Paired Interviews about quantitative learning in EOAS

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2 EXECUTIVE SUMMARY

Goal: gather individual and collective opinions about current identity, departmental responsibilities and recommendations for improving undergraduate learning about quantitative Earth Sciences (QES) across EOAS.

Methods: Nine interviews were conducted with 17 EOAS faculty, eight in pairs, and one solo (Appendix I). Conversations were casual but guided by fixed questions (Appendix I). The focus was on Departmental identify, desired graduating students’ characteristics, and recommendations for reinvigorating quantitative learning about Earth sciences. Each interview was concluded by asking for comments on a list of thoughts synthesized from previous interviews. Recorded interviews were analyzed to identify both common and unique perspectives.

Results: The most commonly agreed upon notion was the importance of helping students develop their “*critical quantitative thinking*” abilities. The meaning and scope of that notion is summarized below in **Appendix II**.

When asked what the department’s responsibility is to BSc students, or “what they should look like upon graduation”, responses mentioned by two or more interview pairs were (in order of agreement):

- The importance of critical quantitative thinking mentioned above.
- The need to enable students to practice aspects of data science NOT related to analysis (data wrangling, visualizing, quality assurance and other examples were given).
- quantitative content and contexts could be aligned more with students' future professional needs and less with current research topics.
- Students must graduate with basic scientific & model-based thinking abilities.

Specific recommendations emerging from interviews can be grouped into five types: quantitative critical thinking, application oriented learning, appropriate levels of rigor, data science, and career preparation. Interestingly, no interviewees focused upon specific disciplinary topics. Most recommendations were about the "types" or "scope" of quantitative thinking that students should encounter & practice rather than the specific topics covered. Recommendations that were most commonly expressed include:

- Explicitly incorporate aspects of "*critical quantitative thinking*" (as opposed to theoretical background) into courses at all levels.
- Leverage the multi-disciplinary nature of the Department by structuring curricula so students can take courses with colleagues in other disciplines.
- Teach by starting with the needs or applications before introducing methods, techniques or relevant theory
- Ensure that the "fundamentals" taught in early courses are as broadly relevant across QES disciplines as possible so all QES students can take senior courses that make use that prerequisite knowledge. It was suggested, for example, that the department "*consider one common 2nd yr quantitative Earth science course for all*".
- Students need to experience large data, data wrangling, visualizing, etc. at all stages in their curriculum. They should build skills that are relevant in all QES programs and then apply them late in their degree programs to address meaningful capstone activities, ideally involving some engagement beyond the academic setting.
- The need for more effective interaction with non-academics (industry, alumni etc.) was expressed by most interviewees.
- Most interviewees mentioned capstone experiences. Precedent within EOAS was mentioned, and it was suggested that all programs should require a capstone experience of some form (perhaps a flexible choice of options).

Details: Sixty one issues or thoughts (or "items") were identified, a third of which were discussed during three or more interviews. Items can be described as either "**statements**" or "**recommendations**". Results should be compared to, and correlated with, results of the survey about students' QES learning tasks from 51 EOAS courses. Summary is on page "QES learning tasks".

Statements can be categorized as about either:

- the strengths or "identity" of the department;
- responsibilities to undergraduate students, including "what graduating students should look like";
- challenges or barriers to change.

Recommendations are suggestions for actions that could be taken to improve quantitative learning in EOAS. They can be grouped under five themes. Some items are relevant to more than one of these themes.

- Actions to support the development of "quantitative critical thinking" abilities and habits-of-mind.
- Actions to enhance the use of application-oriented or problem-based learning.
- Identifying & incorporating appropriate levels of rigor when math, physics or data science are involved.
- Actions that address the fact that data science is increasingly ubiquitous and multifaceted.

- More explicitly supporting career-preparation and development of “soft” skills and professionalism.

Recommendations are further recognized as being either …

- **course-level** recommendations, suitable for implementation in individual courses,
- **program-level** recommendations targeting changes to curriculum of a degree specialization, or
- **department-level** recommendations that would be implemented across the department.

3 Principle statements about quantitative learning in EOAS

Bracketed numbers prior to each bulleted item indicate the number of interviews (9 interviews, 17 individuals) in which that issue or item was mentioned. Lists are sorted in order of most commonly referenced.

3.1 Strengths or “identity” of the department

Based on experience within the Department, there is little disagreement regarding most of these (and other) strengths, regardless of how many interviews actively brought up each item.

- (5) The department is unusually multi-disciplinary in many ways, including the range and types of quantitative science used and taught.
- (4) Data science is key - and growing - across specializations.
- (3) The perceived scope of “quantitative Earth science” varies significantly according to discipline.
- (3) EOAS comprises an "extremely" diverse faculty, both in terms of their disciplines and in terms of their “academic upbringing".
- (2) The Department places a high priority on field/outside learning.
- (2) Geological engineering is unique as an applied science degree administered within a Faculty of Science Department - and it has a strong reputation.
- (2) The department’s role in developing and delivering DSCI 100 was recognized as a “strength”.
- (1) Educational development is a priority within EOAS.
- (1) Students benefit when BASc (problem oriented) and BSc students learn together
- (1) EOAS has a close relationship with the minerals sector.
- (1) ENSC is a program with uniquely effective structure, science focus, & community engagement.

3.2 Responsibilities and “what graduating students should look like”

These (and other) responsibilities and characteristics of graduating EOAS students are more nuanced compared to “strengths”, depending on discipline and individual faculty members.

- (6) The most commonly mentioned responsibility was the importance of developing students’ abilities to think sensibly and critically with, and about, quantitative information. More details in Appendix III.
- (5) Students need to practice aspects of data science NOT related to analysis: examples include finding & wrangling data (including “large” data), visualizing, quality assurance, working wisely with incomplete data and uncertainty, etc.
- (4) The department needs to be explicit about preparing mainly for careers (80-90% of students) and to a lesser degree (10-20% of students) for graduate school. Consequently, quantitative content and contexts could perhaps be aligned more with students' future professional needs and less with current research topics.
- (3) Students must graduate with basic scientific & model-based thinking abilities

- (3) Some of our service courses need to be more representative of the quantitative nature of Earth sciences (although it was recognized that some courses are doing this well).
- (3) Gaining GIS skills is considered important for students across most EOAS specializations.
- (3) The importance of new or emerging tools and techniques needs to be assessed and incorporated into curriculum if and when appropriate. This issue gets brought up most commonly when artificial intelligence or machine learning are discussed.
- (2) Climate issues are a major new priority; we are responsible for delivering climate science to core & service students/
- (2) Meeting professional licensing requirements is a reality in some specializations; we are responsible for helping students prepare adequately to achieve professional standing in their careers.
- (1) Students need to know how to solve equations by hand.
- (1) Students must become unafraid to do a bit of coding, and many should become familiar with opensource practices.
- (1) We should be helping raise students' awareness of their options within EOAS & beyond in careers or further specialized education.
- (1) As a department, we need to find a responsible balance between delivering core or fundamental learning and being agile to meet the changing needs of professions students aspire to.

3.3 Challenges or barriers to change

Barriers to change that are mentioned tend to be “bigger picture” issues that are either unavoidable (such as demographics in some elective courses), or which may require systemic change at the program or departmental levels, or perhaps higher. Never-the-less, even big-picture challenges can be addressed with creativity and support from educational expertise at the local, faculty, institutional or community levels.

- (4) First year requirements do not meet our needs; e.g., no (or irrelevant) contexts and no early exposure to geoscience topics and styles of thinking.
- (3) AI and ML & especially generative AI (eg. chatGPT) are forms of "black box" thinking and need careful, overt attention. (Note - search CTLT and SkyLight for emerging guidelines and recommendations, emphasizing the opportunities as well as identifying “problems” or challenges.)
- (2) EOAS elective courses are taken by students with a wide range of interests and abilities. In most of these courses, there can be few expectations regarding consistent prior or pre-requisite skills, knowledge or attitudes.
- (2) There is no single course taken by all students pursuing EOAS degrees. EOSC211 and EOSC212 were mentioned, but for some specializations, one or both are in the curriculum as part of a "one of..." requirement.
- (2) Licensing requirements are considered a “barrier” by some, but reasonable by others.
- (2) The general need to somehow mitigate "math phobia".
- (1) Flexible programs and prerequisites requirements make it difficult to build capabilities by leveraging prior learning.
- (1) The difficulty of carrying out meaningful assessment in larger courses was identified as a barrier to improving quantitative learning. However, there are resources at Skylight and CTLT for developing effective assessment tactics that are also efficient.

The following challenges or barriers to change emerged during analysis rather than being discussed in any depth during interviews.

- It became evident that faculty members are sometimes unfamiliar with the requirements for programs, especially regarding courses outside their own discipline. Faculty are also not always aware of the kinds of learning experiences students encounter in courses they don't teach.
- A difficulty commonly recognized by interviewees is that of finding time, inclination or incentives to develop or "evolve" their courses.
- Similarly, the benefit of support from educational expertise was clearly recognized, but limited access to such support was considered a "barrier" to keeping courses current.
- Analysis of interviews revealed (mainly by implication) a well-known hurdle faced by all experts who teach; that of "expert blindness". Even the smallest aspect of teaching – such as crafting answer options for multiple choice questions – requires great care to ensure the idea, concept or process is interpreted or understood by students in the same way as it was intended. This aspect of "validating" our teaching and assessment may be particularly challenging in EOAS owing to the wide range of students encountered in our service courses.
- One individual described a quantitative pre-requisite in geology that results in varied capabilities for subsequent courses. Second year students are required to take either introductory programing or introductory GIS. The result has been that neither capability can be relied upon in later courses.

4 Principle recommendations

Conversations during interviews tended to be general and sometimes philosophical so most recommendations are not particularly focused on specific concrete actions. Before each item, the target for recommendations is indicated as either course-level (courses), program-level (programs) or department-level (dep't).

4.1 Quantitative critical thinking

- (6) (courses) Explicitly incorporate aspects of "critical quantitative thinking" into courses at all levels. (See also "Responsibilities" above, and Appendix III). With creativity and support from peers and educational expertise, "critical quantitative thinking" can be practiced without attaining competence with the rigor that might be expected of graduate students. See also "Rigor", section 4.3 below.
- (4) (courses) First year EOAS courses need fewer "facts & pretty pictures", more "Earth processes" & ways of thinking, especially QES and model-based reasoning.

Mentioned only by implication is the role of "model-based reasoning" in quantitative Earth sciences. Thinking with mathematical models means recognizing the range, variety & limitations of outcomes or interpretations. This takes practice and requires students to learn how to stop thinking that there is always one "perfect answer".

4.2 Application oriented learning

- (5) (programs) To benefit from the multi-disciplinary nature of the Department, courses and programs need to enable such opportunities by structuring curricula so students can take courses with colleagues in other disciplines.
- (4) (courses) context-oriented teaching (use of cases, field settings, real problems, etc.) does occur in many quantitative EOAS courses. Yet instructors are encouraged to increase effort to inspire students with (and ground their learning in) meaningful, professionally relevant contexts.

- (3) (courses) Similar to above, but the recommendation here is to teach by starting with the needs or applications before introducing methods, techniques or relevant theory. This is “application-oriented” as opposed to “theory-oriented” teaching.
- (2) (courses) as climate issues are a major new priority, instructors are encouraged to teach using climate-related contexts to both core & service students.
- (2) (dep’t) Two interviews mentioned that partnering with other units (eg. climate math) would increase exposure of quantitative earth sciences to students outside EOAS. (Starting spring 2023, there is already a joint Math / EOAS project to bring climate-related contexts to early math courses.
- (2) (dep’t) In two interviews, it was suggested that there should be more EOAS versions of math, computing, AI/ML and other quantitative courses. Although EOAS already does this, it is still challenging to implement because other departments don’t want to loose student numbers.

4.3 Appropriate levels of rigor

- (3) (courses / dep’t) There would be benefits of focusing upon foundation quantitative learning that is relevant across EOAS disciplines. This may require compromise, but identifying, then incorporating quantitative fundamentals into earlier courses that are relevant in more than one specialization would enable these courses and make subsequent “post-requisite” courses more accessible to students in more than one discipline.
- (3) (courses / dep’t) Similar to previous, but more specific: consider one common 2nd yr quantitative Earth science course for all. Have students across specializations collaborate on projects during the 2nd half of such a course was suggested by one interview pair.
- (2) (courses) Do we leverage early learning in later courses sufficiently, and explicitly enough? This translates into concentrating on scaffolding (or spiraling) strategies[1] that are based on math & physics courses taken outside EOAS.

Issues mentioned or discussed by one interview pair only include:

- (1) “Students need to know how to solve equations by hand”. The scope of this desire was not elucidated.
- (1) EOAS students are less in need of learning fundamental math/physics than students in those departments. Again – scope was not discussed.
- (1) One suggestion was to consider implementing "streaming" in individual courses when diversity of background and interests so that the course does not have to revert to the “lowest common denominator”.
- (1) One pair of interviewees agreed with the need for new specialized courses. This might be true, and is in fact occurring as new faculty establish their roles and priorities within the department. The “zero-sum” challenge (see “Challenges” above) does have to be addressed for any new course developed.
- (1) convert some required courses to electives (eg. min+petrol is 5 courses now but could be 3).

Note: *The QuEST project had hoped to spent time working towards articulating a consensus about foundational content or concepts that span EOAS disciplines. Project reporting will include recommendations for how to discuss, then establish priorities for, foundational content deemed necessary across, and within, degree specializations.*

[1] “Scaffolding” is strategic support for helping learn challenging concepts, while “spiraling” is strategic and explicit revisiting of previously addressed skills or knowledge to support appropriate reinforcement. CTLT can help design and implement corresponding pedagogic strategies in any course or program.

4.4 Data science

Recommendations regarding data science were mostly agreed upon, although interview discussions tended to be general. Basically, data science is growing in importance across all the geosciences, but specifics vary somewhat in disciplines. Three perspectives dominated. (1) Some considered GIS to be critical. (2) Others considered the finding, gathering, assessing, wrangling and visualizing of data as most important. (3) Many claim it is important that students gain experience with the statistical, mathematical, analytical and modelling aspects of data science. These perspectives are already addressed in individual courses by instructors, but there seems to be a lack of coordination across the department regarding what is done in each course or by individual instructors.

- (5) (courses, programs) students need to experience large data, data wrangling, visualizing, etc
- (3) (programs) Several interviewees considered GIS to be a critical aspect of quantitative learning for professionals in geology, engineering, and to a lesser degree in other disciplines.
- (2) (courses) students need early experiences working with data. This general perception is already being incorporated into curriculum via EOSC211 and the introduction of DSCI100 as required in some programs.
- (1) (courses, programs) The gathering, measuring or finding of data is under-represented in EOAS curriculum. Students need to experience how data are obtained, the corresponding limitations, realities of field work, etc. This was mentioned explicitly by one pair of interviewees but hinted at in discussions with other pairs.

4.5 Career preparation

In general, there needs to be clarity and explicit articulation of how the balance is maintained between teaching to prepare future scientists and teaching to prepare students for current and future professions.

- (6) (dep't) The need for more effective interaction with non-academics (industry, alumni etc.) was expressed by 5 interview pairs. Faculty would be kept up to date regarding hiring and career options, and students would learn how the "world of work" differs from academe. They could also gain awareness about how their learning relates to future occupations.
- (4) (programs) Having a required capstone experience was discussed as one of the best ways to help students mature as self-disciplined, productive professionals or graduate students. Environmental sciences and geological engineering already have capstone courses that are required. Other specializations could either introduce such opportunities (easier in smaller programs) or introduce a variety of alternatives that would be accepted for completing the requirement, including co-op terms, other relevant work experiences, thesis projects, or other ideas.
- (3) (courses) Learning about specific tools as a means of career preparation is often debated. Some feel specific tools (e.g. GIS, specific programing languages and remote sensing) are important skills for a student's CV. Others feel that students need to have adaptable skills that are not tied to specific, rapidly evolving "tools". Department-wide compromise is required, and is emerging in some cases (e.g. Python as the programing language of choice, and GIS as a required skill for engineers and geologists).
- (4) (programs, dep't) More purposeful & comprehensive advising and student support is advised. This could include increasing students' awareness of degree options within EOAS as well as the resulting career options after graduating and corresponding curricular implications.

Two aspects were surprisingly rarely mentioned.

1) There was little discussion about work experiences other than to recognize that many BASc students pursue co-op work placement terms. However, BSc students may have fewer such opportunities. Further support for

finding placements for quantitative students, and showcasing these types of opportunities, might increase the relevance and attractiveness of quantitative programs.

2) Students' non-academic experiences were also rarely mentioned. More concrete support for clubs, professional networking, work related activities, etc. would likely help students gain the motivation and experiences that look good on CVs.

4.6 Other recommendations

The following recommendations do not fit clearly within any of the 5 main themes.

1. In two interviews, regular curriculum reviews were mentioned as normal for Geological Engineering and Environmental Science programs. By implication, it could be recommended that regular reviews with (clear guidelines and expectations) become "normal" practice for other programs, or perhaps for quantitative or data science course sequences. After the first is done, subsequent regular reviews are reasonably efficient.
2. Learning goals or learning outcomes were never mentioned, either at the course or program levels. Yet carefully crafted Program Learning Outcomes (PLOs[2]) are important components of well-designed and clearly articulated degree specializations. Course Learning Outcomes (CLOs or learning goals) can best be crafted to target PLOs rather than being developed for each course in isolation. Note that CLOs are a recommended (if not 'required') component of required course syllabi; see UBC Senate Policy V-130 "Content and Distribution of Course Syllabi".

[2] Program Learning Outcomes (PLOs) for each specialization, and Course Learning Outcomes (CLOs) for every course, are critical for ensuring that students, instructors and administrators recognize priorities. UBC has recommendations and can provide support for building PLOs. Few EOAS degree specializations have effective PLOs. Many EOAS courses have respectable CLOs. Based on syllabi examined in 2022 (see EOAS Syllabi and CLOs below), two thirds of EOAS quantitative courses have excellent or acceptable CLOs, while one third either have no CLOs or they are only briefly mentioned.

Appendix I: Participants

A request to participate was sent by personal email to 32 EOAS faculty members thought to be involved in teaching quantitative aspects of Earth, ocean or atmospheric sciences. Of these, 17 participated, 2 refused, 12 did not reply, and 1 re-connected to participate after returning from field research.

Primary Discipline (N = 17)				
hydrology	AtSci / climate	Ocgy	Geoph	Geol
3	4	3	4	3

Stage of career			**Gender**	
early	mid	late	m	f
5	6	6	11	6

Additional Context			
Engineer	Ed'n. focus	applied experience	UBC admin experience
3	1	7	5

Interviews were scheduled according to the availability of interviewees. This proved a labour intensive step as individuals have busy, variable, and sometimes changing schedules.

There are a further eight faculty members who we may consider interviewing after initial analysis, depending upon time and resources. It is possible that recommendations from early to mid-career faculty should take precedent, but that would need discussion. One followup approach might be to ask those who were not interviewed to identify what aspects in this report "resonate" with them, what doesn't, and what could be added or adjusted.

Appendix II: Guiding interview questions

1) Current Identity:
   a) Who are we? What makes us unique?
   b) What are our responsibilities?
2) Future Identity:
   a) Who do we want to be? What aspirations?
   b) What opportunities?
   c) What should graduates look like in 5-10yrs?
3) Implications:
   a) How do we 'get there'?
   b) Changes to courses/programs?
   c) Changes to sequencing/student experience?
   d) How do we attract more and 'the right' students?

Appendix III: Scope of "Critical Quantitative Thinking"

The most commonly mentioned "responsibility" was the need to develop students' abilities to think sensibly and critically with, and about, quantitative information. This is not about gaining advanced mathematical or computing capabilities. It is more about learning to be fundamentally quantitatively- and data-oriented in their thinking. Aspects mentioned include:

- making judgements about data relevance, reliability and quality;
- choosing, finding and curating information that is appropriate to the issue;
- translating a problem or question into its quantitative components;
- thinking in terms of approximations or orders of magnitude;
- relating "reality" to "models" and recognizing the strengths and limits of thinking with models;
- basic statistical ways of thinking;
- distinguishing "signals" from "noise" within a specific context;
- recognizing patterns in data, phenomena, concepts…
- working with datasets that are at different scales;
- other aspects would no doubt arise in further discussions.
- gaining data-centric thinking habits, rather than waiting to be told what to think
- AI & ML are emerging as part of the challenge of gaining maturity regarding quantitative thinking.

Appendix IV: Bibliography

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Note: The "Qualitative Report" is a creative commons qualitative research journal.