introduction to computational methods and internet resources in modern biochemistry and molecular biology. The main topics include: sequence and genome databases, sequence alignment and homology search, use and interpretation of molecular structure, and phylogenetic analysis. Assignments focus on hands-on competence building with web-based bioinformatics tools and databases, downloadable software including a molecular viewer and a multiple sequence alignment editor, and the statistics workbench and programming language "R". For syllabus details see:
www.biochemistry.utoronto.ca/undergraduates/courses/BCH441H/
Note BCB420H1 extends this syllabus to computational topics of systems biology.
Prerequisite: BCH210H1/ BCH242Y1; BCH311H1/ MGY311Y1/ PSL350H1 or special permission of the course coordinator
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)

Program Area Section: Biochemistry

CSB472H1: Computational Genomics and Bioinformatics
Hours: 24L/12T
Computational analyses of DNA and RNA expression data. Understanding biological databases, sequence alignment, sequence annotation, gene prediction, computational analysis of function, motif analysis, phylogenetic analysis, and gene expression profiling analysis. Applied, theoretical and statistical issues will be addressed.
Prerequisite: BIO230H1/ BIO255H1
Recommended Preparation: BIO260H1/ HMB265H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology

CSC311H1: Introduction to Machine Learning
Hours:
24L/12T
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. Basics of reinforcement learning.
Prerequisite: CSC207H1, MAT235Y1/ MAT237Y1/ MAT257Y1/(minimum of 77% in MAT135H1 and MAT136H1)/(minimum of 73% in MAT137Y1)/(minimum of 67% in MAT157Y1), MAT221H1/ MAT223H1/ MAT240H1, STA247H1/ STA255H1/ STA257H1
Exclusion: CSC411H1, STA314H1, ECE421H1. NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Recommended Preparation: MAT235Y1/ MAT237Y1/ MAT257Y1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC320H1: Introduction to Visual Computing
Hours: 24L/12P
Image synthesis and image analysis aimed at students with an interest in computer graphics, computer vision, or the visual arts. Focus on three major topics: (1) visual computing principles—computational and mathematical methods for creating, capturing, analyzing, and

manipulating digital photographs (image acquisition, basic image processing, image warping, anti-aliasing); (2) digital special effects—applying these principles to create special effects found in movies and commercials; (3) visual programming—using C/C++ and OpenGL to create graphical user interfaces for synthesizing and manipulating photographs. The course requires the ability to use differential calculus in several variables and linear algebra.
Prerequisite: CSC209H1/(CSC207H1, proficiency in C or C++); MAT221H1/ MAT223H1/ MAT240H1, (MAT136H1 with a minimum mark of 77)/(MAT137Y1 with a minimum mark of 73)/(MAT157Y1 with a minimum mark of 67)/ MAT235Y1/ MAT237Y1/ MAT257Y1
Exclusion: NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Recommended Preparation: MAT235Y1/ MAT237Y1/ MAT257Y1
Distribution Requirements: Science
Program Area Section: Computer Science

CSC336H1 - Numerical Methods
Hours: 24L/12T
The study of computational methods for solving problems in linear algebra, non-linear equations, and approximation. The aim is to give students a basic understanding of both floating-point arithmetic and the implementation of algorithms used to solve numerical problems, as well as a familiarity with current numerical computing environments.
Prerequisite: CSC148H1; MAT133Y1(70%)/(MAT135H1, MAT136H1)/ MAT135Y1/ MAT137Y1/ MAT157Y1, MAT221H1/ MAT223H1/ MAT240H1
Exclusion: CSC350H1, CSC351H1. NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC343H1: Introduction to Databases
Hours: 36L
Introduction to database management systems. The relational data model. Relational algebra. Querying and updating databases: the query language SQL. Application programming with SQL. Integrity constraints, normal forms, and database design. Elements of database system technology: query processing, transaction management.

Prerequisite: CSC165H1/ CSC240H1/(MAT135H1, MAT136H1)/ MAT135Y1/ MAT137Y1/ MAT157Y1; CSC207H1. Prerequisite for Engineering students only: ECE345H1/ ESC190H1/ CSC190H1/ CSC192H1
Exclusion: CSC443H1. NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC373H1: Algorithm Design, Analysis & Complexity
Hours: 36L/12T
Standard algorithm design techniques: divide-and-conquer, greedy strategies, dynamic programming, linear programming, randomization, network flows, approximation algorithms. Brief introduction to NP-completeness: polynomial time reductions, examples of various NP-complete problems, self-reducibility. Additional topics may include approximation and randomized algorithms. Students will be expected to show good design principles and adequate skills at reasoning about the correctness and complexity of algorithms.
Prerequisite: CSC263H1/ CSC265H1
Exclusion: CSC375H1. NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC384H1: Introduction to Artificial Intelligence
Hours: 24L/12T
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.
Prerequisite: (CSC263H1/ CSC265H1, STA247H1/ STA255H1/ STA257H1)/Permission of the Cognitive Science Director

Exclusion: NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Recommended Preparation: CSC324H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC401H1: Natural Language Computing
Hours: 24L/12T
Introduction to techniques involving natural language processing and speech in applications such as information retrieval, speech recognition and synthesis, machine translation, summarization, and dialoque. N-grams, corpus analysis, neural methods, and information theory. Python and other software.
Prerequisite: CSC207H1/ CSC209H1; STA247H1/ STA255H1/ STA257H1
Exclusion: NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Recommended Preparation: MAT221H1/ MAT223H1/ MAT240H1 is strongly recommended
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC412H1: Probabilistic Learning and Reasoning
Hours: 24L/12T
An introduction to probability as a means of representing and reasoning with uncertain knowledge. Qualitative and quantitative specification of probability distributions using probabilistic graphical models. Algorithms for inference and probabilistic reasoning with graphical models. Statistical approaches and algorithms for learning probability models from empirical data. Applications of these models in artificial intelligence and machine learning.
Prerequisite: CSC411H1/CSC311H1/ STA314H1
Exclusion: NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC413H1: Neural Networks and Deep Learning
Hours: 24L/12T
An introduction to neural networks and deep learning. Backpropagation and automatic differentiation. Architectures: convolutional networks and recurrent neural networks. Methods for improving optimization and generalization. Neural networks for unsupervised and reinforcement learning.
Prerequisite: CSC311H1/ CSC411H/ STA314H1, MAT235Y1/ MAT237Y1/ MAT257Y1, MAT221H1/ MAT223H1/ MAT240H1
Exclusion: CSC321H1/ CSC421H1. NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

CSC420H1: Introduction to Image Understanding
Hours: 24L/12P
Introduction to basic concepts in computer vision. Extraction of image features at multiple scales. Robust estimation of model parameters. Multiview geometry and reconstruction. Image motion estimation and tracking. Object recognition. Topics in scene understanding as time permits.
Prerequisite: CSC263H1/ CSC265H1, (MAT135H1, MAT136H1)/ MAT135Y1/ MAT137Y1/ MAT157Y1, MAT221H1/ MAT223H1/ MAT240H1
Exclusion: NOTE: Students not enrolled in the Computer Science Major or Specialist program at the UTSG, UTM, or UTSC are limited to a maximum of three 300-/400-level CSC/ECE half-courses.
Recommended Preparation: CSC320H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Computer Science

EEB313H1: Quantitative Methods in R for Biology
Hours: 24L/24P
The quantitative analysis and management of biological data is crucial in modern life sciences disciplines. Students will develop skills with R as applied to problems in ecology and evolutionary biology to learn reproducible approaches for data management, data

manipulation, visualization, modelling, statistical analysis, and simulation for solving biological problems.
Prerequisite: BIO220H1, EEB225H1/ STA288H1/ STA220H1
Exclusion: STA130H1, PSY305H1
Recommended Preparation: CSC108H1/ CSC120H1/ CSC121H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Ecology and Evolutionary Biology

EEB430H1: Modeling in Ecology and Evolution
Hours: 24L/12P
Study of ecology and evolution uses models to explain biological phenomena including the maintenance of biodiversity, population growth, competition, eco-evolutionary dynamics, trait and molecular evolution, epidemiology, spatial ecology, phylogeny and extinction. Students will learn to develop, assess and apply analytical, simulation and statistical models for analysis and data interpretation.
Prerequisite: BIO220H1, EEB225H1, MAT136H1/ MAT137Y1/ MAT223H1, and at least one of EEB319H1/ EEB321H1/ EEB322H1/ EEB323H1

Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology

EEB459H1: Population Genetics
Hours: 24L/12T
A focus on theoretical population genetics, using mathematical models to understand how different evolutionary forces drive allele frequency change. Students learn how to mathematically derive classic results in population genetics. Topics include drift, coalescence, the relationship between population and quantitative genetics, selection in finite populations, and mutation load. Offered in alternate years; next offered in 2018-19.
Prerequisite: BIO260H1/ HMB265H1, EEB323H1
Recommended Preparation: A solid understanding of basic algebra and calculus.
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology

EEB460H1: Molecular Evolution and Genomics

Hours: 36L
Processes of evolution at the molecular level, and the analysis of molecular data. Gene structure, neutrality, nucleotide sequence evolution, sequence evolution, sequence alignment, phylogeny construction, gene families, transposition.
Prerequisite: BIO220H1, BIO230H1/ BIO255H1, BIO260H1/ HMB265H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology

EEB498Y1: Advanced Research Project in Ecology and Evolutionary Biology
Hours: TBA
An advanced research project (a literature review alone is not sufficient) requiring the prior consent of a member of the Department to supervise the project. The topic is to be one mutually agreed on by the student and supervisor. They must arrange the time, place, and provision of any materials and submit to the Undergraduate Office a signed form of agreement outlining details prior to being enrolled. This course is normally open only to highly self-motivated students who are in their Fourth-Year and have adequate background in ecology and/or evolutionary biology. Students are required to write up the results of their research in a formal paper, often in the format of a research article, and are also required to present the results at a poster session and/or oral presentation. The time commitment is approximately 8 hours per week. Students should contact their potential supervisors over the summer before classes begin in September. Information regarding how to register for the course is available on the EEB website. Students in this course are also concurrently enrolled in EEB488H1Y Research Issues in Ecology and Evolutionary Biology. Not eligible for CR/NCR option.
Prerequisite: Permission of department
Corequisite: EEB488H1Y
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology

EEB499Y1: Advanced Research Project in Ecology and Evolutionary Biology II
Hours: TBA
Allows students to do another independent project, supervision of which must be different from EEB497H1/EEB498Y1. Operates in the same manner as EEB498Y1. Not eligible for CR/NCR option.
Prerequisite: EEB497H1/ EEB498Y1 and permission of department
Distribution Requirements: Science

Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Ecology and Evolutionary Biology

MAT332H1: Introduction to Graph Theory
Hours: 36L
This course will explore the following topics: Graphs, subgraphs, isomorphism, trees, connectivity, Euler and Hamiltonian properties, matchings, vertex and edge colourings, planarity, network flows and strongly regular graphs. Participants will be encouraged to use these topics and execute applications to such problems as timetabling, tournament scheduling, experimental design and finite geometries.
Prerequisite: MAT224H1/MATB24H3/MAT224H5/ MAT247H1/MAT247H5
Corequisite: Recommended Corequisite: MAT301H1/ MAT347Y1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT335H1: Chaos, Fractals and Dynamics
Hours: 36L
An elementary introduction to a modern and fast-developing area of mathematics. One-dimensional dynamics: iterations of quadratic polynomials. Dynamics of linear mappings, attractors. Bifurcation, Henon map, Mandelbrot and Julia sets. History and applications.
Prerequisite: MAT137Y1/(MATA30H3, MATA31H3, MATA37H3)/MAT137Y5/ MAT157Y1/ MAT157Y5/ MAT235Y1/MAT235Y5/(MATB41H3, MATB42H3)/ MAT237Y1/(MATB41H3, MATB42H3, MATB43H3)/MAT237Y5, MAT223H1/MATA23H3/MAT223H5/ MAT240H1/ MAT240H5
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MAT344H1: Introduction to Combinatorics
Hours: 36L
Basic counting principles, generating functions, permutations with restrictions. Fundamentals of graph theory with algorithms; applications (including network flows). Combinatorial structures including block designs and finite geometries.
Prerequisite: MAT223H1/MATA23H3/MAT223H5/ MAT240H1/MAT240H5
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)

Program Area Section: Mathematics

MAT351Y1: Partial Differential Equations
Hours: 72L
This is a first course in Partial Differential Equations, intended for Mathematics students with interests in analysis, mathematical physics, geometry, and optimization. The examples to be discussed include first-order equations, harmonic functions, the diffusion equation, the wave equation, Schrodinger's equation, and eigenvalue problems. In addition to the classical representation formulas for the solutions of these equations, there are techniques that apply more broadly: the notion of well-posedness, the method of characteristics, energy methods, maximum and comparison principles, fundamental solutions, Green's functions, Duhamel's principle, Fourier series, the min-max characterization of eigenvalues, Bessel functions, spherical harmonics, and distributions. Nonlinear phenomena such as shock waves and solitary waves are also introduced.
Prerequisite: MAT257Y1/85% in MAT237Y1, MAT267H1
Exclusion: APM351Y1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Mathematics

MGY428H1: Functional Genomics
Hours: 24L
A broad-ranging course that covers many aspects of genomics and functional genomics, which is the discipline of defining and attributing function to all of the heritable material of an organism on a genome-wide scale, as applied to invertebrates and vertebrates. The primary and review literature will be the basis of all lectures.
Prerequisite: BCH210H1/ BCH242Y1; BIO260H1/ HMB265H1; MGY311Y1/ CSB349H1/ BCH311H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Molecular Genetics and Microbiology
PHY431H1: Topics in Biological Physics
Hours: 24L/12T
An introduction to the physical phenomena involved in the biological processes of living cells and complex systems. Models based on physical principles applied to cellular processes will be developed. Biological computational modeling will be introduced.
Prerequisite: PHY250H1, PHY252H1/ CHM222H1/ CHM225Y1, PHY331H1

Exclusion: PHY346H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Physics

PSY305H1: The Treatment of Psychological Data
Hours: 36L
This course emphasizes the advanced use of statistical computer program packages for the treatment of psychological data collected in laboratory and field studies. Students analyze sets of data and interpret results. Various methods of ensuring the trustworthiness and accuracy of analysis are discussed.
Prerequisite: PSY202H1 (or exclusion)
Exclusion: EEB313H1
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Psychology

STA302H1: Methods of Data Analysis I
Hours: 36L
Introduction to data analysis with a focus on regression. Initial Examination of data. Correlation. Simple and multiple regression models using least squares. Inference for regression parameters, confidence and prediction intervals. Diagnostics and remedial measures. Interactions and dummy variables. Variable selection. Least squares estimation and inference for non-linear regression.
Prerequisite: STA238H1/ STA248H1/ STA255H1/ STA261H1/ ECO227Y1/ STAB57H3/STA258H5/STA260H5/ECO227Y5; CSC108H1/ CSC120H1/ CSC121H1/ CSC148H1/ CSCA08H3/CSCA48H3/CSC108H5/CSC148H5; MAT221H1(70%)/ MAT223H1/ MAT240H1/ MATA23H3/MAT223H5/MAT240H5
Exclusion: STAC67H3, STA302H5
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA303H1: Methods of Data Analysis II
Hours: 36L
Analysis of variance for one-and two-way layouts, logistic regression, loglinear models, longitudinal data, introduction to time series.

Prerequisite: STA302H1/STAC67H3/STA302H5
Exclusion: STAC51H3
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA304H1: Surveys, Sampling and Observational Data
Hours: 36L
Design of surveys, sources of bias, randomized response surveys. Techniques of sampling; stratification, clustering, unequal probability selection. Sampling inference, estimates of population mean and variances, ratio estimation. Observational data; correlation vs. causation, missing data, sources of bias.
Prerequisite: ECO220Y1/ ECO227Y1/ GGR270H1/ PSY201H1/ SOC300H1/ SOC202H1/ STA220H1/ STA255H1/ STA261H1/ STA248H1/ STA238H1/ STA288H1/ EEB225H1/ STAB22H3/ STAB57H3/ STA220H5/ STA258H5/ STA260H5/ ECO220Y5/ ECO227Y5
Exclusion: STAC50H3, STAC52H3, STA304H5
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA305H1: Design and Analysis of Experiments
Hours: 36L
Experiments vs observational studies, experimental units. Designs with one source of variation. Complete randomized designs and randomized block designs. Factorial designs. Inferences for contrasts and means. Model assumptions. Crossed and nested treatment factors, random effects models. Analysis of variance and covariance. Sample size calculations.
Prerequisite: STA302H1/STAC67H3/STA302H5
Exclusion: STAC50H3, STAC52H3, STA305H5
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

STA365H1: Applied Bayesian Statistics
Hours: 36L
Bayesian inference has become an important applied technique and is especially valued to solve complex problems. This course first examines the basics of Bayesian inference. From

there, this course looks at modern, computational methods and how to make inferences on complex data problems.
Prerequisite: STA302H1/STAC67H3/STA302H5
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Public Health Sciences, Statistical Sciences

STA480H1: Fundamentals of Statistical Genetics
Hours: 36L/9P
Statistical analysis of genetic data is an important emerging research area with direct impact on population health. This course provides an introduction to the concepts and fundamentals of statistical genetics, including current research directions. The course includes lectures and hands-on experience with R programming and state-of-the-art statistical genetics software packages.
Prerequisite: STA303H1

Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Statistical Sciences

BCB410H1: Applied Bioinformatics
Hours: 24L
Practical introduction to concepts, standards and tools for the implementation of strategies in bioinformatics and computational biology. Student led discussions plus a strong component of hands-on exercises.
Prerequisite: BCH311H1/ MGY311Y1; (CSC324H1/ CSC373H1/ CSC375H1) or permission of the course coordinator
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Biochemistry, Cell and Systems Biology

BCB420H1: Computational Systems Biology
Hours: 24L
Current approaches to using the computer for analyzing and modeling biology as integrated molecular systems. Lectures plus hands-on practical exercises. The course extends and complements an introductory Bioinformatics course, such as BCH441H1.
Prerequisite: BCH441H1/ CSB472H1 or permission of the course coordinator

Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Biochemistry, Cell and Systems Biology

BCH441H1: Bioinformatics
Hours: 24L/12T
This course is an introduction to computational methods and internet resources in modern biochemistry and molecular biology. The main topics include: sequence and genome databases, sequence alignment and homology search, use and interpretation of molecular structure, and phylogenetic analysis. Assignments focus on hands-on competence building with web-based bioinformatics tools and databases, downloadable software including a molecular viewer and a multiple sequence alignment editor, and the statistics workbench and programming language "R". For syllabus details see:
www.biochemistry.utoronto.ca/undergraduates/courses/BCH441H/
Note BCB420H1 extends this syllabus to computational topics of systems biology.
Prerequisite: BCH210H1/ BCH242Y1; BCH311H1/ MGY311Y1/ PSL350H1 or special permission of the course coordinator
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Biochemistry

CSB435H1: Regulatory Networks and Systems in Molecular Biology
Hours: 24L
This course will expose students to several of the best-understood regulatory networks in molecular biology, as well as recent technological and methodological developments. Emphasis is on the mechanistic basis for these systems, methods and models for quantitative analysis of regulatory networks and the biological logic they encode.

Prerequisite: BCH311H1/ CSB349H1/ MGY311Y1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology

CSB472H1: Computational Genomics and Bioinformatics
Hours: 24L/12T
Computational analyses of DNA and RNA expression data. Understanding biological databases, sequence alignment, sequence annotation, gene prediction, computational analysis of function,

motif analysis, phylogenetic analysis, and gene expression profiling analysis. Applied, theoretical and statistical issues will be addressed.
Prerequisite: BIO230H1/ BIO255H1
Recommended Preparation: BIO260H1/ HMB265H1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology

CSB498Y1: Independent Research in Cell and Systems Biology I
Hours:
TBA
An original research project (a literature review alone is not sufficient) requiring the prior consent of a member of the Department to supervise the project. The topic is to be mutually agreed upon by the student and supervisor. They must arrange the time, place, and provision of any materials and submit to the Undergraduate Office a signed form of agreement outlining details prior to being enrolled. In the Fall/Winter session, a commitment of 8-10 hours per week is expected for research and related course activities. In the Summer session, the number of hours doubles (16-20 per week) as the length of the term is halved. This course is normally open only to fourth year students with adequate background in Cell and Systems Biology. Course requirements include a final report and either an oral presentation (Summer session) or a poster presentation (Fall/Winter session). Four workshops on scientific research are scheduled and highly recommended. Details for enrollment are available at https://csb.utoronto.ca/undergraduate-studies/undergraduate-courses/undergraduate-course-level-400/ (Lab Materials Fee: $50). Not eligible for CR/NCR option.
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology

CSB499Y1: Independent Research in Cell and Systems Biology II
Allows students to do a second independent project. Operates in the same manner as CSB497H1/ CSB498Y1. Students who have completed both CSB497H1 and CSB498Y1 are excluded from taking CSB499Y1. (Lab Materials Fee: $50). Not eligible for CR/NCR option.
Prerequisite: CSB497H1/ CSB498Y1
Distribution Requirements: Science
Breadth Requirements: Living Things and Their Environment (4)
Program Area Section: Cell and Systems Biology

PSY474H1: Computation in Psychology
Hours: 36L
This lecture course surveys computational perspectives on the mind and brain and introduces computational tools for connecting psychological and neural data to theory. Topics may include neural networks, probabilistic models, pattern recognition, and other techniques applicable to psychological research and general analysis. Basic familiarity with programming is recommended but not required.
Prerequisite: PSY202H1 (or exclusion)
Exclusion: PSY471H1 (Fall of 2015)
Distribution Requirements: Science
Breadth Requirements: The Physical and Mathematical Universes (5)
Program Area Section: Psychology

Appendix B: Undergraduate Calendar Copy

Quantitative Biology Major (Science Program) — ASMAJXXXX

Description

The Quantitative Biology Major program (8.0 FCEs) is designed for students with a deep interest in biology who wish to gain a strong grounding in quantitative methods and their application to biological questions. More than ever, advancements in biology, from the molecular through the organismal to the ecosystem level, require quantitative thinking and skills along with a strong understanding of biological processes. Interdisciplinary research that draws from the natural sciences, mathematics, statistics and computer science, is an important aspect of modern biology. This major provides foundations in biology and quantitative approaches used to test and advance biological knowledge, and is appropriate for students who wish to pursue a career or graduate studies in a broad range of life sciences, ranging from biomedical to conservation to epidemiology.

The program is delivered through a mixture of classroom-learning and applied laboratory teaching, with an emphasis on understanding how quantitative methods inform our understanding of biology, and how they can be applied to test and develop new hypotheses. Students also have access to independent research opportunities that enhance professional skills, science communication, and the development and application of knowledge in quantitative biology.

Quantitative Biology Major students have priority enrollment in EEB courses, but not in courses offered by other departments, such as STA, MAT, CSC, CSB and BCB. Students should be aware that some courses listed have prerequisites that are not listed below. For students intending to pursue graduate studies, it is strongly recommended that an independent research course such as EEB498Y1 be included as part of the Quantitative Biology major.

Enrolment Requirements

This is a limited enrolment program. To enroll, students must have completed 4.0 FCE, and:

- a minimum grade of 70% in an introductory biology course (BIO120H1/ BIO130H1) and

- a minimum grade of 70% in an introductory quantitative course (CSC108H1/ CSC120H1/ CSC148H1/ CS110Y1/MAT135H1/ MAT136H1/ MAT137Y1/ MAT157Y1)

Completion Requirements

(8.0 FCEs including at least 2.0 FCEs at the 300+ series with at least 0.5 of at the 400 series level)

First Year (2.5 FCEs): BIO120H1; BIO130H1; CSC108H1/CSC120H1/ CSC148H1/CS110Y1; (MAT135H1,MAT136H1)/MAT137Y1/MAT157Y1

Higher Years:

1. 1.5 FCE: BIO220H1, BIO230H1/BIO255H1, BIO260H1/HMB265H1
2. 1.0 FCE in introductory probability and statistics: EEB225H1, GGR270H1, PSY201H1, PSY202H1, STA220H1, STA221H1, STA237H1, STA238H1, STA247H1, STA248H1, STA255H1, STA257H1, STA261H1, STA288H1
3. 0.5 FCE in intermediate math: APM236H1, MAT221H1/MAT223H1, MAT224H1, MAT240H1, MAT237Y1, MAT247H1
4. 1.0 FCE from: CSB352H1, EEB319H1, EEB323H1, EEB324H1, EEB362H1, GGR337H1, GGR372H1, GGR373H1, PHY331H1
5. 1.0 FCE from: APM346H1, APM446H1, APM461H1, APM462H1, BCH441H1, CSB472H1, CSC311H1, CSC320H1, CSC336H1, CSC343H1, CSC373H1, CSC384H1, CSC401H1, CSC412H1, CSC413H1, CSC420H1, EEB313H1, EEB430H1, EEB459H1, EEB460H1, EEB498Y1, EEB499Y1, MAT332H1, MAT335H1, MAT344H1, MAT351Y1, MGY428H1, PHY431H1, PSY305H1, STA302H1, STA303H1,STA304H1, STA305H1, STA355H1, STA365H1, STA480H1
6. 0.5 FCE at 400 series from: BCB410H1, BCB420H1, BCH441H1, CSB435H1, CSB472H1, CSB498Y1, CSB499Y1, EEB430H1, EEB459H1, EEB460H1, EEB498Y1, EEB499Y1, PHY431H1, PSY474H1, STA480H1

Appendix C: Library Statement

University of Toronto Libraries Report for
Quantitative Biology (QBIO) Major Program,
Department of Ecology & Evolutionary Biology, 2020

Context: The University of Toronto Library (UTL) system is the largest academic library in Canada and is currently ranked third among academic research libraries in North America.[3] The UTL has an annual acquisition budget of $39 million. Its research and special collections comprise over 12.3 million print volumes, 5.6 million microforms, over 10,000 print journal subscriptions, and rich collections of manuscripts, films, and cartographic materials. The system provides access to more than 2.4 million electronic books, 150,000 electronic journals, and rich primary source materials.[4] Numerous, wide-ranging collections, facilities and staff expertise reflect the breadth of research and instructional programs at the University, and attract unique donations of books and manuscripts from around the world, which in turn draw scholars for research and graduate work.

Major North American Research Libraries					
	2013-2014	**2014-2015**	**2015-2016**	**2016-2017**	**2017-2018**
ARL RANK	**UNIVERSITY**	**UNIVERSITY**	**UNIVERSITY**	**UNIVERSITY**	**UNIVERSITY**
1	Harvard	Harvard	Harvard	Harvard	Harvard
2	Yale	Yale	Yale	Yale	Yale
3	**Toronto (3rd)**	Columbia	Michigan	Michigan	**Toronto (3rd)**
4	Columbia	**Toronto (4th)**	Columbia	Columbia	Columbia
5	Michigan	Michigan	New York	New York	Michigan
6			**Toronto (6th)**	**Toronto (6th)**	

Top 5 Canadian Universities in the ARL Ranking of Major North American Research Libraries				
2013-2014	**2014-2015**	**2015-2016**	**2016-2017**	**2017- 2018**
RANK/UNIVERSITY	**RANK/UNIVERSITY**	**RANK/UNIVERSITY**	**RANK/UNIVERSITY**	**RANK/UNIVERSITY**
3/Toronto	**4/Toronto**	**6/Toronto**	**6/Toronto**	**3/Toronto**
22/British Columbia	27/Alberta	31/Alberta	29/Alberta	29/Alberta
26/Alberta	31/British Columbia	35/British Columbia	37/British Columbia	33/British Columbia
35/McGill	43/McGill	42/McGill	40/McGill	38/McGill
36/Montreal	49/Calgary	63/Calgary	75/Calgary	69/Manitoba

[3] As per Association of Research Libraries Statistics.

[4] Figures as of August, 2019

Space and Access Services: The UTL's 42 libraries are divided into four administrative groups: Central, Departmental/local, Campus (UTM & UTSC) and Federated and Affiliated College Libraries. The UTL provides a variety of individual and group study spaces for students. Study space and computer facilities are available twenty four hours, five days per week at one location, Robarts Library, with additional extended hours during study and exam periods at both UTSC and UTM. Web-based services and electronic materials are accessible at all times from campus or remote locations.

Teaching, Learning & Research Support: Libraries play an important role in the linking of teaching and research in the University. To this end, information literacy instruction is offered to assist in meeting the Quantitative Biology Major program level expectations in the ability to gather, evaluate and interpret information. Librarians collaborate with instructors on assignment design, provide student research consultations, and offer just-in-time student research help in person, by phone, or through online chat. Librarians are also available to support curriculum mapping initiatives. Special initiatives, such as the Libraries Undergraduate Research Prize, and an annual forum for student journal editors, extend information literacy beyond the classroom. These services align with the Association of College and Research Libraries (ACRL) *Framework for Information Literacy for Higher Education*.[5]

Program Specific Instructional Support: Instruction occurs at a variety of levels for Ecology & Evolutionary Biology, Mathematics, Statistical Sciences, and Computer Science students and is provided by the faculty liaison librarians for Earth Sciences, Mathematics & Statistics, and Computer Science. The Earth Sciences, Mathematical Sciences, and Engineering & Computer Science libraries facilitate formal instruction integrated into the class schedule and hands-on tutorials related to course assignments including library instruction in CSC290 – Communications Skills for Computer Scientists and MAT198 – Cryptology: The Mathematics of Secrecy & Security. The Library, through its liaison librarians, customizes feeds of library resources which appear prominently in Portal/Quercus course pages. Course specific research guides have been created for BIO120 – Adaptation & Biodiversity, MAT135 – Calculus 1(A), MAT135 – Calculus 1(B), MAT198 – Cryptology: The Mathematics of Secrecy & Security, CSC290 – Communication Skills for Computer Scientists, as well as a general Statistics, Mathematics, and Computer Science subject area research guides.

Collections: Many college and campus libraries collect materials in support of the Quantitative Biology Major program; the largest collection of materials is located in the Earth Sciences, Mathematical Sciences, and the Engineering & Computer Science libraries. Collections are purchased in all formats to meet the variety of preferences and styles of our current students and faculty. The University of Toronto Library is committed to collecting both print and electronic materials in support of Earth Sciences at the University of Toronto.

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[5] Association of College & Research Libraries. Framework for Information Literacy for Higher Education. ACRL, 2016. http://www.ala.org/acrl/sites/ala.org.acrl/files/content/issues/infolit/Framework_ILHE.pdf

Journals: The Library subscribes to 25 of the top 25 journals listed in Journal Citation Reports (JCR)[6] in subject area of biology. Of these titles, all 25 are available electronically to staff and students of the University. We prioritize acquisition of online journals where possible.

Monographs: The UTL maintains comprehensive book approval plans with 50 book vendors worldwide. These plans ensure that the Library receives academic monographs from publishers all over the world in an efficient manner. In support of Earth Sciences, monographs are purchased in electronic form where possible, and the Library currently receives all current e-books directly from the following publishers: Springer, Elsevier, Oxford University Press, Cambridge University Press, ACM, IEEE, & CRC.

Preservation, Digitization, and Open Access: The UTL supports open access to scholarly communication and research information through its institutional research repository (known as T-Space), its Downsview print repository, its open journal services, subscriptions to open access publications, and support for preservation of research materials in all formats. In addition to acquiring materials in support of Earth Sciences, the Library has digitized its monograph holdings published before 1923. These books are available without charge to any Internet user.

Key Databases: Biosis, Scopus, Web of Science, MathSciNet

Prepared by: Bruce Garrod, Head Librarian, Earth Sciences Library; Mathematical Sciences Library
Michelle Spence, Engineering & Computer Science Librarian. March 10, 2020

Submitted by: Larry Alford, Chief Librarian, University of Toronto Libraries, June 12, 2020

[6] 2018 Journal Citation Reports® (Thomson Reuters, 20xx)

Appendix D: Student Support Services

Student Service Information for Quality Assurance Framework, St. George Campus

All University of Toronto undergraduate and graduate students have access to student services on all three campuses, Mississauga, St. George (downtown Toronto), and Scarborough, regardless of their 'home campus.' The services and co-curricular educational opportunities provide a complement to the formal curriculum by engaging and challenging students to reach their full potential as learners, leaders and citizens. At the University of Toronto (St. George Campus) these services are organized by Student Life Programs and Services, and the academic division registrar offices, which support the success of our students from the time they are admitted through degree completion and beyond.

Students have access to comprehensive **physical and mental health care** on campus including a medical clinic, travel medicine services, immunization, contraception and sexual health education. Counselling and treatment options for psychological and emotional concerns include psychotherapy, group therapy and pharmacotherapy, as well as specialized assault counseling services.

Housing needs, including off-campus housing listings and resources for students living independently, are met through the Student Housing Service.

Coaching and education in the development of key **learning skills** — from time management to overcoming exam anxiety — is provided through the Academic Success Centre. The ASC also partners with faculty to integrate success strategies and support into the curriculum.

Students' career exploration and employment services are provided through a **Career Centre** offering resume and interview coaching, workshops, career resources, on- and off-campus employment and volunteer listings, job shadowing, and career counseling.

Specialized services are provided for **international students** (orientation, advising, cross-cultural counselling), students with **disabilities** (academic accommodations, advising), students with **children or other family responsibilities** (advising, resources, subsidized child care), **aboriginal students** (academic support, financial counselling) and **lesbian, gay, bisexual and transgender** students (counselling, referrals, equity outreach and engagement).

Participation in **campus life** and **experiential learning** are facilitated through Hart House (clubs, committees, events), the Centre for Community Partnerships (service learning), the Multifaith Centre (interfaith dialogue, events), and the Office of Student Life (leadership development, orientation, recognition and support for student groups, activities.) **Sport and recreational facilities and programs** are provided to all students through both Hart House and the Faculty of Kinesiology and Physical Education.

Students in the QBio program will also have access to Writing Centres and Math Learning Centres, both of which are designed to provide students with the support needed to excel in understanding and communicating Quantitative Biology. Further details on these centres and other support systems are available at (http://www.eeb.utoronto.ca/undergrad/undss.htm).

The Department of Ecology and Evolutionary Biology also provides resources targeted specifically at its students and their needs. These services include many networking and support opportunities sponsored by EEB, such as the departmental peer-to-peer mentor program, student-alumni networking programs like the “Backpack-to-Briefcase” networking dinner, organized events at the Koffler Scientific Reserve (University of Toronto field station), and regular info-meetings on research, career and graduate school opportunities for undergraduates in EEB. It also hosts a student lounge that serves as a meeting place for undergraduate students. Each year, the department hosts a scientific poster competition, which acts as a student peer networking opportunity and also provides a window into student involvement in research being pursued in EEB. Finally, EEB actively supports and coordinates with the EEB undergraduate student union (EEBU) to facilitate peer-to-peer sharing of information and opportunities. EEB’s Wellness Committee is also focused on growing additional networking opportunities between undergraduates, graduate students and faculty, and acting as a departmental liaison for accessing university resources and workshops on student mental health.

Appendix E: Compilation of Faculty CVs

See attachment

Appendix F: Sample Paths of Study for Double Major

There are many paths that students can elect to use to combine a major in Quantitative Biology with other major programs. Here we list a few examples of course options that a student might elect to take when combining QBio with major programs in EEB, Math, Stats, CS, Human Biology, and Psychology. We anticipate that these double-major combinations would be attractive to students and also provide exciting cross-sections of coursework for student training.

Note. Students enrolled in two Majors must ensure they have a minimum of 12.0 different courses (FCEs) between the programs.

QBio Major (8.0 FCEs) + EEB Major (8.0 FCEs)

In order to meet the 12.0 different course requirement, this student may have up to 4.0 overlapping credits between her majors (8.0 + 8.0 = 16.0; 16.0 – 12.0 = 4.0).

Year 1		
QBio	EEB	
BIO120H1	BIO120H1	0.5 overlap
BIO130H1	BIO130H1	0.5 overlap
CHM135H1, CHM136H1	CHM135H1, CHM136H1	1.0 overlap
CSC120H1		
MAT135H1		

Year 2		
QBio	EEB	
BIO220H1	BIO220H1	0.5 overlap
BIO230H1	BIO230H1	0.5 overlap
BIO260H1	BIO260H1	0.5 overlap
EEB225H1	EEB225H1	0.5 overlap
STA247H1	BIO251H1	
MAT221H1	ENV234H1	

Year 3		
QBio	EEB	
EEB362H1	EEB386H1	
EEB323H1	EEB384H1	
	EEB328H1	
	EEB375H1	
	EHJ352H1	

Year 4		
QBio	EEB	
EEB459H1	EEB433H1	
EEB460H1		

QBio Major (8.0 FCEs) + Mathematics Major (7.5 FCEs)

In order to meet the 12.0 different course requirement, this student may have up to 3.5 overlapping credits between her majors (8.0 + 7.5 = 15.5; 15.5 – 12.0 = 3.5).

Year 1		
QBio	Math	
MAT135H1	MAT135H1	0.5 overlap
BIO120H1	MAT136H1	
MAT223H1	MAT223H1	0.5 overlap
BIO130H1		
CHM135H1, CHM136H1		
CSC108H1		

Year 2		
QBio	Math	
BIO220H1	MAT224H1	
BIO230H1	MAT235H1	
BIO260H1	MAT244H1	
EEB225H1	MAT246H1	
STA247H1	ETH210H1	

Year 3		
QBio	Math	
EEB362H1	ACT230H1	
EEB323H1	MAT301H1	
MAT332H1	MAT332H1	0.5 overlap
	MAT309H1	
	MAT334H1	

Year 4		
QBio	Math	
EEB430H1	MAT401H1	
	MAT402H1	

QBio Major (8.0 FCEs) + Statistics Major (7 FCEs)

In order to meet the 12.0 different course requirement, this student may have up to 3 overlapping credits between her majors (8.0 + 7 = 15; 15 – 12.0 = 3).

Year 1		
QBio	Stats	
CSC120H1	CSC120H1	0.5 overlap
MAT135H1	MAT135H1, MAT136H1	0.5 overlap
BIO120H1	STA130H1	
BIO130H1	MAT223H1	
CHM135H1, CHM136H1		

Year 2		
QBio	Stats	
BIO220H1	MAT235Y1	
STA237H1	STA237H1	0.5 overlap
STA238H1	STA238H1	0.5 overlap
BIO230H1		
BIO260H1		
MAT240H1		

Year 3		
QBio	Stats	
EEB323H1	STA302H1	
EEB362H1	STA347H1	
STA303H1	STA355H1	

Year 4		
QBio	Stats	
STA480H1	STA480H1	0.5 overlap
	STA410H1	

QBio Major (8.0 FCEs) + Computer Science Major (8.0 FCEs)

In order to meet the 12.0 different course requirement, this student may have up to 4.0 overlapping credits between her majors (8.0 + 8.0 = 16.0; 16.0 – 12.0 = 4.0).

Year 1		
QBio	CompSci	
CSC108H1	CSC108H1	0.5 overlap
MAT135H1	MAT135H1, MAT136H1	0.5 overlap
BIO120H1	CSC148H1	
BIO130H1	CSC165H1	
CHM135H1, CHM136H1		

Year 2		
QBio	CompSci	
BIO220H1	CSC207H1	
BIO230H1	CSC236H1	
BIO260H1	CSC258H1	
EEB225H1	CSC263H1	
STA247H1	STA247H1	0.5 overlap

Year 3		
QBio	CompSci	
EEB323H1	CSC304H1	

MAT335H1	MAT335H1	0.5 overlap
MAT221H1	MAT221H1	0.5 overlap
EEB362H1		

Year 4		
QBio	CompSci	
EEB460H1	CSC321H1	
	CSC343H1	
	ECE489H1	

QBio Major (8.0 FCEs) + Human Biology Major (8.0 FCEs)

In order to meet the 12.0 different course requirement, this student may have up to 4.0 overlapping credits between her majors (8.0 + 8.0 = 16.0; 16.0 – 12.0 = 4.0).

Year 1		
QBio	HMB	
CSC120H1		
MAT135H1	MAT135H1	0.5 overlap
BIO120H1	BIO120H1	0.5 overlap
BIO130H1	BIO130H1	0.5 overlap
CHM135H1, CHM136H1	CHM135H1, CHM136H1	1.0 overlap

Year 2		
QBio	HMB	
BIO220H1	BIO220H1	0.5 overlap
BIO230H1	BIO230H1	0.5 overlap
BIO260H1	BIO260H1	0.5 overlap
STA220H1	BHC210H1	
STA221H1	HMB204H1	
MAT221H1		

Year 3		
QBio	HMB	
EEB323H1	PSL300H1	

EEB362H1	PSL301H1	
	HMB302H1	
	ANA300Y1	

Year 4		
QBio	HMB	
EEB459H1	HMB452H1	
EEB460H1	EEB428H1	

QBio Major (8.0 FCEs) + Psychology (7.0 FCEs)

In order to meet the 12.0 different course requirement, this student may have up to 3.0 overlapping credits between her majors (8.0 + 7.0 = 15.0; 15.0 – 12.0 = 3.0).

Year 1		
QBio	PSY	
CSC120H1	PSY100H1	
BIO120H1	BIO120H1	0.5 overlap
BIO130H1	BIO130H1	0.5 overlap
MAT135H1		
CHM135H1, CHM136H1		

Year 2		
QBio	PSY	
PSY201H1	PSY201H1	0.5 overlap
BIO220H1	BIO220H1	0.5 overlap
BIO230H1	PSY210H1	
BIO260H1	PSY220H1	
STA221H1	PSY260H1	
MAT221H1	PSY270H1	

Year 3		
QBio	PSY	
EEB323H1	PSY311H1	
PSY305H1	PSY305H1	0.5 overlap

	PSY336H1	
	PSY332H1	

Year 4		
QBio	PSY	
EEB459H1	PSY450H1	
PSY474H1		

Appendix G: Appraisal Report

New Program Proposal Appraisal Report Quantitative Biology Major

Appraisers:

Simon A. Levin, James S. McDonnell Distinguished University Professor in Ecology and Evolutionary Biology, Princeton University

Gregor Fussmann, Strathcona Chair in Zoology and Chair, Department of Biology, McGill University

Date of site visit: October 6, 2020 (remote visit via Microsoft Teams)
Date of Appraisal Report: October 26, 2020

Report Summary

This is an exciting and timely proposal, and we are strongly supportive overall. The faculty is very strong and committed, and the program is well thought-out and seems to meet a demand. Undergraduate and graduate students that we met during our site visit confirmed that they would have been excited to enroll in the QBio Major, had it already existed. We do feel that some more clarity regarding what a typical program will look like will be important.

Thought also should be given to making sure that all students have some field experience, as well as an independent research experience.

Finally, no program can cover all bases, but there are several core areas lacking, and areas that are likely to be in demand among the students. These include biophysics and functional morphology, behavior, ecosystems, and topics at the interface with the social science, including policy. Some of these might be targeted in future hires; for others, the program might look to adding affiliated faculty from other disciplines.

Program Evaluation Criteria

1 Objectives

We are very supportive concerning the objectives of the proposal for a new Undergraduate Program Major in Quantitative Biology (QBio), in the Department of Ecology and Evolutionary Biology (EEB). Biology in general is becoming increasingly quantitative, with mathematical, statistical and computational approaches playing essential roles. Ecology and evolutionary biology have been among the leaders in that transformation, and no leading EEB department can afford to shortchange quantitative approaches. U of T has built an impressive core of faculty with quantitative strength; and, like other leading departments, the effects are apparent in their graduate program. However, few departments have developed formal tracks in quantitative biology at the undergraduate level, and U of T is in an excellent position to play a leadership role there.

We had some minimal concern that the title "quantitative biology" might raise some broader expectations among students, given that this program is strongly focused in ecology and evolutionary biology, with minimal content for example in biophysics and other subdisciplines that one might expect in a comprehensive quantitative biology program. The location of the program in EEB is likely to remove most confusion; but it might be good to have a webpage for all students interested in this area discussing the relation to the Bioinformatics and Computational Biology Specialist, the Biological Physics Specialist, and other programs like Genome Biology and the Specialist in Statistical Science: Methods and Practice (SSS).

The proposed plan is well thought out, and entirely consistent with the mission of the department and of the university. U of T has been a leader in EEB across a broad spectrum, and this is a natural step to continue its leadership. The requirements and associated learning outcomes are clearly developed and stated, and entirely appropriate in terms of the division's UG Degree-level expectations.

2 Admission Requirements

The target steady-state enrolment in the QBio Major is 100 students, which means that QBio will be one of the smaller undergraduate programs in the Faculty of Arts and Sciences. We feel the initial admission requirements of a minimum grade of 70% (B-) in an introductory biology course and in an introductory quantitative course are appropriate. They will assure that biology students enrolling in the program will have had prior exposure to quantitative concepts and that non-biology students who will join have a basic background knowledge in biology. We also think that it is a good idea to allow for future adjustments to the entry requirements as it is customary in other U of T programs of comparable size (e.g., the Bioinformatics & Computational Biology Specialist). However, in the spirit of reducing the fraction of life science students that leave university with only minimal quantitative skills, it will be important to keep the QBio program accessible to students without a strong prior quantitative record.

3 Structure

The program structure is well thought out, and the addition of courses in R, in Systematics and in Modeling will create new opportunities for students.

The program learning outcomes and requirements are clearly stated, and the range of available courses is impressive. Table 4b seems to provide a clear delineation of required and elective courses, and the footnotes indicate the number of FCE required in each category. However, this information must be provided to students in a more compact way to make it easy for them to navigate their pathway through the program. Although there are no streams within the Major, it should be possible to give a typical path or several typical paths through the Major.

Also, although advanced research projects are one way to satisfy category 3 requirements, consideration should be given to having a research project be a requirement.

It was difficult to ascertain what requirements and opportunities exist beyond those offered within the Major, beyond the entry requirements. For example, how much flexibility will exist in the program for students who would like to take an advanced course in mathematics, computing or statistics beyond Year 2?

4 Program Content

The Quantitative Biology Major will be located in the EEB department, but students will have the opportunity to fulfill the program requirements by choosing from a broad variety of courses in Biology, Cell & Systems Biology, Molecular Genetics, Human Biology, Mathematics, Applied Mathematics, Statistics, Computer Science, Bioinformatics and Computational Biology, Biochemistry, Psychology, Physics, Geography – and EEB. Indeed, only 16 out of the 85 courses listed as part of QBio are EEB courses. We see this as a strength and as an indication that the developers of the program have resisted the temptation to create a "Quantitative EEB Major" in disguise, favoring breadth and interdisciplinarity instead. However, as raised in Section 1, some highly quantitative fields in biology, such as biophysics, could be perceived to be underrepresented in a program broadly named "Quantitative Biology." During our online visit we had the opportunity to speak with the representatives from cognate units, and it was encouraging to hear that there was general support for the new QBio program, particularly because QBio students will have priority enrollment in EEB courses, but not in courses offered by other departments.

New undergraduate programs are typically put together from existing courses and others that are designed explicitly with the program in mind, and therefore define its originality. All courses proposed for QBio exist already, but EEB313H1 (Quantitative Methods in R for Biology) and EEB430H1 (Modeling in Ecology and Evolution) were developed during the proposal phase of QBio and constitute the core of novel, topical courses available to students. We have learned that EEB will be recruiting new faculty over the coming years and suggest that the capability of and interest in developing new courses for QBio be made a selection criterion.

It is beyond any doubt that the QBio will be an excellent training environment for students that move on to graduate studies in the life sciences. In academics there is an increasing demand for highly qualified personnel with skills in mathematical modeling, statistics and computational techniques, and QBio graduates will be highly competitive. But we feel that the QBio education will also be very beneficial for students who decide not to embark on graduate studies or seek employment in a field unrelated to biology. As defined in its Program Learning Objectives, QBio provides students with a set of hard and soft skills that will make them eminently hirable in any workplace requiring quantitative, analytical and social skills. These skills include data analysis, use of publicly available data bases, communication skills (oral and written presentation, graphical representation of data, scientific debate, accessible language), power of criticism and capability of assessment (placing own work into a broader context, peer review), understanding the societal context of scientific issues (emerging diseases, biodiversity loss), and team work.

5 Mode of Delivery

QBio will be delivered through a mix of classroom-learning and laboratory- or field-based learning. This is a fully appropriate mode of delivery to achieve the program objectives.

There was a bit of confusion on our side about the extent of independent undergraduate research opportunities in the program. In Table 3 (on page 20) it is stated that “At the senior level, students are required to take an integrated quantitative biology or research experience course.” However, the Completion Requirements listed on page 84 suggest that courses such as EEB498Y1: Advanced Research Project in Ecology and Evolutionary Biology or CSB498Y1: Independent Research in Cell and Systems Biology I are merely selectable from a list that also includes classroom-based courses. We believe it would be highly desirable to assure that QBio students are required to take at least one course where they perform an original research project in a laboratory or in the field, supervised by a professor. It seems that this sort of requirement would be very much in line with the idea that the QBio Major “is appropriate for students who wish to pursue a career or ***graduate studies*** in a broad range of life sciences …” (page 83; emphasis added by us).

6 Assessment of Teaching and Learning

The program learning expectations and ways to evaluate performance are clearly stated. Although lab work is mentioned explicitly in the list of first two years expectations, there is no mention of field work. This seems a bit surprising for an ecology and evolution Major, and perhaps it is simply a language problem. Field work is listed as coming in at the intermediate level; but some exposure for all by the second year would seem to be desirable.

The social and mental aspects of student development are assumed to flow from their interactions in upper level courses. This aspect probably needs more direct attention, perhaps through fora in which students have to present research work, or journal clubs that encourage presentation and discussion.

There is a natural development from lower-level courses to upper-level ones, and the expectations seem clear and explicit.

7 Resources

It is evident that there is broad endorsement and support for the new QBio program by the faculty in EEB. Thirteen professors across all ranks (plus one quantitative biologist starting in January 2021) are committed to contributing to the delivery of the program. During our discussions we got the impression that professors are excited about QBio, that many consider it "their" program, and that they are especially motivated by the perspective to train undergraduates that will have the quantitative skills to immediately take up research as graduate students in the labs of EEB faculty or elsewhere.

The faculty listed in Table 5 will not only contribute to the success of QBio by course teaching, but also by means of their active research programs and research laboratories. Undergraduate students will have (and already have) the opportunity for independent research projects as well as for interaction with graduate students and postdocs, who often take the roles of ad hoc supervisors and mentors in lab and field settings. As one of the internationally leading research programs in Ecology and Evolutionary Biology, EEB at U of T also provides highly qualified graduate students who will take the role of teaching assistants in QBio courses.

Because our site visit had to be remote, we were not able to convince ourselves of the adequacy of physical spaces. But judging from the description of space and IT resources in the document, we have no reason to question their adequacy for the QBio program.

8 Quality and Other Indicators

The quality of the faculty is outstanding, and the expectation that there will be additional hires will greatly strengthen this alternative major. Given the historical tradition that many of the top students in the Major will remain at U of T to pursue graduate work suggests that the linkage of programs at the various levels should be made clearer. Exposure of undergrads to graduate students with similar interests, as well as postdocs, will enrich the undergraduate experience. Some of that will be realized through contact with teaching assistants, and in research and lab experiences as part of the Major; the intention to provide those opportunities is explicit in section 12.3. It would be desirable for the best QBio students to be able to take part in selected graduate courses as well.

The faculty research programs represent a diverse sampling of research in ecology and evolution. It would be advantageous to use the new hires to broaden that menu even further.

The faculty have an excellent record of publication, of advising undergraduate research projects, and of mentoring graduate students and postdocs (though the latter category seems a bit thin according to Section 12.3). There is substantial strength in molecular genetics and genomics, in population and quantitative genetics, in population and disease modeling, and in biodiversity. Those are important areas and well covered, but it leaves significant gaps in areas like behavior, resource management, climate change, ecosystem structure and function, and linkages with the social sciences and management in areas like antibiotic resistance, land-use planning, and sustainability studies. Those are all likely to be areas of great interest for lots of students. The program cannot be expected to cover everything, but should explore the degree to which faculty in other programs of the university might serve as resources for students as affiliates in the program, and also look to these areas as new hires are made. Attention to other aspects of diversity will also be important, for example in relation to the environmental issues related to First Nations.

Appendix H: Dean's Administrative Response

UNIVERSITY OF TORONTO
FACULTY OF ARTS & SCIENCE

November 11, 2020

Professor Susan McCahan
Vice-Provost, Academic Programs
Office of the Vice-President & Provost
University of Toronto

RE: Administrative Response to the External Appraisal for the Proposed Major in Quantitative Biology (QBio)

Dear Professor McCahan,

I am very pleased to have received such a supportive report from Professor Gregor Fussmann and Professor Simon Levin regarding their appraisal of the proposed major in Quantitative Biology (QBio), within the Department of Ecology & Evolutionary Biology (EEB). Over the course of their virtual site visit, the appraisers met with EEB students, EEB faculty members and leadership, myself and three Vice-Deans, and leaders in 6 cognate units of EEB. My colleagues and I are very grateful to Professors Levin and Fussmann for their time and for their constructive feedback on this program proposal.

I am also very grateful to the Chair and Associate Chair, Undergraduate, of EEB, who have prepared a thoughtful and thorough response to the appraisers' report, in consultation with my office. The Department of EEB submitted their response letter to me on October 29, 2020, and it has substantively informed my response below, in which I address the appraisers' main comments and suggestions for the QBio major.

The appraisers note that the QBio major is timely, recognizing that, despite a transformation in biology towards quantitative approaches, "few [biology] departments have developed formal tracks in quantitative biology at the undergraduate level, and U of T is in an excellent position to play a leadership role." They also highlighted that EEB is "very strong and committed," and thus, ideally placed to lead this initiative. The resulting conclusion about the value of the program is precisely in line with the values and commitments of the University of Toronto:

It is beyond any doubt that the QBio will be an excellent training environment for students that move on to graduate studies in the life sciences. In academics there is an increasing demand for highly qualified personnel with skills in mathematical modeling, statistics and computational techniques, and QBio graduates will be highly competitive. But we feel that the QBio education will also be very beneficial for students who decide not to embark on graduate studies or seek employment in a field unrelated to biology.

The appraisers suggest that, "some more clarity regarding what a typical program will look like will be important." EEB has modeled sample degree paths for a set of 6 possible double majors (one of the majors in each pair being QBio) in Appendix F of the proposal. The Department will make these sample pathways available to students through undergraduate coordinators, as well as faculty in EEB's cognate units to facilitate student wayfinding through various program pathways that incorporate the QBio major.

The appraisers also suggest that a clear delineation of quantitative programs (QBio major, Bioinformatics and Computational Biology Specialist, etc.) be provided for students attempting to navigate options at the University of Toronto. We appreciate this suggestion. Determining what is possible and what can be augmented or enhanced in the Arts & Science Calendar, specific to this need, I will work with my colleagues in the Office of the Faculty Registrar to explore options for presenting this information, perhaps in a similar manner to the various Life Sciences programs that are already listed in the A&S Calendar.

As the appraisers note, an undergraduate independent research course is a foundation for students planning to pursue graduate studies in many areas. Although EEB cannot make one of these courses mandatory within the confines of a major (as they are for specialist programs), we have now added the following sentence to the proposal Calendar entry in Appendix B for the QBio major: "For students intending to pursue graduate studies, it is strongly recommended that an independent research course such as EEB498Y1 be included as part of the Quantitative Biology major." Since the QBio major is aimed at providing training both for those who wish to pursue graduate studies in the field and those who are seeking careers outside of academia, this helps clarify the clear importance of the research project option for those planning to pursue graduate studies.

The appraisers also mention a lack of fieldwork requirements in the first two years of the program. Indeed, constraints on EEB's large introductory classes preclude having a field component in BIO120 or BIO220. That said, those who pursue EEB as their second major will be able to take courses with field components in their second year of study, such as ENV234. Overall, given the credit constraints on a major program, EEB feels that field experience would be obtained if the student opts to pursue a second major in EEB, rather than requiring all quantitative biology majors to pursue this.

In addition to ensuring strong communication with students, the appraisers raised suggestions about growing the program with courses aimed at specific topics. In particular, they note that some current courses in EEB, like ecosystem ecology, global change ecology, field-based courses, and conservation, could be re-envisioned in future to address the quantitative goals of QBio. We agree, and EEB sees both revamping of courses and course turn-over with new instructors as opportunities to reassess if they could meet QBio Program Learning Objectives, either through larger-scale renovation or through incorporation of a quantitative component or module. In addition, the Faculty has struck a Data Science Computational and Data Science Education Working Group that has been charged with identifying and developing proposals for sector-specific foundational courses in these areas for all Arts & Science students beginning as early as Fall 2021. We regard this effort as a positive contributor to the QBio major, made all the more so by EEB's willingness to develop and teach a Life Science-specific foundational course in this area.

We also agree with the appraisers that QBio is an important area to develop further with future hires. EEB has a new hire (a mathematical biologist arriving January 1, 2021) and a search this year in computational ecology and evolutionary biology – adding 2.0 full-time equivalents (FTE) to the QBio faculty complement in the immediate term (the program proposal has been updated to incorporate the ongoing search). These faculty will be developing new quantitative courses that will add to the program options. EEB will continue to prioritize additional faculty lines in the area of QBio, as appropriate, in line with their current departmental plans. Having said this, I confirm that the QBio program has the appropriate number of faculty to launch in September 2021.

The Department and I also agree with the importance of paying further attention to broader aspects of diversity in the program in future years. Indeed, this year, EEB has their first EDI TA, who is working with a core faculty member in the QBio program to help support EDI initiatives in the EEB curriculum, including courses required in the QBio major. This faculty member and the Chair of EEB have begun a cross-disciplinary dialogue with other units on broadening curriculum development. Two EEB faculty members are currently developing a graduate course, to commence January 2021, focused on diversity and inclusion in STEM, and in future years they will explore how the material covered in this course could be further integrated into the undergraduate curriculum. Finally, EEB's present and future hires in this area will prioritize diversifying their faculty complement, and faculty position postings emphasize commitment to EDI as a key hiring criterion.

The appraisers also suggested that EEB seek affiliates from other departments who offer specific expertise not currently offered through EEB, such as biophysics and more advanced computing. We interpret this suggestion as recommending that the program should have enough flexibility to allow students the opportunity to pursue more advanced courses in various cognate units. The program does indeed allow this flexibility through both the breadth of course options and the broad possibilities for double majors. For example, QBio students who take listed courses such as PHY331 (Introduction to Biological Physics) or PHY431 (Topics in Biological Physics) will develop skills and knowledge in the areas of biophysics and computing.

The appraisers suggested including opportunities for the strongest students in the program to be able to take graduate courses and/or interact directly with graduate students. The QBio major facilitates this contact in two main ways: EEB has several senior level undergraduate courses listed in the QBio major that are offered at the same time as analogous graduate level courses (e.g., EEB430, EEB459). Although the requirements and assessment of graduate and undergraduate students in these analogous courses are distinct, the format allows these two student bodies to engage and learn from each other. Undergraduate and graduate students learn together and are taught by a graduate faculty member, which allows for an advanced level of engagement in the discipline for undergraduate students. As well, students who pursue research project courses have many opportunities for direct interaction and collaboration with graduate students.

Finally, the appraisers asked about providing a forum for students in the program to present their research and/or have journal club discussions. EEB's introductory course, BIO120, has a presentation component which all students in this program complete, as do many of the upper year courses like EEB430. Additionally, for students pursuing research project courses, presentations and discussions of research are integral components of the courses, including a complementary course in the fourth year that includes peer evaluation of proposals and peer discussions. EEB's peer-to-peer mentorship program provides another avenue for student mentorship and support, in this case from more senior students in the program.

In summary, the appraisers highlighted a number of strengths in the QBio major, and made clear suggestions about communicating the program with undergraduates and ensuring coverage of a broad range of quantitative courses. These suggestions have clarified the vision for implementing this program and provided clear and helpful direction for EEB's priorities in areas such as curriculum, faculty recruitment, and inter-departmental communication.

Again, I would like to express my gratitude to Professors Fussmann and Levin for their keen and supportive observations and recommendations. The Department and my office look forward to implementing this major and providing this valuable pathway for our excellent undergraduate students.

Sincerely,

Melanie Woodin
Dean, Faculty of Arts & Science
Professor, Cell & Systems Biology

cc: Professor Stephen Wright, Chair, Department of Ecology & Evolutionary Biology
Professor Benjamin Gilbert, Associate Chair, Undergraduate, Department of Ecology & Evolutionary Biology

Appendix I: Vice-Provost, Academic Programs' Letter of Response

UNIVERSITY OF TORONTO

OFFICE OF THE VICE-PROVOST, ACADEMIC PROGRAMS

November 11, 2020

Melanie Woodin

Dean, Faculty of Arts & Science

University of Toronto

Re: Appraisal Report, Proposed New Major in Quantitative Biology

Dear Melanie,

I am very pleased to receive the appraisal of the proposed Major in Quantitative Biology. Your administrative response to the appraisal nicely summarizes the report and highlights the specific suggestions made by the appraisers for consideration.

To support clarity for students, the appraisers suggested sharing typical pathways for progressing through the Major and differentiating for students the existing quantitative programs. Your report indicates that the six possible double major pathways contained in the proposal will be made available to students, program advisers and faculty. In addition, your office will explore options for presenting program information clearly, so students are aware of quantitative program options and differences between them.

The appraisers made a number of suggestions regarding the curriculum including: making independent research courses, now optional in the program, required; adding field courses to Years 1 and 2 of the program; and eventually including other academic areas in the Major. Your report indicates that senior independent research courses are required for Specialist programs, and not Major programs in the Faculty. However, to support students who wish to pursue graduate school, the Major's calendar entry was revised to indicate those students are advised to take an independent research course. On requiring field courses in Years 1 and 2, you indicate this is not possible, due to the resource constraints of the large introductory courses in those years. Students may have this experience though an alternative Major program that is paired with this program. You agree with the appraisers that the academic content of the curriculum could be expanded in the future. To this end, the Faculty has struck a Data Science Computational and Data Science Education Working Group that will identify and develop proposals for sector-specific foundational courses, including this program. You agree with the appraisers that quantitative biology is an important area for future hires. Your report indicates that in addition to the new hire in mathematical biology starting on January 1, 2021, there is a search this year in computational ecology and evolutionary biology and this position will support the new program. The program proposal has been updated to incorporate this information.

Finally, you agree with the appraisers on the importance of paying further attention to broader aspects of diversity in the program. Your report outlines several current initiatives in this area in the Department. They include: the Department's first Equity, Diversity and Inclusion (EDI) teaching assistant, who will support EDI initiatives in the curriculum; the Department's ongoing cross-disciplinary dialogue with other units on broadening curriculum development; and development of a graduate course to focus on diversity and inclusion in STEM that will provide a template for integrating this material into undergraduate curriculum. You also confirm that the Department's present and future hires in this area will prioritize diversifying their faculty complement.

I will be very pleased to recommend this new undergraduate program to governance for approval, following approval at the Divisional level.

Sincerely,

Susan McCahan

Vice-Provost, Academic Programs

cc: Daniela Trapani, Executive Assistant to the Dean, Faculty of Arts & Science

Randy Boyagoda, Vice-Dean, Undergraduate, Faculty of Arts & Science

Caitlin Burton, Academic Planning & Review Officer, Faculty of Arts & Science

Mark Schmuckler, Vice-Provostial Advisor, Academic Programs

Daniella Mallinick, Director, Academic Programs, Planning & Quality Assurance, Office of the Vice-Provost, Academic Programs

Jennifer Francisco, Coordinator, Academic Change, Office of the Vice-Provost, Academic Programs

Ecology & Evolutionary Biology
UNIVERSITY OF TORONTO
OFFICE OF THE CHAIR

Stephen I. Wright
Professor and Chair,
Department of Ecology
and Evolutionary Biology

October 28, 2020

Professor Melanie Woodin
Dean, Faculty of Arts & Science
University of Toronto

RE: External Appraisal for the Proposed Major in Quantitative Biology (QBio)

Dear Professor Woodin,

I am pleased to have received such a supportive report from our program appraisers, Professor Gregor Fussmann and Professor Simon Levin. The site visit, conducted entirely virtually for the first time in Arts & Science, allowed for valuable discussions between our appraisers and EEB students (undergraduate and graduate); faculty members who will support the program; myself and our Associate Chair, Undergraduate; representatives from cognate units and Arts & Science leadership. Below, I discuss the key points raised by the appraisers in their report; they have provided much valuable feedback and many useful suggestions for how to implement and sustain the QBio major at a world-class level of excellence.

The appraisers note that the QBio major is timely, recognizing that despite a transformation towards quantitative approaches, "few [biology] departments have developed formal tracks in quantitative biology at the undergraduate level, and U of T is in an excellent position to play a leadership role." They also highlighted that our department is "very strong and committed," and thus ideally placed to lead this initiative. The resulting conclusion about the value of the program is precisely in line with the values and commitments of the University of Toronto:

It is beyond any doubt that the QBio will be an excellent training environment for students that move on to graduate studies in the life sciences. In academics there is an increasing demand for highly qualified personnel with skills in mathematical modeling, statistics and computational techniques, and QBio graduates will be highly competitive. But we feel that the QBio education will also be very beneficial for students who decide not to embark on graduate studies or seek employment in a field unrelated to biology.

The appraisers suggest that "some more clarity regarding what a typical program will look like will be important." Indeed, we have included sample degree paths in Appendix F, and these will be made available to students through undergraduate coordinators, as well as through faculty in cognate units to allow students to navigate various pathways through the program.

The appraisers also suggest that a clear delineation of quantitative programs (QBio major, Bioinformatics and Computational Biology Specialist, etc.) be provided for students attempting to navigate options at the University of Toronto. We appreciate this suggestion, and we will be happy to collaborate with your office and cognate units to explore options for presenting this information in the Arts & Science Calendar. We suggest that this could be presented in a similar manner to the various Life Sciences programs.

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As the appraisers note, an undergraduate independent research course is a foundation for students planning to pursue graduate studies. Although we cannot make one of these courses mandatory within the confines of a major (as they are for Specialist programs), we have edited the calendar copy so that students understand their importance to graduate studies prospects. Specifically, we have now added the following sentence to the Calendar entry for the QBio major: "For students intending to pursue graduate studies, it is strongly recommended that an independent research course such as EEB498Y1 be included as part of the Quantitative Biology major." Since this major is aimed at providing training both for those who wish to pursue graduate studies in the field and those who are seeking careers outside of academia, this helps clarify the clear importance of the research project option for those planning to pursue graduate studies.

The appraisers also mention a lack of fieldwork requirements in the first two years of the program. Indeed, constraints on our large introductory classes preclude a field component in BIO120/BIO220. That said, those who pursue EEB as their second major will be able to take courses with field components in their second year of study, such as ENV234. Overall, given the credit constraints on a major program, our feeling is that field experience would be obtained if the student opts to pursue a second major in EEB, rather than requiring all quantitative biology majors to pursue this.

In addition to ensuring strong communication with students, the appraisers raised suggestions about growing the program with courses aimed at specific topics. In particular, they note that some current courses in EEB, like ecosystem ecology, global change ecology, field-based courses and conservation, could be re-envisioned in the future to address the quantitative goals of QBio. We agree and see both revamping of courses and course turn-over with new instructors as opportunities to reassess if they could meet QBio Program Learning Objectives. We also agree that this is an important area to develop further with future hires, and in fact we have a new hire (a theoretical biologist arriving Jan 1, 2021) and a search this year in computational ecology and evolutionary biology – adding 2 positions immediately in QBio. These faculty will be developing new quantitative courses that will add to the program options. We will also be prioritizing additional faculty lines in the area of QBio as part of this year's development of our department plan.

We also agree with the importance of paying further attention to broader aspects of diversity in the program in future years. Indeed, this year, we have our first EDI TA, who is working with a core faculty member in the QBio program to help support EDI initiatives in our EEB curriculum, including courses required in the QBio major. This faculty member and I have begun a cross-disciplinary dialogue with other units on broadening curriculum development. Two EEB faculty members are currently developing a graduate course, to commence January 2021, focused on diversity and inclusion in STEM, and in future years they will explore how the material covered in this course could be further integrated into the undergraduate curriculum. Finally, our present and future hires in this area will prioritize diversifying our faculty complement, and our faculty position postings emphasize commitment to EDI as a key hiring criterion.

The appraisers also suggested that we seek affiliates from other departments who offer specific expertise not currently offered through EEB, such as biophysics and more advanced computing. We interpret this suggestion as recommending that the program should have enough flexibility to allow students the opportunity to pursue more advanced courses in various cognate units. The program does indeed allow this flexibility through both the breadth of course options and the broad possibilities for double majors. For example, QBio students who take listed courses such as PHY331 (Introduction to Biological Physics) or PHY431 (Topics in Biological Physics), or accompanying majors in these units, will develop skills and knowledge in these areas.

The appraisers suggested including opportunities for the strongest students in the program to be able to

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take graduate courses and/or interact directly with graduate students. The program in fact enables this in two ways: we have several courses in this program that are cross-listed as graduate courses (e.g. EEB 459), and also those who pursue research project courses will have many opportunities for direct interaction and collaboration with graduate students.

Finally, the appraisers asked about providing a forum for students in the program to present their research and/or have journal club discussions. EEB’s introductory course, BIO120, has a presentation component which all students in this program complete, as do many of the upper year courses like EEB430. Additionally, for students pursuing research project courses, presentations and discussions of research are integral components of the courses, including a complementary course in the fourth year that includes peer evaluation of proposals and peer discussions. EEB’s peer-to-peer mentorship program provides another avenue for student mentorship and support, in this case from more senior students in the program.

In summary, the appraisers highlighted a number of strengths in the QBio major, and made clear suggestions about communicating the program with undergraduates and ensuring coverage of a broad range of quantitative courses. These suggestions have clarified the vision for implementing this program and provided clear and helpful direction for our Department’s priorities in areas such as curriculum, faculty recruitment, and inter-departmental communication.

We very much appreciate your support for the proposed program, and look forward to the next steps in implementation.

Sincerely,

Stephen I Wright
Professor and Canada Research Chair in Population Genomics
Chair, Department of Ecology and Evolutionary Biology, University of Toronto

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