Desirable capabilities & attributes

Francis Jones, Nov. 2023 – Dep't EOAS, the QuEST project.[1]

Contents

NOTE: when the terms such as "Earth sciences" or "geoscience" are used, they are meant to encompass all geologic, atmospheric, ocean, environment and climate sciences.

This report is about desirable **skills**. The QuEST report section on recommendations discuss desirable **tactics** for attaining (and fostering) those skills.

1. Summary

Capabilities and attributes that students **should** be able to demonstrate upon graduation from a quantitatively oriented Earth science (QES) program are described and discussed. This is not about the **current** QES curriculum in the department of EOAS. That is described on the current QES course content page. Options and preferences are based on input from interviews, surveys and discussions with EOAS

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faculty and students, from peers and peer institutions, and from literature about career preparation from academic and employer perspectives.

The QuEST project focuses on quantitative earth sciences, and the desirable skills here reflect that. However, the "employability" of a student depends at least as much on abilities and attributes that are not unique to a discipline. Saunders and Zuzel, 2010, quote a useful definition of employability as "*a set of achievements - skills, understandings and personal attributes - that make graduates more likely to gain employment and be successful in their chosen occupations, which benefits themselves, the workforce, the community and the economy*." Usher, 2022, discusses some aspects of why it seems difficult for institutions to anticipate market demand – i.e. to define how best to prepare society's future professionals. Four basic (and perhaps obvious) aspects are (a) the future is hard to predict, (b) companies, governments and universities/colleges don't have the same priorities, (c) companies are precise about skills they want when hiring, but most of those skills arise from experience not academic learning and (d) academics (and institutions) are slow and sometimes reticent to change.

A more "academic" articulation of forward-looking goals for a university-based undergraduate science education come from Kwok, 2018 (the first half in particular is clear and well worth reading and re-reading): "*A lot of factual information is available on the Internet, and artificial intelligence is making certain occupations obsolete. It is therefore much more important to give our students fundamentals that will stay with them for the rest of their lives. These essential tools include* ***language skills such as comprehension, expression, and communication****, as well as* ***quantitative skills such as analysis, seeing hidden patterns, identifying variables, and formulating solutions to problems.***"

To reflect the distinction between discipline specific capabilities and the more general characteristics of highly employable graduates, desirable skills identified below are organized into three main categories; (a) knowledge, skills and attitudes that are essentially quantitative (i.e. math, physics and computation), (b) those that are unique to the geosciences, and (c) capabilities associated with a person's readiness to enter the workforce or advanced education. Therefore, the majority of desirable skills (with a few exceptions) are considered "generic" rather than targeting specific careers or disciplines.

Preparing highly employable graduates is not only a responsibility of the Department, but successful graduates are also important from the recruiting or "marketing" perspective.

1.1 Regarding quantitative capabilities

One persistent theme is the importance of "higher-level" aspects of QES learning, i.e. the need to nurture critical thinking involving quantitative and data-oriented information. It takes time and guided practice to gain the necessary maturity to make reliable decisions and judgements based on physics, data sets, and mathematical models.

Quantitative "topics" are easy to list and they seem relatively consistent across QES degree programs. However, rather than listing topics like "ODEs" or "linear algebra", the important concepts would be more usefully described in terms of the scope, context and expected level of mastery. The department's research expertise will inform these contexts and those chosen should span the degree specializations, however, students also need to experience settings that reflect the broader world of work.

Computing should be integrated throughout quantitative courses and curriculum. A balance is needed between the development of coding skills versus quantitative knowledge that uses computing codes. These two "goals" are not the same and mixing them can compromise success.

AI/ML (including generative AI) is rapidly emerging as a necessary component of thinking across the STEM disciplines. Forward looking curriculum must include opportunities for students to gain mature and well-informed capabilities involving AI.

Sources that consider desirable skills more generally for geoscience graduates are not focused on smaller quantitative programs, but they do remind us that basic numerical capabilities should not be lost in the advanced math; capabilities such as data visualization, managing uncertainty, informed use of statistics, wrangling large and/or public data sets, etc.

Collected quantitative capabilities

To be selected or adjusted and specified with contexts & levels of mastery, appropriately for the specific degree specialization.

- Pervasive *critical quantitative thinking* involving numerical, model-based and data-oriented information in Earth science settings.
- Basic numerical capabilities: fluent algebra & trig, plotting, uncertainty, data organizing, spreadsheet uses.
- Fundamental math including calculus, ODEs & PDEs, numerical methods - BUT in context.
- Specialized math including signals and spectra, image analysis, inversion, modelling.
- Statistics and statistical thinking.
- Fundamental physics, including mechanics, waves, thermodynamics, continuum mechanics, E&M, measurement, instrumentation.
- Specialized physics: atmospheric physics, geophysical fluid dynamics, potential fields, waves of all types.
- Fundamental computing including programming and code-based problem solving, integrated throughout curriculum.
- Data science, including data access, wrangling, visualization, quality assessment.
- Pros, cons and ways of applying artificial intelligence and machine learning, including potential and limitations of Generative AI.

1.2 Capabilities unique to the Earth sciences

Specific geoscience-based capabilities are important because it is the Earth science context that distinguishes an EOAS quantitative degree from a physics, math or computer science degree. Research faculty in quantitative disciplines naturally focus on their own important methods and concepts. But they also tend to gloss over the unique aspects of geoscience and how geoscientists think when hypothesis testing or problem solving. Increasing the attention paid to field, lab, mapping (especially GIS), observational and related skills was considered desirable by employers. Researchers who interact with non-academics also identified these priorities, but purely academic scientists were less likely to mention them. Students also highlight their desire for more “application oriented” settings or contexts while practicing with fundamental concepts.

The distinction between important “geoscience concepts” and important “geoscience skills” was made by the most comprehensive evaluation of current and future geoscience education (Mosher and Keane, 2021). For example, “concepts” include **deep time, climate change, Earth materials, natural hazards** and others, while “skills” include **spatial and temporal interpretation, working with uncertainty, integrating disparate data,** and others. This distinction helps clarify how the more quantitative capabilities should be expressed. On their resumes, students need to be able to demonstrate “capabilities” rather than simply listing “concepts encountered”.

One category of capabilities rarely considered in curriculum discussions is the so called “*societal relevance skills*”. These are important for preventing the sense of “isolated knowledge” that young students experience when learning (for example) basic calculus from abstract mathematical perspectives. When students can articulate the personal and societal relevance of their learning, they are more motivated and consequently more successful.

Collected Earth science capabilities

To be selected or adjusted and specified with contexts & levels of mastery, appropriately for the specific degree specialization.

- Fundamental geoscience: deep time, rates of geological, atmospheric and ocean processes, scales of influence, spatial information, observational nature of geoscience.
- Specifics: tectonics, geological materials, resources, hazards, geomorphology, hydrogeology, ocean behavior, basic meteorology and climatology.
- Field, lab, GIS and observational skills (but not necessarily "specialized" software).
- Instrumentation, measurement, data management and analysis, where relevant, for geophysical, atmospheric, oceanographic and hydrological work.
- Multi-disciplinary nature of geoscience (physics, chemistry, biology, geology).
- Inter-disciplinary nature of the Earth, ocean, atmospheric, and environmental sciences.
- Societal relevance of geoscience topics, ideally based on engagement with civic or commercial sectors.

1.3 Career-readiness capabilities

Note that interviews were conducted with EOAS faculty to ask specifically about **tactics** (not skills) they consider effective at helping student prepare for post graduation opportunities. The full report is revealing about different tactics considered important by faculty with different backgrounds and experiences with non-academic sectors. More is discussed in the QuEST report recommendations section on Career Preparation, and details are in the full report.

Career-readiness capabilities are those aspects of “maturity” sometimes called soft skills, work-place competencies, or something similar. Faculty know these are important and many were mentioned or implied during interviews, including communication skills, teamwork, reliable synthesis of information, and the ability to relate learning to societal and work-place priorities. Conversations focused on tactics for supporting student development rather than articulating the required capabilities. Students certainly benefit from these activities but more clarity about exactly what capabilities are targeted - and why - would increase motivation and help them relate their studies to future occupations.

From the perspective of employers, relevant work experience is highly desirable. This is not a “skill” or “capability” but many employers believe that the “soft skills” and “work-oriented attitudes” can best be obtained in the workplace rather than by studying at school. Unfortunately, finding a first job that is relevant is increasingly difficult. Ng, 2023, refers to this problem as “*experience inflation*”. Employers also expect students to be able to set appropriate expectations about work habits and the commercial and business aspects of employment. Can degree programs provide relevant experiences without compromising academic priorities? Probably, but a little creativity is needed. Consulting with colleagues, instructional designers and career preparation experts will help weave relevant work-related settings into learning activities. In addition, employers want examples of students applying fundamentals in applied situations, and evidence of a student’s experience in both team-working and leadership roles.

Collected capabilities supporting career & post-graduate readiness

To be selected or adjusted and specified with contexts & levels of mastery, appropriately for the specific degree specialization.

- Logical and deliberate approaches to problem solving including scientific design and hypothesis testing by observation or experimentation.
- Develop a sense of curiosity and acquire the confidence to ask questions and challenge assumptions.
- Synthesis of diverse information & use of public & proprietary literature.
- Ability to relate learning to societal and work-place priorities.
- Cooperative aptitudes regarding teams, leadership and self-directed working situations.

- Communication skills, especially written and oral.
- Professionalism regarding technical, commercial, business and personal aspects of the workplace.
- Time or project management tactics practiced (for example) during capstone or project activities.
- Awareness of the importance of ethics, budgets, balancing needs of clients and employers.
- Personal skills associated with appropriate behavior regarding justice, equity, diversity and inclusion.
- Career and self-development skills including life-long learning abilities and habits.
- Ability to plan for career progress and establish & maintain a network of colleagues and peers to support professional or academic development.
- Tailor a resume or other expression of personal abilities to suit any relevant job, study or other opportunity.

2. Introduction

What should students be capable of when they graduate from a quantitative Earth science (QES) degree program? What should they learn and practice in order to become effective employees or post-graduate students? These questions can be addressed by considering the following "domains" of knowledge, skills and attitudes:

- Quantitative concepts and competencies including math, physics & computing,
- Geoscience concepts and competencies
- Career readiness skills and attitudes that employers and supervisors desire when they first take on a new BSc graduate.

For each of these domains, the desirable capabilities and attributes expressed from six types of sources are first listed, then implications are summarized. The sources include:

- Curriculum discussions among EOAS faculty (2019 & 2020);
- Paired interviews with EOAS faculty (2022)
- Individual interviews with EOAS faculty (2022);
- Colleagues and curricula at other degree-granting institutions;
- Scholarly literature and activities of colleagues beyond UBC.

Insights from peer institutions are from a review of course lists at 7 comparable institutions (results, by CTLT) and personal email discussions provided by colleagues of C. Schoof at 8 institutions. Other institutions exhibit various challenges, some of which EOAS also experiences. For example, institutions in Alberta (UofA, UofC) are constrained by the petroleum industry and expectations regarding professional registration. Memorial (in Newfoundland) is similar, and University of Toronto is unique in that geophysics is embedded within the physics department.

Student perspectives are also included based on discussions, surveys and responses to open questions.

How should desirable capabilities be expressed? Employers tend to articulate "*desired abilities & attributes*" in their job ads, instructors often list "*topics or concepts that students should learn*", while educational experts prefer to describe "*learning activities and experiences students will engage in*". Ideally, instead of listing "topics" or "concepts", desirable capabilities and attitudes should be expressed more like "*students will be able to demonstrate …*", with each capability expressed with some indication of context, and level of mastery. For the sake of efficiency, the capabilities expressed herein are not necessarily articulated in this preferred form. In fact, doing so should really be carried out as part of curriculum renewal, by iteratively generating a comprehensive set of Program Learning Objectives (PLOs) for existing or future QES degree specializations.

This collection of capabilities is not the result of an exhaustive literature review nor does it represent a purely departmental perspective. However, it does hopefully provide a useful combination of local and broadly based perspectives about what students should be learning and the abilities they should be developing in QES degrees offered by the Department of EOAS.

Finally, a reminder that this section is focused on **what** knowledge, skills, attitudes and habits students should be able to demonstrate, not **how** the department and instructors could foster those abilities. The "how" is addressed as recommendations elsewhere in QuEST documentation.

3. Math, physics & computing capabilities

First, data about capabilities identified by several sources are described, then implications are summarized.

3.1 Earlier deliberations among EOAS faculty

Discussions in 2019 & 2020 (see summaries of desirable content and priorities) resulted in the following lists of suggested topics that students should encounter in all QES programs offered in EOAS. "Geophysical concepts" such as fluids, potential fields etc. are listed below under "Geoscience Capabilities".

Fundamental concepts	**Methods, tools, strategies**
• conservation laws, mechanics, thermodynamics • equations of state, constitutive laws • waves (how? to what degree of sophistication?) • diffusion, damping, advection • signals and noise • forcing and feedback, stability, bifurcation • scientific hypothesis testing by both experimentation and observation • simulation and prediction using empirical / statistical models	• ODEs & PDEs (initial & boundary value problems) • scaling & dimensional analysis • systematic model simplification, heuristic lumped (box) models • dynamical systems • numerical methods for deterministic models, discretization methods • inverse models • spectral analysis, signal analysis • data analysis, image analysis • statistics • machine learning & artificial intelligence.

One aspect that is either "assumed" or forgotten is programing skills.

These are not described as "capabilities" but they do provide insights regarding the priorities of EOAS faculty. To be more useful, the list could be converted to capabilities by articulating what a successful student should actually be able to do with each concept or method. This would help clarify scope and "level of mastery".

In their **2019 report on data science** to the UBC Faculty of Science, Austin and colleagues, 2019**,** stated that *"university graduates now and into the future will need skills to organize, interact with and extract meaning from data."* This is a useful, succinct articulation of desirable capabilities, especially relevant in QES degree programs.

Another useful result from that report was obtained by asking instructors and current 4th year students "*how important is each of nine themes for a data-literate graduating student*". The two themes considered **least important** were

• "*mathematical foundations and reasoning*" and • "*computational foundations & reasoning*".

Those themes were certainly not considered unimportant, but from a data science perspective, other themes were considered more important, including

• *"communication of data and interpretations"*, • *"statistical foundations and reasoning"*, • *"scientific reasoning and process in context"*, • *"data management"* and • "*data visualization*".

Finally, the range of quantitative concepts that current (2022) EOAS students encounter is summarized in figure 2 of the report on QES content in EOAS courses. The diversity of these concepts and courses suggests that QES learning in EOAS is likely as comprehensive as in any peer institution.

3.2 Paired interviews with EOAS faculty

Discussions during interviews with pairs of colleagues were more about "types" or "scope" of quantitative thinking rather than the specific topics or concepts covered (see the report for details). When asked what the department's responsibility is to quantitatively oriented 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 helping students develop their "*critical quantitative thinking*" abilities - explained and summarized in Appendix I - was by far the most commonly agreed upon notion.
- It was considered desirable that "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 of consistent prerequisite knowledge. It was suggested, for example, that the department "*consider one common second year quantitative Earth science course for all*".
- Students need to practice aspects of data science NOT related to analysis such as "large" data, publicly accessible data, data wrangling, visualizing, quality assurance, etc.
- 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.

3.3 Interviews about balancing fundamentals versus career preparation

Individual interviews focused on how EOAS degrees and courses currently support career preparation, and what tactics could be incorporated to increase a student's readiness to begin careers or further studies (see report for details). Results about desirable math, physics & computing capabilities include:

- Students should be **using more mathematics** in existing EOAS courses, including derivatives, plotting slopes, visualizing data, calculus, linear algebra, differential equations, and others.
- Suggestions regarding **data visualization**:
    - Ensure students know how to plot without using spreadsheets, and
    - Teach more sophisticated uses of spreadsheets since these are standard (and powerful) tools in many employment situations.
- Development of **critical, scientific and precise thinking** skills was mentioned by several individuals in these interviews.
- Interestingly, when asked "*what tactics for enhancing career preparation do you use now or you would like to use?*" …
    - Eleven out of the 13 interviewees with little experience outside of academia referred to "*a focus on math, physics and computing skills*".
    - In contrast, none of the 7 faculty members with experience or collaborators outside of academia recommended focusing more on fundamentals. See the report Figure 3.

3.4 Peer institutions

Institutions considered "comparable" in terms of the diversity, rigor, and department size all seem to have similar perspectives on fundamental math, physics and computing topics, while the types of upper level courses depend either on a department's research expertise, or on specific demands of professions targeted by the institution (eg. oil/gas, engineering, environmental services, etc.)

One attractive articulation of desirable capabilities comes from Stanford University. They reduced their core requirements to just 5, but everyone else's priorities are embedded in this short list:

1. Measurements, Instruments, Fields and Waves
2. Mathematics, Computation, Mechanics and Dynamics
3. Laboratory Studies
4. Exposure to the breadth of the department via an introductory "parade" of guests by all faculty with a recitation involving short readings and one problem.
5. A thesis-writing senior capstone

Most of the single-word desirable capabilities in this list are consistent with other institutions as well as EOAS faculty's priorities. However, three topics that are **unique in Stanford's priorities** are measurement, instrumentation and laboratory studies.

Other observations: A useful comment from one colleague was that "*…future grad students will take more advanced numerical methods later anyway.*" U. of Alberta gets their QES students off to a good start with a 2nd yr. numerical methods course involving Python. This exemplifies everyone's attempts to both combine computing with mathematics and provide students early with skills they can leverage in senior courses.

3.5 Sources beyond EOAS and UBC

Published discussions about capabilities specifically for QES degree programs seem hard to find. There is more literature that addresses desirable capabilities for geoscience disciplines more broadly.

Mosher and Keane 2021, "*Vision and Change in the Geosciences: The Future of Undergraduate Geoscience Education*" may be the most comprehensive assessment of desirable capabilities in geosciences generally. This study did not consider specific disciplines (eg. geology, geophysics, etc.) individually. Instead, their perspective is that specific degree programs should each develop their own understanding of what defines their program's success, but to do so while taking into account the overarching messages about the future of geoscience education expressed in the report.

In this report "desirable capabilities" are addressed in chapter 3, "*What Undergraduate Geoscience Education Should Accomplish*" using three headings: **Core Concepts for Success, Core Geoscience and Science Skills for Success,** and **Core Competencies**. Their Figure 3-2 summarizes the collective opinions of academics and employers regarding the relative importance of six "science" - as opposed to more specifically "geoscience" - skills. This aggregates opinions from across the geoscience sub-disciplines so it is not a reflection specific to quantitative Earth sciences, however, it serves as a starting point for discussions about the expectations for BSc degree graduates generally.

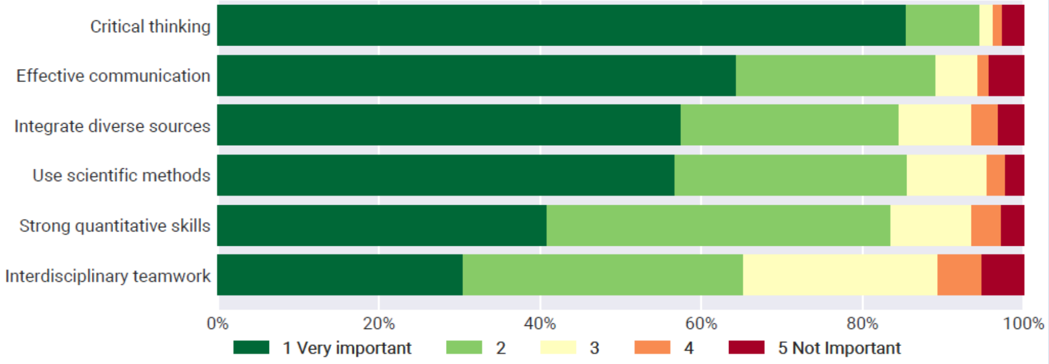


Figure 3-2: Science Skills Importance

Survey Question: The Summit report identifies the following skills as critical to undergraduate education. For each, please indicate the importance from your perspective of these skills for undergraduate-level curricula.

Abilities that employers identified as rapidly increasing in importance for geoscientists can be summarized as follows. Note concepts are given a certain broad context rather than being stated in isolation.

- Calculus, and especially statistics involving probability, uncertainty and risk;
- Differential equations as key to understanding fluid flow and other pervasive geoscience concepts;
- Linear algebra which prepares students to work with complex multivariate systems and problems;
- Analysis and management of large data sets, including integrating and analyzing multiple related data sets;
- Visualizing data & models and thinking that involves models and modeling;
- Computational methods including programing (at appropriate levels of sophistication).

More generally regarding "quantitative skills", 2 of the 6 key recommendations that conclude their chapter 3, "*What Undergraduate Geoscience Education Should Accomplish*" are:

- Identify the key quantitative reasoning skills required for your graduates and incorporate practice in these skills at multiple points in their degree program.
- Students need to practice acquiring and analyzing real data using multiple methods and tools to solve geoscience problems, including handling large data sets, understanding accuracy, limitations, and uncertainty, and communicating results.
- Students should be able to demonstrate logical and deliberate approaches to problem solving including scientific design and hypothesis testing by observation or experimentation.

McGovern and Allen's 2021 article "*Training the Next Generation of Physical Data Scientists*" (in AGU's EOS magazine) advocates for increasing the emphasis on artificial intelligence and machine learning (AI/ML) and data science. Quote: "*Quickly adapting education to leverage new technologies has traditionally not been a strength of academics. Yet with the rapid growth of AI/ML and data science methods, and the range of pressing geoscience questions to which they can be applied, … time and investment are needed to recast instructional approaches to train students in physical data science and to better prepare them for the workforce of the future.*"

Liemohn, 2023 (also in AGU's EOS magazine) identify a critical component of undergraduate STEM education as "*understanding sets of numbers and how to process, plot, and compare them*". They claim that "*most programs only scratch the surface of data analysis techniques, data visualization, and uncertainty*". The article describes a new (late 2023) book in AGU's Advanced Textbook Series, *Data Analysis for the Geosciences* which provides an introduction to these concepts and skills within a framework of uncertainty.

4. Geoscience capabilities

What distinguishes an EOAS quantitative BSc from a physics degree? The contexts. Thinking about deep time, slow physical processes, scales of influence from microscopic to global and beyond, spatial information, and the observational (rather than experimental) nature of geoscience hypothesis testing; all these contribute to distinctively "geoscientific" ways of thinking and problem solving. The Earth sciences are truly both multi-disciplinary (combining physics, math, chemistry, biology, geology) and inter-disciplinary. EOAS faculty may have had these or related aspects of geoscientific thinking in mind during curriculum discussions (2019 & 2020) & in course content surveys (2020/21) but none of these issues were mentioned explicitly.

QES students who wish to register as professional geoscientists in Canada must take four geoscience courses: mineralogy/petrology, sediments/stratigraphy, structures, and a field course. Quantitative students in atmospheric, oceanography and environmental specializations should also gain similar breadth within their own disciplines. Colleagues from outside of academia agree that this is necessary to ensure QES students are effective contributors in any team or enterprise they pursue beyond graduation.

4.1 Earlier deliberations among EOAS faculty

Discussions in 2019 & 2020 resulted in the following list of suggested priorities for geoscience concepts or skills that students should pursue in all QES programs.

1. Continuum mechanics (plus basic classical mechanics)
2. Fluids, solids, porous media
3. Geophysical fluid dynamics
4. Convection in a variety of settings
5. Hydrology & hydrogeology
6. Seismic wave propagation
7. Potential fields: gravity, magnetics, electromagnetics in context
8. Climate physics

Concepts **not mentioned** include temporal, spatial & observational geoscience. Specific subjects like mineralogy, petrology, structures, hydrology, etc. were also never mentioned.

4.2 Paired interviews with EOAS faculty

Paired interviews focused on quantitative rather than geoscience aspects of curriculum. However, one aspect mentioned by several interviewees was the importance of leveraging the multi-disciplinary nature of the Department by structuring curricula so students can take courses with colleagues in other disciplines.

Another specific topic recommended as desirable for all geoscience students, especially those faculty who interact with the non-academic sectors, was exposure to GIS and how it facilitates spatial thinking and problem solving.

4.3 Interviews about balancing fundamentals versus career preparation

Individual interviews focused on *how* EOAS degrees and courses currently support career preparation, and what *tactics* could be incorporated to increase each student's readiness to begin a career or further studies. Regarding desirable geoscience capabilities:

- Increasing the focus on field, lab, mapping, observation and related skills was considered desirable by 4 out of 7 environmental, geology or geotechnical faculty but only 2 out of 13 geophysics, atmospheric sciences or oceanography faculty.
- To help students relate newly learned quantitative concepts and skills to important geoscience problems and occupations, many faculty mentioned use of meaningful, relatable contexts for problems and assignments.

Students agree on the importance of more meaningful contexts rather than learning advanced techniques in abstract, or specialized research situations. Two quotes from student are:

1. "…[early in the course] *we learned a lot about Fourier transform properties and how to do them, and then in assignment 7 we used them to remove the effects of tides from seismograms. That gave me a moment of clarity, and definitely helped me understand Fourier transforms a lot better*".

2. “*The program leans heavily to the global geophysics side of the field and does not prepare students for industry. It needs to be updated to remove old course requirements (Phys 203) and fulfill EGBC requirements*” from the survey of geophysics students (Jolley, 2018)
3. Other students also stated a desire for more industry-relevant examples and more support for making connections with work-related opportunities.

4.4 Sources beyond EOAS and UBC

Mosher and Keane’s 2021 report from the NSF-funded project “*Vision and Change in the Geosciences: The Future of Undergraduate Geoscience Education*” summarize in their Figure 3-1 (below) the collective opinion of the many academics and employers who contributed regarding the importance of 9 “*geoscience concepts*” for undergraduate curricula.

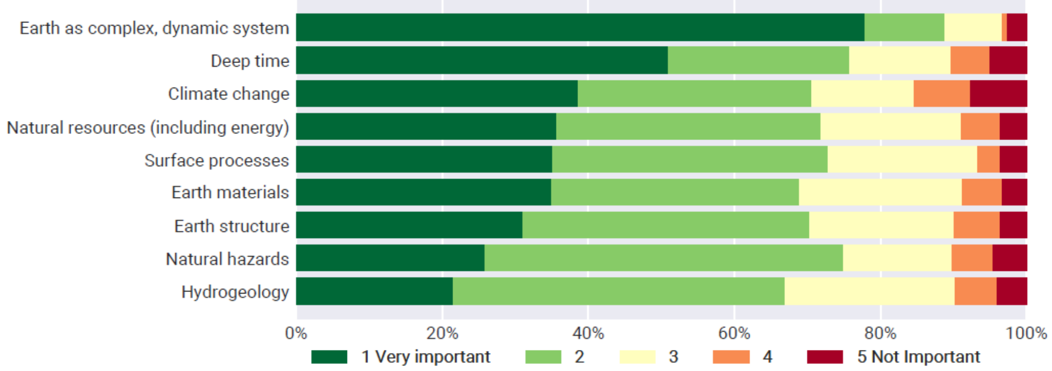


Figure 3-1: Geoscience Concepts Importance

Survey Question: The Summit report identifies the following concepts as critical to undergraduate education. For each, please indicate the importance from your perspective of these concepts for undergraduate-level curricula.

This list of topics is not very informative about “desirable geoscience capabilities” for QES degrees, however it does suggest what BSc graduates should have encountered if they are to call themselves “geoscientists”. Therefore, each topic is a potential context for learning activities or lessons involving math, physics or computing techniques.

Mosher and Keane also summarized the relative importance of the 6 highest priority “*geoscience skills*” for undergraduate curricula in the following figure:

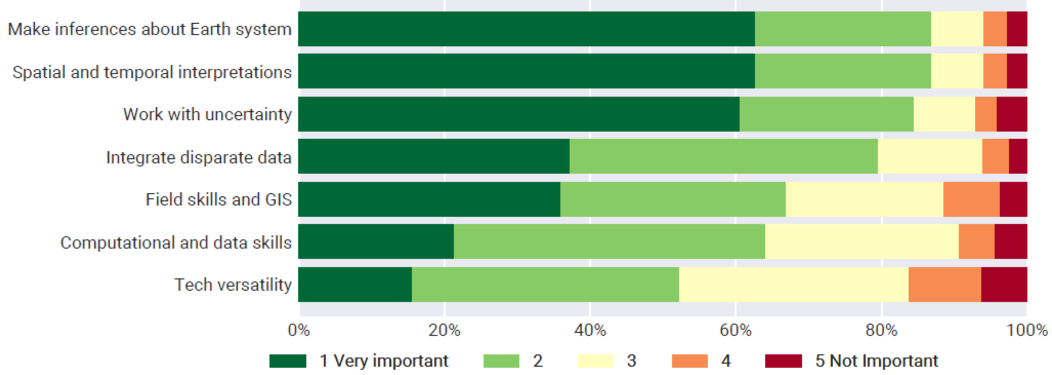


Figure 3-3: Geoscience Skills Importance

Survey Question: The Summit report identifies the following skills as critical to undergraduate education. For each, please indicate the importance from your perspective of these skills for undergraduate-level curricula.

Interestingly, the *concepts* and *skills* considered to be most important both involve “Earth systems”. In contrast, when investigating what is currently taught, Viskupic et al., 2021 found that “systems thinking skills” were much less frequently taught than other more concrete topics. Also, Shafer et al., 2023 found that “interdisciplinary thinking” and “systems thinking” were never identified in any of the 3668 job ads they analyzed, all targeting recent BSc geoscience graduates. This may reflect the difference between what employers assume students learn and what they state (in job ads) as necessary abilities or attributes for new employees.

Field and GIS skills are more highly valued compared to computational and data skills but these are aggregate results that do not reveal the difference in priorities among various sub-disciplines of the geosciences. The other skills in this table are all informative for QES desired capabilities because they identify aspects of “mature quantitative thinking” that are not usually well-articulated in curriculum descriptions. These seven “important geoscience skills” should help inform the kinds of wording needed for program learning outcomes that will describe renewed quantitative programs.

Regarding “geoscience skills”, 2 of the 6 key recommendations that conclude their chapter 3, “*What Undergraduate Geoscience Education Should Accomplish*” are:

- Provide opportunities for students to develop their understanding about broad concepts, processes, and impacts so they can build a **working framework for geoscience knowledge**, careers and lifelong learning.
- Incorporate **geoscience knowledge and skills identified by employers and academics** across multiple courses to help students build their corresponding competencies.

Viskupic etal. 2021 also compared desired geoscience workforce skills against reported teaching practices. A synthesis of these data suggests that *data-related (including quantitative) skills* and *team & communication skills* are taught in many types of courses. This indicates that quantitative capabilities across the geoscience sector are increasingly important, but it says little that is specific to QES programs. In contrast, *systems thinking skills* and *societal relevance skills* are more rarely taught, except in climate, environment and hydrology courses. The five specific “*societal relevance skills*” are important because they enable students to recognize their learning as important. QES curriculum renewal should incorporate these attitudinal capabilities into courses and QuEST project recommendations provide ideas about how this can be done efficiently in any existing course.

5. Capabilities supporting career & post-graduate readiness

This section focuses on the second, “soft” or “work-related” skills that ensure students will be readily employable in inspiring and impactful careers.

5.1 From students

Students from all EOAS degree specializations provided data for the EOAS specialization survey. They were largely positive about their learning experiences in EOAS. They particularly appreciated the interdisciplinary, enthusiastic and knowledgeable faculty and their attention to students. Three points they recommend could be considered desirable capabilities:

- Students said they needed initiatives to address stress management and well-being. Is this a “desirable capability” or a “service to support students”? If the former – where in this document should it go? More generally – are there capabilities that don’t fit into the 4 categories here? Maybe capabilities related to student wellbeing need a separate heading?
- Concerns about being prepared for professional registration were also expressed.
- There was a general impression that students wanted their courses to be updated “*to better reflect needs of the majority of students.”*

Geophysics students were asked in spring 2019 “*Has the geophysics program prepared you for your (intended) career? Why or why not?*”. Feedback they provided included (survey report):

- Core skills" (problem solving, mathematics, computing) are well developed.
- Students felt they were prepared for research but less prepared for immediate employment, saying (for example) they are "unaware of geophysical techniques in these settings" and "…don't feel as competitive on the job market as graduates from other institutions".
- A direct quote: "*in some ways. It prepares us to think mathematically and logically. The geophysics major is good at geophysical theory and prep for an academic career. It was helpful this year to learn how to write reports and present our research in (450 and 453). I intend to work in the industry but I had advice from previous undergraduates and sought some help on my own such as getting all the EGBC pre-reqs or taking on a co-op.*"

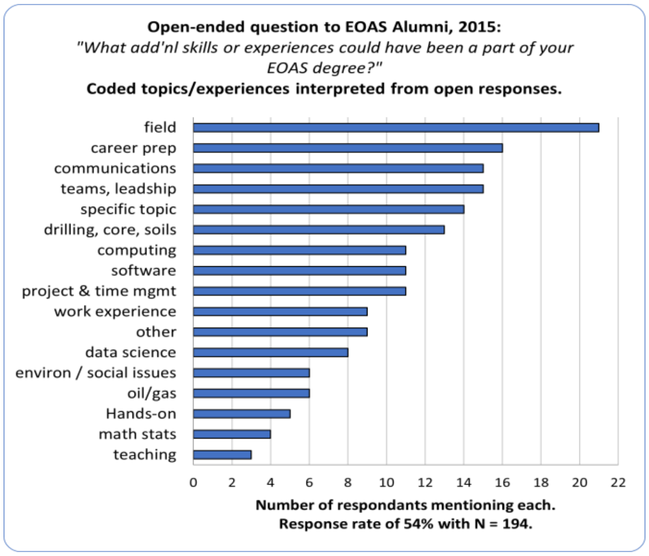
5.2 Capabilities expected for registration as a professional geoscientist

In British Columbia, these are expressed as course lists that EGBC will check when a student applies for status as a "geoscientist in training" – the first step towards obtaining official status as a practicing professional geoscientist (geology, geophysics or environmental scientist). Links to course lists for these disciplines can be found on the EGBC website. Geophysics is the only relevant quantitative BSc Earth sciences program teaching students who will be required to register as professionals in order to practice. The EGBC requirements (derived from the 2019 version of the Geoscientists Canada Geoscience Knowledge & Experience Requirements or GKE) are largely consistent with the UBC geophysics degree requirements, EXCEPT for the expectation that geoscience professionals gain a minimum exposure to "geology". Thus, desirable capabilities for geophysics students include the need to fit at least four courses into their schedules as electives: mineralogy/petrology, sediments/stratigraphy, structures and field techniques (which can be attained by job-experience rather than a course). Resources to help students meet the requirements were prepared as part of QuEST project. Corresponding recommendations are on the "Career preparation" recommendations page.

5.3 Earlier deliberations among EOAS faculty and alumni

Conversations in 2019 and 2020 centered around the fundamentals, methods or tools, and broad geophysical concepts that are desirable for QES students. Desirable capabilities that directly relate to readiness for the workplace were rarely mentioned. However, one of the proposed Program Learning Objectives (PLOs) was "*Students will be ready for research/industry/government positions, not limited to Earth-science related fields.*" A note attached to this PLO reads "*Transferable skills is central to what we teach, similar to physics, but mostly more directly applicable.*" Evidently the intent to prepare students for the workplace is there, but no non-technical capabilities were articulated.

Alumni were surveyed in 2015 with help from UBC alumni engagement. Although "old", results are consistent with most other perceptions about desirable abilities and attributes. A response rate of 54% was obtained when 194 BSc, MSc & PhD alumni from all disciplines. A succinct summary of priorities is provided by the following analysis of responses to the open question in the figure title:



These results are consistent with other data and opinions about desirable abilities and attributes. Even if items that are less relevant for graduates of quantitative degrees (like field work, drilling, etc.), it seems that the "soft" skills needed to be an effective employee are missing from degree preparation. All evidence presented in this document suggests this is a ubiquitous perception of professionals with working experience and not a "problem" unique to EOAS.

Employers sometimes suggest that students "need" skills associated with specific software tools or techniques. Reaction of academics to this expectation is mixed since degree programs are considered "education" rather than "training". Students can be expected to "pick up" details of particular tools when needed. However, GIS skills may be a reasonable exception because spatial thinking is significantly influenced by the capabilities of modern geographical information systems.

EOAS Hiring Survey result, 2010: Results may be over a decade old but they are "local" and consistent with more recent, extensive and broadly based investigations about geoscience hiring & employment discussed elsewhere. Selected conclusions include:

- The need for field work experience and attitudes were persistent themes.
- Employers want focused employees with discipline-specific experience and training.
- Strong writing, communication and team working skills were important.
- Cooperative and self-directed attitudes about work, expectations for advancement and understanding of how companies and industry work were all important to employers.
- One shortcoming mentioned by several interviewees is "*unrealistic expectations*". With a little effort, it should be possible to help students set appropriate expectations by incorporating work-place scenarios that use the capabilities being developed.

A separate section of this hiring survey focused on geophysicists. Interestingly, math, physics and "theory" were considered a lower priority for new hires. (Of course, this does not reveal the longer term benefits of these capabilities as employees advance within their organizations.) Higher priorities are **communication skills** and **applications oriented** learning & experiences, including **geology** and the ability to **integrate various types of geoscience information**.

Comparing this decade-old data with more recent investigations suggests that the capabilities of most interest in the minerals sector (including exploration geophysics) are persistent, and hence worth addressing in all courses taken by students who may be hired into these career opportunities.

5.4 Paired interviews with EOAS faculty

Five of the 9 interview pairs mentioned enabling more effective interaction with non-academics (industry, alumni etc.). This is a tactic, not a desirable capability, but it would help students meet two desirable capabilities:

- Since 80-90% of EOAS students are aiming for employment upon graduation (Jolley, 2020) a desirable skill is the ability to choose and apply foundational concepts and skills appropriately in a wide range of non-research oriented contexts. This may require instructors to identify situations outside their areas of research for teaching and learning contexts.
- Another desirable skill to foster involves developing strategies and confidence in networking with potential colleagues or employers.

5.5 Interviews about balancing fundamentals versus career preparation

These interviews ended up being mainly discussions about "tactics" – that is, "*how to support career preparation*". Resulting data have no stated desirable capabilities or attitudes. However, tactics considered can be reverse engineered to express desirable capabilities. Based on the 14 "career preparation tactics" summarized and discussed in the report, some desirable capabilities are:

- The ability to transfer newly learned capabilities for application in settings they have not encountered before.
- Team working abilities, both to lead and contribute.
- Strong communication abilities - mainly written but also oral and other.
- Appropriate expectations about how the world of work differs from being a student.
- Some awareness of the importance of ethics, budgets, balancing needs of clients and employers, and so on. These are not "quantitative" skills, but they could be employed as examples of constraints on carrying out quantitative work.
- Seven interviewees identified support for networking as beneficial for students' development as professionals. This translates into a desirable skill that could be expressed as "*the ability to establish and maintain a network of colleagues and peers that will support professional or academic development.*" Should this be taught or fostered at university? Some will debate this, but it should be possible to incorporate into the curriculum with minimal negative impact on efficiency or coverage.

5.6 Peer institutions

Career-readiness capabilities that can be developed during a BSc program will depend somewhat on how an institution balances its purely scientific versus professional or industry-related priorities. Nevertheless, all peers we spoke to recognized that many (or most) undergraduates aspire to enter the workforce upon graduation, and that their respective programs either should be – or already are – including explicit opportunities for students to familiarize with their post-graduation options and develop the necessary awareness, attitudes, "soft" skills and personal resources that will help them succeed in an the increasingly competitive job (and graduate school) markets.

As one example, Georgia Tech's three new geoscience degrees all have a 1-credit 4th year course called "Career Development". Other institutions have similar explicit career preparation initiatives, although some argue that these are more useful in the 2nd or 3rd year (eg. Shabram, 2020). Other examples, including specific short courses targeting career readiness are given in the next section.

In general, employers seem to want more "industry ready" first-time employees. BSc degree programs may not be primarily about "job training", and students can gain such experiences with co-op or other job experiences. However, this common desire does support the recommendation to weave more applied contexts throughout the curriculum that students encounter. **The National Association of**

Colleges and Employers (NACE) has many validated resources, e.g. "What is Career Readiness?" which succinctly lists eight domains of an individual's career readiness: •Career & Self-Development, •Communication, •Critical Thinking, •Equity & Inclusion, •Leadership, •Professionalism, •Teamwork, •Technology. This list is consistent with other general sets of personal attributes and capabilities.

5.7 Sources beyond EOAS and UBC

Desirable capabilities outlined here are based on what employers and society need, not what academic research groups look like. Of course, a department's strengths will influence curricular decisions. In fact, the EOAS 2021 strategic plan's executive summary states that EOAS aspires to *address the evident and urgent need for expertise that can apply rigorous basic and emerging scientific capabilities to address the challenges facing societies that involve the Earth's surface, subsurface, atmosphere, oceans and environments, and how these all interact.*

From a 3-day workshop at the 2023 Earth Educators Rendezvous conference, career readiness abilities are expressed in Boise State University's course "Geoscience Career Exploration and Planning" as: "*At the end of the course, students will be able to…*

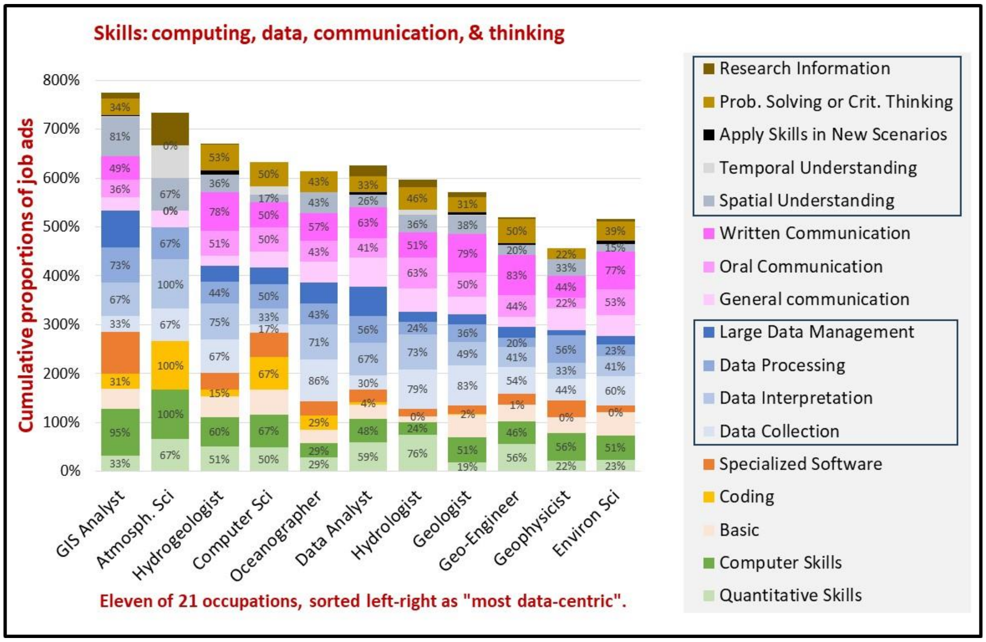
- *Analyze their interests, values, and abilities as related to potential careers*
- *Describe career options in the geosciences that match their interests, values, and abilities*
- *Evaluate the skills and experiences needed to pursue careers of interest*
- *Tailor their job/internship applications so that they are competitive*
- *Write a career development plan*"

Regarding desirable "*attitudes*", a short article titled "Boosting Support for Students and Early-Career Professionals" (August 2023, in AGU's EOS magazine) notes that "*Having a positive sense of one's career trajectory and a sense of belonging within an institution can remedy distress and contribute to career success and personal well-being.*". The implication is that students benefit from active promotion of these perceptions of belonging and optimism regarding their futures. These are "nebulous" desirable attributes, but they can be incorporated into the curriculum and into the "culture" of the department.

Ng, 2023 (for Harvard Publishing) reminds us that perhaps the most desirable aspects for **a student's resume** is "**relevant work experience**". Students increasingly face "*experience inflation*"; i.e., entry-level jobs that require previous work experience. The result is a chicken-or-egg problem; graduates need employment to prove themselves, yet employers are unwilling to give "beginners" a chance.

Shafer etal 2023 suggest that *skills* expected of a new employee may be implied by the person's degree qualifications (such as geology or geophysics), whereas *"soft"* or *work-place* capabilities are not similarly implicit and are therefore more prominent in job ads. For all degree programs, it may be challenging for instructors to recognize how and when to foster these skills. Therefore, it is important to be explicit and transparent about where in the curriculum such capabilities are targeted and assessed.

The chart below was adapted from by Shafer et al. who analyzed 3668 job ads to determine the skills most requested from geoscience employers. It shows the proportion of job ads for 11 "quantitative" entry-level occupations that identified 17 selected skills or dispositions. The prominence of communications and data science capabilities (pink and blue) is evident. Regarding the entire data set, these authors noted that "*Quantitative skills were requested less frequently (23%) but were usually mentioned several times in the ads that did request them, signaling their importance for certain jobs.*".



Work of **Mosher and Keane, 2021** and **Viskupic etal. 2021** were both discussed above. Their contributions address mainly the "geoscience skills and aptitudes" necessary for geoscience graduates, but their results also encompass the "soft skills" or career-readiness capabilities desired by employers. Their Figure 3-2 (above) refers to communication, team working, critical thinking and information synthesis abilities, all of which involve aspects of workplace skills. Regarding "soft skills", 2 of the 6 key recommendations that conclude their chapter 3, "*What Undergraduate Geoscience Education Should Accomplish*" are:

- Students need authentic experiences that incorporate geoscience thinking and problem solving in **both work-related and curiosity-driven settings**.
- Incorporate the development of **professional or "soft" skills** in all courses.

Mosher and Keane 2021 also include an entire chapter on recruitment. Desirable capabilities are not addressed specifically but needs and strategies for attracting a diverse student body contain implications regarding aspirations for what graduating students should be like.

The messages about employers' needs and geoscience education from Mosher and Keane are followed up by subsequent studies by Viskupic et al. 2021, Shafer et al. 2023, and others.

Finley, 2021 provides a general perspective on what employers consider as important attributes of college graduates. Nine key messages emerged from surveying almost 500 executives and hiring managers. These are not specific to geoscience nor quantitative careers, but they do represent an expert perspective on what employers look for when hiring recent graduates. Of the nine key messages, these 5 seem relevant here, with comments in italics and square brackets:

- Personal **aptitudes** and **mindsets** play an important role in career success.
  [All EOAS degree programs should foster attitudes and habits such as self-directedness, confidence to detect and address errors, eagerness to learn, and so on. These may be "presumed" to be learned but students are better served by explicit attention to all expectations of BSc degree programs.]
- Completion of **active** and **applied** learning experiences gives job applicants a clear advantage.
  [Students need to be able to point future employers and supervisors to the concrete applications of fundamentals that they have encountered, including how they managed challenges that arose.]
- Both **breadth** and **depth** of learning are needed for long-term career success.
  [This balance is addressed in the Faculty's requirements for graduation, but it is also relevant in

specific curricula and courses. Exactly what that balance looks like is debatable, but both need to be visible in a student's resume.]

- Compared to older employers, those younger than 40 placed a significantly higher value on **civic skills** and **civic engagement** experiences.
  [QES courses and programs can do more here by including opportunities to engage with community, societal and commercial situations as well as research contexts.]

Summa et al., 2017 reported that 75% of geoscience employers say that *development of problem-solving skills, competencies, and conceptual understanding* are more important as **predictors of workforce success** than the particular courses a job candidate has taken. Several effective pathways can help develop these attributes including work, co-op, undergraduate research, and other experiences.

Sarkar et al., 2016, describe results from the Graduate Employability for Monash Science (GEMS) project, which explored perceptions about skills needed by 167 recent science graduates and 53 employers. They discuss: (a) whether there is a mismatch between the knowledge and skills developed through undergraduate study and those required at work, (b) what knowledge and skills employers view as important when employing recent graduates, and (c) what graduates and employers consider universities can do to better support employment for graduates.

Their list of 20 skills and knowledge areas considered important for employability was based on literature, with an Australian focus. Among other results, of particular interest was a characterization of (a) skills that were said to be "*well developed at school*" by **more** respondents than those who considered it was "*useful*" (i.e. these were "**overdeveloped**" at university), and (b) skills that were said to be "*well developed at school*" by **fewer** respondents than those who considered it was "*useful*" (i.e. these were "**underdeveloped**" at university).

Skills that were "overdeveloped"	**Skills that were "underdeveloped" at university**
• Disciplinary knowledge • Application of disciplinary knowledge and skills • Science in society • Research skills • Appreciation of ethical scientific behaviour • Technical analysis • Analytical and critical thinking skills • Written communication skills	• Commercial awareness • Mathematical skills • Information and communication tech. • Problem-solving skills • Verbal communication skills • Information retrieval • Leadership skills • Team-working skills • Time management and organisational skills • Flexibility or adaptability • Use of own initiative • Independent learning ability

Themes that emerging from asking the open-ended question "*what could universities do to help students prepare for employment*" included:

- Help students find work-related placement or capstone that expose them to "how industry works";
- "teach" or model appropriate work-place behaviour and attitudes;
- support networking and encourage students to take advantage of networking opportunities;
- actively clarify and showcase career directions, pathways and opportunities;
- incorporate into curriculum aspects such regulatory issues, safety, business perspectives, etc.;
- expose students problem-solving with incomplete data & other types of uncertainty or ambiguity.

Appendix I: Scope of "critical quantitative thinking"

The most commonly mentioned "responsibility" identified by EOAS faculty during paired interviews was the need to develop students' abilities to think sensibly and critically with, and about, quantitative information. Aspects mentioned by EOAS faculty include (actions in *italics* involve making *decisions*):

- 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;
- gaining data-centric thinking habits, rather than waiting to be told what to think
- Artificial intelligence and machine learning are emerging as part of the challenge of gaining maturity regarding quantitative thinking.

Critical quantitative thinking is not about advanced mathematical or computing capabilities. It is more about "scientific decision making" (eg Holmes et al., 2020, and Burkholder et al., 2020) or learning to be fundamentally quantitative and data-oriented in one's thinking and decision making. Inspiration for enhancing the sophistication of students' scientific thinking abilities is being provided by these and other research groups. For example, the Weiman Group at Stanford studies the thinking of skilled practitioners in science, engineering, and medicine, and is developing methods for measuring and teaching this style of expert thinking.