Quantitative Earth Sciences Transformation (QUEST)

Project Team:

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Project Overview (500 words)

Clearly state the project's rationale, overall objectives, scope, and how it aligns with the focus area and enhancement of teaching and/or learning. Specifically, how many students are enrolled in the target program (major, specialization, minor, etc.)? How many non-major students take these courses? If a subset of courses will be renewed, please list these courses and their average enrolment.

The QUEST initiative (QUantitative Earth Sciences Transformation) seeks to transform and modernize quantitative Earth sciences (QES) education at UBC. The Department of Earth, Ocean and Atmospheric Sciences (EOAS) currently offers multiple majors, honors and combined undergraduate specializations in a range of disciplines that are built on fundamental concepts in mathematics and physics. These different specializations, from geophysics and geological engineering to atmospheric sciences and oceanography, have largely run on parallel tracks, reflecting the amalgamation of EOAS from separate departments 25 years ago. Yet, modern Earth sciences have changed significantly over the past quarter century, with a much greater emphasis on collaboration across fields, and the deployment of core mathematical and computational techniques to solve complex problems from a range of perspectives. The next generation of students – those who will be responsible for tackling the climate crisis and for developing sustainable resource exploration industries – will need to apply their education much more broadly than ever before. For this reason, we seek to critically evaluate current QES offerings across the EOAS undergraduate curriculum, creating a road map to rejuvenate multiple specializations, while forging a new approach to inter-disciplinary education across the Earth sciences. We seek to re-align our undergraduate specializations with the rapidly shifting landscape of Earth Science research, and the corresponding changing employment market.

The main goals of this project are to define new, forward-looking outcomes for our QES specializations, and to articulate specific strategies for re-design that will enable students to meet these outcomes and core competencies. At the same time, we will directly address Strategy 14 of the UBC Strategic Plan, by providing *opportunities for students from different perspectives and disciplines to work together on complex or emergent problems*. In specializations re-designed with a QES focus, students will be able to develop core competencies in common mathematical and computational tools that can be applied to a wide range of critical problems. This will increase student scientific literacy and better equip them for success in a range of careers. At the same time, specialization re-design will maximize the efficiency of teaching resources in EOAS, and build new inter-disciplinary synergies, giving students a more integrated and holistic understanding of Earth Science. We believe that the rejuvenated QES specializations will be a model for Earth Sciences departments around the world.

Specifically, the QUEST initiative will: 1) engage in extensive discussions with multiple stake-holders, from faculty members and students, to employers and professional accreditation bodies to identify key quantitative skills that are essential for success in a wide range of Earth Science applications; 2) develop

a plan to reframe our academic specializations in terms of learning outcomes and competencies, produce comprehensive inventories of key concepts and capabilities, and identify different potential approaches to present fundamental quantitative tools across different specializations; and 3) collect information on current understanding and perceptions of QES among first year UBC students and senior high school students to understand how curriculum renewal could help increase student recruitment and better align program specializations with student needs.

Department Readiness (250 words)

Why is now the right time for this project in your Department or Unit? What pre-work has been done? How do you know the Department / Unit is committed to the success of this program renewal?

EOAS is established as a leader across UBC (and internationally) in science education. Our department was an early and enthusiastic participant in the CWSEI, with a proven track record of driving positive shifts in teaching culture and practices. We have a number of Killam-winning instructors and TLEFs as well as a full-time embedded Science Education Specialist. The proposal will support partial salary for a geoscience education specialist who also has industry and/or research experience in geophysics or other quantitative Earth science. Critically, EOAS has a large group of highly motivated faculty members from various disciplines who are committed to the success of this initiative. The core participant list includes 18 EOAS faculty members (close to half of our entire faculty complement!) from across the academic ranks, including 4 new Assistant Professors who are working at the forefront of quantitative Earth Science and Data Science. The Assistant Professors will bring energy and novel ideas to the QUEST initiative, while also benefitting significantly from mentoring by senior faculty. Discussions related to QUEST have been on-going for over two years, but progress has been limited due to lack of time and resources. The time is now right, however. Building on our recently successful TLEF proposal - "Embedding Open-source Computational Tools into the Quantitative Earth Science Specializations", and working towards our 25th anniversary and external department review in 2021, we are now ready and fully committed to take a bold step towards rejuvenating quantitative Earth Science education in our department.

Project Work Plan, Timeline & Milestones (1000 words)

Provide a clear work plan for how you will achieve the stated objectives of the project. Please include major milestones relevant to the curriculum renewal cycle.

The QUEST initiative will be undertaken through a multi-pronged approach, with individual team members tasked with leading each of these initiatives, working with the department Head and a program coordinator (roughly 50% FTE on this project) who will ensure overall project coordination and accountability. The result will be a major report, with three chapters focused on our core focus areas: **1)** curriculum data collection and analysis; **2)** market research; and **3)** curriculum mapping. Below, we indicate the main periods of focus for these different activities, although, in reality there will be concurrent activity on all three prongs.

Chapter 1 – An Overview of QES in EOAS: Data Collection and Analysis (April, 2020 – March, 2021): The first major component of the initiative will involve collection of data to support specialization renewal and the articulation of common outcomes and competencies for QES. We will build on our existing collaborations with curriculum services staff at CTLT, who are leading the Undergraduate Program Evaluation and Renewal initiative. The relevant data fall into two broad categories. First, we will begin by creating an inventory of all physical and mathematical concepts and methods that are either taught or applied in EOAS courses. (Examples of concepts/tools that cut across many EOAS disciplines include conservation laws, waves, signals and noise, spatial analysis, forcing and feedback, vector calculus, differential equations and matrix algebra.) Once we understand what is actually taught in our different specializations, we will identify potential deficiencies and opportunities for synergies across courses. For example, once we identify how and when courses use time-series methods, we will be able to recommend ways of delivering this technique in revamped, cross-disciplinary foundational courses (likely in the 2nd year). Current course content will be matched against concept lists generated by faculty, with input from a range of stakeholders (see 'Stakeholder Engagement'), to understand areas that may need to be strengthened or perhaps de-emphasized in refurbished degree specializations. Second, we will identify other relevant QES offerings in Canada (e.g. the University of Toronto) and beyond (Princeton, MIT), and collect information from their curriculum specialists on core competencies expected of graduating students, and approaches to delivering mathematical concepts.

Chapter 2 – Beyond EOAS: Engagement and Market Research (March, 2021 – December, 2021):

Awareness of QES fields is very low among potential students and the advisers they consult when making educational choices; many high senior school students and first year UBC students simply do not know that there are challenging, interesting and relevant problems and careers in Earth Science that require advanced math and physics. As part of consultations with undergraduate EOAS students, we received the following message: "A *common thread across many of our backgrounds is an underrepresentation of earth sciences in high schools*." If our curriculum renewal efforts are to be successful, we must understand the factors affecting the visibility of QES disciplines and the motivation of prospective students, and how the design of program specializations influences these questions. As part of the QUEST initiative, we will develop market research strategies to learn how students make degree choice decisions, and how renewed QES degree specializations could provide attractive options for interested students. A deeper picture of why people choose QES will significantly inform the creation of better degree specializations, with additional knock-on effects on graduate EOAS programs.

We will focus our market research on high school students and guidance counsellors, first and second year UBC students, EOAS graduate students and alumni, all of whom will have different perspectives into educational opportunities in QES. We will seek to identify students who have transferred into and out of QES fields to understand the reasons for their choices. Among UBC students, we are particularly interested in engaging with students who are (or were) in Vantage College, because those students come from diverse cultural backgrounds where many acquire strong quantitative skills, but may not have had significant exposure to Earth sciences. Another source of data will be EOAS graduate students and postdocs; we want to know how they ended up in QES disciplines, and what they found inspiring or helpful as they were making career decisions. Finally, we will also gather existing data about the evolving job markets and societal needs that can be found at professional organizations such as the EGBC, AGU, GSA and others.

The data will help identify ways of prioritizing our own QES curriculum, especially regarding first and second year courses and content. The data will also suggest opportunities for highlighting materials that will increase QES awareness in high schools. Our goal in the context of this curriculum development project is to find ways of raising awareness of, and interest in, the many intellectual and career opportunities in QES for those with strong interests in physical, mathematical, data-science and computational disciplines.

Chapter 3 – Pathways forward: Curriculum Mapping (April, 2021 – March, 2022): Once we have articulated a clear set of common QES outcomes and competencies, we can focus on planning the details of specialization renewal. This does not mean developing or adjusting specific courses at this stage. Rather, the result of this mapping phase will include the following aspects.

- First, internal and external constraints (such as professional accreditation) need to be clarified and QES outcomes adjusted appropriately.
- Second, an integrated curriculum model will be developed for QES. In light of the new outcomes, opportunities for adjusting foundational experiences in first- and second-year courses will be identified, and preferred pathways for improvement will be recommended. For example, there may be good arguments for launching one or more new introductory courses, or there may be existing UBC courses that are appropriate for students pursuing quantitative Earth sciences.
- Third, we will identify ways of integrating the initial exposure to fundamental concepts with application opportunities within relevant upper year contexts.
- Fourth, we will identify opportunities for scaffolding and integrating each specializations' curriculum to enable instructors to leverage prior learning more effectively. The results will represent recommendations about which courses to modify, as well as when, and how to modify them, in the years following this curriculum development project.

Stakeholder Engagement (250 words)

How have you engaged stakeholders to gather feedback on your existing program? How has that feedback shaped your proposal? How will you engage stakeholders during the project?

The QUEST initiative will impact students, faculty members in multiple UBC departments, off-campus employers, and professional bodies who review our degree specializations for accreditation. Student engagement is addressed in the 'Student Involvement' section. We have already initiated discussions with Computer Science around some of our course offerings, and these discussions will broaden to include Math, Physics and Statistics, to ensure that any planned initiatives build off foundational elements delivered by those departments. A group of EOAS faculty have already formed an ad-hoc committee to consider relevance and sequencing of QES subjects in geophysics courses, and their work represents a springboard for the QUEST initiative. Many EOAS students find employment within the local industry sector, and we have a large number of alumni in leadership positions in companies around the province. Engagement with these alumni will thus provide an effective way to obtain feedback on proposed curriculum re-design initiatives from an employer perspective. We will use annual professional and academic meetings to connect with a range of EOAS graduates in industry, government and academia, host discussion groups, and gather relevant information about practical, professional and intellectual needs and priorities. Specific meetings we plan to target include professional resource industry conventions (e.g. AME Round-up) and the American Geophysical Union. Similarly, we will reach out to

EOAS alumni employed at various government agencies (*e.g.* Fisheries and Oceans Canada) and consulting firms (e.g. Golder Associates) to gather information on desirable skills in recent graduates.

Project Outputs, Products or Deliverables (300 words)

List or describe the project's intended tangible outputs. What will the project do or create as a result of the implementation of its work plan?

Our primary objectives are to define common outcomes and core competencies in Quantitative Earth Sciences, map these onto existing EOAS undergraduate specializations, and produce a concrete plan to achieve curriculum renewal. We will produce a detailed document, with three chapters, identifying existing gaps and limitations in our current offerings, as well as opportunities for synergies and collaborations across disciplines to deliver the required quantitative skills to students.

This document will specifically address:

1) Learning Outcomes, describing the expected capabilities (i.e. knowledge, skills and attitudes) of graduates, and an inventory of core concepts outlining foundational knowledge and tools that are required of students.
2) Articulation of common outcomes that bridge existing QES specializations
3) A detailed roadmap outlining a path towards achieving undergrad program renewal that meets the desired learning outcomes. This will include articulation of an integrated curriculum, recommendations on course redesign, creation and, potentially, elimination of existing redundancies.
4) A plan to interface analytical and numerical mathematical skills with emerging Data Science initiatives spanning the Earth, ocean and atmospheric sciences
5) Analysis of accreditation requirements for various professional societies and employers, and (potentially) recommended updates to these requirements.
6) Results of market research into student perceptions of QES subjects and the how these would be affected by curriculum renewal.

Project Impact (500 words)

Referring to the project's objectives and expected outputs, what are the expected direct, short-term, and sustainable benefits? What changes or impacts do you hope to see as a result of this project? Explain how these will contribute toward program redesign.

We expect that the QUEST initiative will pave the way for a major restructuring of quantitative Earth Science education across EOAS. It will directly impact students by transforming their undergraduate experience, giving them a much deeper and holistic understanding of quantitative tools in Earth science, and better equipping them for employment in a range of fields. In written comments on an early draft of this proposal, one undergraduate student wrote: "*Some of our members are particularly keen on the program, especially an interdisciplinary approach, as they wouldn't be completely limited like our more rigid programs today."* Indeed, the QUEST initiative will help break down existing 'silos' between fields, directly supporting Strategy 14 of the UBC Strategic plan ('Inter-disciplinary Education'). QUEST will also help stimulate new research collaborations among faculty EOAS faculty (and other departments) who will work closely together over a two-year period, and discover unexpected synergies between their interests

and expertise. For example, geophysicists, oceanographers and geological engineers may come to better appreciate how their common set of quantitative research tools can be applied to address complex problems that span these different domains. The specific anticipated impacts of QUEST include:

1) Significantly enhanced teaching and learning potential across a broad range of disciplines, integrating concepts, methods and contexts from various fields into a more holistic, interdisciplinary understanding of Earth sciences;
2) Fostering of new collaboration among a large group of faculty members from different EOAS disciplines;
3) Greater 'cross-pollination' among undergraduate students in different specializations;
4) A stronger mathematical foundation to support EOAS student's participation in UBC-wide Data Science initiatives;
5) Significantly increased awareness of and engagement with quantitative Earth science among first year UBC students and local high school students;
6) Increased efficiency, sustainability and effectiveness of EOAS teaching strategies and resources;
7) Stronger linkages and engagement with off-campus stakeholders and potential employers;
8) Better preparation of EOAS graduates for careers in a range of sectors, as demand in traditional sectors weaken, and alternative opportunities emerge for skilled, quantitative professionals in the sustainable resource, energy and environmental industries.

Evaluation Plan (500 words)

Describe how you will evaluate if the project resulted in the intended impact(s). What evaluation strategy will be used? What data will you collect to evaluate the project's impact(s), and how will you collect this data? Outline any key indicators that will be used to determine the project's success/performance.

The ultimate metrics for success of the QUEST initiative will only emerge after the curriculum renewal is implemented. These metrics will include increased student numbers and diversity in QES specializations, and improved learning outcomes, which can be assessed based on increased student performance in QES courses. Other longer-term metrics will be centered around tracking of student employment outcomes.

Over the two years of the QUEST initiative, ongoing evaluation will be carried out as a form of reflective practice. Team members will meet monthly to address questions including:

- Are team members still benefiting, keen, engaged and contributing?
- Is the quality of project work acceptable as the project unfolds?
- Is there progress towards each stated project output, product or deliverable?
- Are there curricular goals missing, and, if so, where can they be addressed in future course development projects?
- Have there been surprises? Are there needs for changing priorities or directions? What evidence points to those needs? What are resulting appropriate actions?
- What decisions can be made? What data / processes contribute towards decision making?
- How are data being gathered? How are they being used?
- Are there opportunities for sharing the process and outcomes with others, both within and outside of UBC?

The regular team-based progress meetings will be supplemented by an annual progress report and discussion session at the department retreat in April. The report and discussion will provide an

opportunity to inform the entire EOAS department about the on-going QUEST initiative, and gauge broader understanding and support for the work. Regular team-based progress meetings will be facilitated by the project coordinator with advice from CTLT personnel, who will help our team reflect on progress or consider adjustments. Additional meetings will be organized with undergraduate students (as described in the 'Student Involvement' section), and also with peers and colleagues at academic meetings, and with alumni, industry and other stakeholders (as described in the 'Stakeholder Engagement' section).

We will also assess other specific project deliverables, including (a) the map of curricular connections across degree specializations; (b) a course / curriculum matrix with "attributes" that examines student-centric capabilities, and developed 'evidence-based approaches to gauge student progression of learning at beginner, intermediate and senior levels. EOAS has recently used this process to establish Geological Engineering accreditation requirements.

These regular, facilitated and documented reflective practices will establish expectations and habits within EOAS for a regular curriculum review process. Aspects of this process would include examination of discipline-specific curriculum, service course offerings, field-based & experiential learning, as well as quantitative Earth sciences across our degree specializations.

With the upcoming external review of EOAS in 2021, we have a unique opportunity to obtain high-level feedback on the QUEST initiative from an independent expert panel. We will submit a description of the QUEST action plan as an appendix to our self-study document. In this way, we will benefit from the advice of some of the world's leading Earth scientists and educators who will sit on the review committee.

Student Involvement (250 words)

Describe how students were consulted and involved in preparing and reviewing this proposal, and how they will be involved in the implementation of the project.

EOAS has an engaged group of undergraduate students, and provides high quality space and financial support for a number of undergraduate clubs (https://www.eoas.ubc.ca/academics/ugrad/organizations). We have worked with these clubs to engage students in discussions of the QUEST project, and recently hosted a 1.5-hour lunch attended by nearly 20 students, representing all of the specializations in our department. Student response was strong, and we received extensive feedback and comments on the proposal text. For example, the day after our lunch meeting, we received a note from one of the club leaders, which read, in part: "*I was just reaching out to let you know that we're still interested in talking about this more. It would be nice if we could meet more, since a good portion of us are graduating. Let me know what you think, we are super appreciative that you are reaching out to the student body".* Going forward, we will create a student committee (including both undergraduates and graduates) to interface with the QUEST project team leaders, with meetings at least once per term (over pizza lunch) to collect feedback about proposed course re-design activities. The QUEST initiative will also create part-time employment opportunities for EOAS undergraduates and/or graduates, who will be recruited to participate in data collection and analysis in support of our curriculum mapping exercise. In this way, students will feel a strong sense of connection to the program, and a certain amount of 'ownership' over the resulting outcomes.

Students Reached by the Project

How many students overall do you estimate will be reached by this project annually? (Please provide a number)

The initial focus of QUEST will be on courses delivered through the existing geophysics specialization (GEOP), including the following EOSC geophysics courses: 250, 350, 352, 353, 354, 442, 450, 453, 454. In addition, we will look for synergies across courses in different specializations, and expect impacts on courses offered through ATSC (201, 301, 303, 404, 405, 406 and 409); OGCY (340 and 471) and GEOENG (210, 213, 329, 429, 430, 431, 433 and 434). As we seek to redefine our approach to teaching quantitative skills across the full Earth science curriculum, we thus anticipate reaching a significant fraction of all EOAS students, with estimated numbers close to 500 per year based on the 2015-2019 combined average of 2nd, 3rd & 4th year enrolments in current QES-related specializations, including environmental science and geological engineering. We expect to reach an increasing number of students over the next five years, as we attract new students to our programs, and thus boost enrolments. Actual increase in numbers will depend on specialization, and will be tracked over time.