Quantitative Skills Framework in Solid Earth Geophysics
National Academies of Sciences, Engineering, and Medicine
Scoping Meeting - January 25 and Feb 4, 2021
Main Messages/Issues

Background and Objective

A quantitatively-literate workforce is needed to investigate the multi-scale, multi-physics solid Earth science processes at the core of many scientific and societally-relevant problems. However, such skills are in short supply in some Earth science disciplines and curriculum modernization is challenging. Additionally, there is an associated issue of a lack of diversity in Earth science disciplines. While there exist training networks in academia, national laboratories, and industry, the education and career pathways that lead to skilled quantitative workers and researchers are not robust nor well-coordinated, and individual academic departments are often ill-equipped to tackle these challenges on their own.

The scoping meeting was planned to bring together stakeholders in academia, government, and industry to discuss new and innovative approaches to develop sustained training initiatives that can fill these educational gaps at the senior-level undergraduate or graduate level, with a plan to develop a new NASEM activity. The scoping meeting was planned to help explore the space around this idea and develop interest among potential sponsors.

This activity is a collaboration of several parts of the National Academies: the Committee on Solid Earth Geophysics, the Computer Science and Telecommunications Board, the Board on Mathematical Sciences and Analytics, and the Board on Science Education.

Agenda

On Day 1, we discussed the problems that exist around current training for quantitative geophysics. The agenda included:

- Framing talk/goals for the meeting (Cindy Ebinger)
- Geophysics curricula (Craig Partridge and Mark Behn)
- Breakouts on the following topics:
    - What needs to change in current curricula?
    - What are the impacts of curricular changes on the mix and support of students?
- Breakout reports and discussion
- Synthesis discussion (Diane Doser)

On Day 2, we delved more deeply into some current activities as well as potential solutions needed. The agenda included:

- Recap of Day 1/goals for Day 2 (Cindy Ebinger)
- Data acumen (Nick Horton)
- Distributed expertise (Boots Cassel)

- Presentations on training activities
    - CSDMS (Irina Overeem)
    - CIG (Jolante van Wijk)
    - IRIS (Michael Brudzinski)
    - GETSI (Beth Pratt-Sitaula)
    - OpenTopography (Ramon Arrowsmith)
- Breakouts on the following topics:
    - How do we increase the skilled workforce and expand the quantitative skillset in geophysics? What are the workforce needs?
    - What actions could universities take to increase quantitative skills? Where are the resources to do this?
    - How do we interest more students (particularly diverse voices) to the field, train them, and prepare them for careers?
- Breakout reports and discussion
- Synthesis – structural considerations (Kate Miller)
- Synthesis – curricular considerations (Cathy Manduca)
- Wrap-up and next steps (Mark Behn)

Main Messages/Issues

The scoping meeting discussed current challenges in U.S. higher education in geophysics, while drawing on international experiences. The discussions highlighted some specific issues associated with degree programs where advising and course sequencing remain major challenges to increasing the ability to provide students with stronger quantitative skill development. Discussions highlighted several topics, including:

1. Need to create opportunities to increase data acumen for geophysics students and evolve existing geophysics/geoscience programs toward curricula that are more focused on quantitative methods and skills.
    - Identify core quantitative (e.g., computing, math, statistics, data science) knowledge needed and learning/skills outcomes
    - Overhaul of the geophysics curriculum, taking backwards design approach to re-define what is needed for students to succeed
    - Make the hard choices to drop content that was once considered essential
    - Create recommended pathways/tracks to degrees and careers (feedback from international programs with more focused degrees?)
    - Advising and course design to require prerequisites and reinforce material from other disciplines in major-level courses
    - Infuse quantitative techniques and develop acumen throughout all geoscience courses
    - Reinforce critical knowledge and skills through online supplemental lessons
    - Perhaps design program-specific math and computing courses

    - Are courses from computer science/math/statistics appropriate for geophysics and other applied subjects?
    - Teach quantitative skills as practical courses, not theory
    - Are combined courses (e.g., diff eq/linear algebra) created in other disciplines specifically for geophysics (and/or other STEM fields) an option?
    - What courses can be taught within the geophysics program (e.g., Python)?
  - Faculty issues:
    - What are incentives for faculty to change existing curricula?
    - Additional training/ensuring that faculty get credit
    - Consortia to develop shared courses (online modules, webinar series)
    - Team teaching with other science/engineering faculty
    - Offering courses outside of an institution
    - How to pay for consortia, team taught classes, outside courses and how/ whether to provide credit for such models (both for students and instructors) needs thought
    - Credit for faculty involvement in extracurricular activities (e.g., advising)
  - Scaffolding is critical - mentoring, advising, coordination to ensure repetition/skills transfer across curriculum
  - Create structured peer mentor system
  - Identify immediate need for modules in aspects of geodesy, geoelectrics, potential fields (before such expertise retires)

2. The role of auxiliary training activities in bolstering quantitative skills.
  - There is already a robust set of summer programs and training activities for quantitative skills in geophysics and related fields.
    - What mechanisms exist for more investment in and coordination among existing programs in geophysics, but perhaps also physics and computation?
    - How can they be scaled up to reach more students?
  - Bridging classes to increase quantitative skills, increase diversity, recruit from schools that lack geoscience programs
  - Certificate programs
  - Outreach activities – NSF facilities, REUs
  - Internships (especially paid)
  - For all auxiliary activities, how can they made more sustainable?
    - Need sustained funding (not just a 2-3 yr effort)
    - Activities are currently under-resourced
    - Activities do not seem to be working with/part of EarthCube or Harnessing the Data Revolution (both NSF) - if priority efforts on data science miss application areas like geophysics, then these initiatives are missing important opportunities
  - Programs will have more impact if a large fraction of geophysics students have access to them.

- Partner with industry and federal agencies (especially through paid internships)
- Employer issues:
  - What do employers want from geophysics students (vs geoscience students)?
  - What are employers willing to sponsor? (e.g., internships, short courses, summer programs)
- Student issues:
  - Accessibility (e.g., online vs in-person, asynchronous)
  - Affordability (especially if summer work is required)
  - Role for structured peer mentor systems
  - Role of cohorts

3. Diversity and the pipeline
   - Geophysics is critical to issues of societal relevance (e.g., energy, climate change, natural hazards. Use this as a way to:
     - Open up the pipeline at multiple levels - K-12, undergrad, graduate school; 2 year and 4 year colleges
     - Make connections to issues relevant to communities
     - Attract students from other quantitative disciplines who want to work on something "real"
     - Increase diversity at all levels
   - Embrace role of 2 year colleges to mentor and support students with interest in geophysics and attract students from fields such as chemistry, math, physics
   - Create cohorts to support increased diversity – learn from successful programs
   - Other student issues:
     - Attracting students who may have been told they weren't "good enough" to do math and programming
     - Will more quantitative pre-requisites detract from increasing diversity and/or numbers?
     - Affordability of program (especially if summer work required)
   - Advising techniques
   - Promoting geophysics as a career
     - Role for professional societies

<u>**Next Steps**</u>

1. **Proposed NASEM consensus study (page 6)**

2. Modules/experiential learning (e.g., instructional materials, videos) that could be used for publicity/visibility as well as bridging/scaffolding.
   - Key role for professional societies (AGU, GSA, EGU, etc.), academic leaders, federal agencies (e.g., NASA, NSF, NOAA, NGA, DOE)
   - Geophysics content of current and planned government agency programs and missions is not supported/embraced by current outreach materials

- Develop better links to museums, unions of science teachers, professional societies, local organizations who can fund professional YouTube and documentary series on well-researched science
- Do existing training activities already have some of this? Build on their work
    - As an example, production of a series of computational skills modules accessible by a physicist from a HBCU, or by a geophysicist from a small research department?
- For instructional materials, build on NAGT curricula workshops - they lead to collections of materials that get posted online at the SERC Teach the Earth website, also sponsor webinars to highlight topics like attracting diverse students. These could promote development/dissemination of instructional materials.

Strengthening a Quantitative Skills Framework in Solid Earth Geophysics Programs
National Academies of Sciences, Engineering, and Medicine
Proposed Consensus Study
Draft – April 6, 2021

Background

The ability to manage, analyze, model, and extract knowledge from data are increasingly important features for careers in science, engineering, and computing. The 2020 National Academies consensus report, *A Vision for NSF Earth Sciences 2020-2030: Earth in Time*, noted that *"future Earth scientists will need to be trained in an increasingly quantitative educational framework… This type of training will need targeted strategies that lead to the development of more expertise in terms of both cyber-savvy Earth scientists and Earth science–savvy computer scientists and software engineers, and will increase the potential workforce pool of future Earth data scientists."*
Academic programs from a wide variety of disciplines have recognized the need to adapt educational approaches to better prepare students for the needs of a quantitatively-skilled workforce, but educators face challenges in adding quantitative skills (including data science, computing, modeling, mathematics, statistics) to an already full curriculum. Solid Earth geophysics disciplines (including seismology, geodesy, geodynamics, and geophysical potential fields) are among the fields seeking to strengthen the data analysis, modeling, and theoretical skills of their students. A quantitatively-literate workforce is needed to investigate the multi-scale, multi-physics solid Earth geophysics processes at the core of many scientific and societally-relevant problems. Solid Earth geophysics disciplines have much to contribute in this area, from expertise in synthesizing diverse, disparate datasets to building geoscientific models that integrate observations and laboratory results in order to understand the dynamics of Earth's physical processes.

However, such quantitative skills are in short supply in solid Earth geophysics (and the broader geosciences) for a number of reasons. One is a small number of students entering the discipline, in part because of omissions and deficiencies in K-12 STEM education, and in part owing to weak scaffolding for those entering undergraduate programs with limited math and computational experience. Another is limited postsecondary curricula focused on geoscience theory and applications. Within solid Earth geophysics programs, improvements in educational strategies and approaches, including mentoring and advising, are needed to produce students who are well prepared to meet the demands of a more quantitatively-skilled workforce. Currently, there are diverse approaches to engaging with quantitative methods across institutions and communities, including internships and training programs; however, these approaches are poorly coordinated and under-resourced across the geosciences.

A National Academies study that explores priority content areas and successful delivery mechanisms of quantitative skills could help 2- and 4-year academic departments refine future course offerings and/or training activities (such as summer programs), and better prepare students for increasingly quantitative careers. This study could also help departments and the broader Earth science community determine how focused training such as this could increase the pipeline of students, both in terms of number and diversity, that are needed for quantitative Earth science careers in the private sector and government.

While not directly focused on the Earth sciences, a recent National Academies report on *Data Science for Undergraduates: Opportunities and Options* provides comprehensive information on data science education, including concepts for developing data acumen in students. The broad, cross-disciplinary concepts outlined in that report provide a foundation for a geophysics-focused approach that could be used in this study. Another recent report sponsored by NSF, *Vision and Change in the Geosciences: The Future of Undergraduate Geoscience Education*, examined concepts, skills, and competencies for undergraduates across the broad spectrum of geosciences and discussed the recruitment and retention of underrepresented populations; both would serve as important background information for this study. However, the report did not have a specific focus on geophysics, especially the core content and implementation essential to address future needs in geophysics teaching, research, and employment.

<u>Proposed Statement of Task</u>

A National Academies of Sciences, Engineering, and Medicine consensus study will explore how to strengthen quantitative training and skills in solid Earth geophysics (e.g., seismology, geodesy, geodynamics, potential fields). This report will:

1. Identify the most important quantitative concepts, skills, and methods for undergraduate and graduate level students in solid Earth geophysics.
2. Discuss the changes needed to facilitate the inclusion of these concepts, skills, and methods in solid Earth geophysics curriculum. Provide examples of specific geophysics tracks (e.g., geodesy) and how they might fit into/differ from broader geophysics graduate curricula. Consider how potential curricular changes could leverage interdisciplinary strengths of other departments.
3. Summarize selected existing models for training students in physics-based modeling, computation, and data analysis skills in solid Earth geophysics (e.g., programs through IRIS, UNAVCO, CIG, CSDMS) and in other disciplines. Discuss how existing or new approaches (e.g., shared modules, online training, internships, certificate programs, industry or national laboratory partnerships) could complement curricular changes to best prepare students for careers in solid Earth geophysics.
4. Define the impact of existing and proposed curriculum requirements on the number and diversity of students who enter and complete geophysics programs.