VISION AND CHANGE IN THE GEOSCIENCES

Shaping the Future of Graduate Geoscience Education

Sharon Mosher, Jeffrey Ryan, and Christopher Keane

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Executive Summary

Geoscientists play a central role in addressing global and societal challenges. With the critical state of our global climate and need for reliable energy and mineral resources, water, and societal resilience to earth processes, we must ensure that the future geoscience workforce is prepared to meet these challenges, including 1) making the transition to sustainable and environmentally responsible energy and food sources; and 2) forecasting and mitigating the dramatic economic and environmental impacts from the increase in the number of detrimental weather, climate, and oceanic events and from geohazards. Earth, Ocean, and Atmospheric Science graduate programs must educate students to understand Earth System Science, the complex interactions and feedback between parts of the Earth system, and the influence of human activities in perturbing this system. These geoscience graduate students need to develop the skills and competencies to investigate and find solutions to these challenges. Additionally, new expertise is required by the big data revolution, the explosive growth in AI, and the movement toward modeling the Earth system.

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To educate and prepare the future geoscience workforce for their critical role, the National Science Foundation sponsored this Graduate Geoscience Education initiative to address three critical questions:

1. What universal skills and competencies should be part of graduate geoscience education for doctoral and master's students in Earth, Ocean, and Atmospheric Sciences to be successful in the workforce?

2. What are the best means of developing these skills and competencies in graduate geoscience programs nationally?

3. What implementation strategies can department heads/chairs and graduate program directors use to integrate these skills and competencies into graduate programs?

Since 2018 over 300 geoscientists in the academic and employer communities have collectively developed a vision for the future of geoscience graduate education, inclusive of Earth, Ocean, and Atmospheric Sciences. This report articulates that vision and identifies strategies for transformative change in graduate geoscience education. This vision builds on the previous NSF-sponsored undergraduate initiative documented in the *Vision and Change in the Geosciences: The Future of Undergraduate Geoscience Education* (Mosher and Keane, 2021).

We summarize the key strategic findings of the graduate effort below and highlight recommendations documented in this report that capture the extensive work of the community. These recommendations are comprehensive and each department, program or institution should consider how to appropriately implement them in the context of each institution's educational mission and research strengths. External stakeholders, including employers, alumni, professional societies and funding agencies, should consider their role helping departments accomplish these goals. Collaboration between faculty, departments and external stakeholders will greatly improve graduate geoscience education. Geoscience educators have an unparalleled opportunity to capitalize on the expanding role the geosciences play in addressing global societal challenges and ensure the long-term health and future of geoscience graduate programs.

KEY FINDINGS AND RECOMMENDATIONS

The need for geoscientists to address societal problems is expanding, and geoscience employment is changing both in scope and scale, requiring new skills and competencies. At the same time, graduate enrollments in the geosciences have decreased significantly for the first time in four decades (46.6% since 2018), a trend that started before the pandemic (~2011); graduate degrees have also plummeted (master's 32.3%; doctorate: 48.4%). With ongoing shortages of qualified geoscientists, many of those positions are being filled by non-geoscientists, currently constituting ~22% of the geoscience workforce. There is an immediate overall need for geoscience graduate programs to increase enrollments and degrees granted. Geosciences also needs to move toward a more diverse student body and workforce. A geoscience profession that is responsive across society requires that programs recognize the need for a combination of cultural change, effective mentoring, the shifting of educational and research topics to stay relevant, and better career preparation for students.

Most importantly, geoscience education and research must change to meet the needs of graduate students so they can be successful in their future careers. Programs need to be student focused and promote the development of skills and competencies students need for a wide variety of careers. There is a mismatch between graduate geoscience education and research in Earth, Ocean, and Atmospheric Sciences and those skills and competencies that graduates will need in future careers in these fields. The private sector is growing rapidly in some areas of the geosciences and shrinking in others, so that programs often need to adapt and realize that collaboration across the geosciences is both beneficial for students and the health of geoscience departments. Most geoscience graduate programs focus on preparing students for academic positions in their discipline, yet these positions represent only a small fraction of the total geoscience workforce (8%). Only about half of geoscience doctoral students end up in academia, and many of those in academic positions are primarily teaching focused.

The combined academic and employer community has established a consensus on the skills and competencies that need to be developed to prepare graduates for meaningful employment across most employment sectors, including academia. These range from problem solving, critical thinking, geoscientific and systems thinking, and communication to a wide variety of audiences — to quantitative and computational skills, data management and analytics, geostatistics and geospatial reasoning, among other technical skills. Teamwork and collaboration, leadership, communication skills, social dynamics, interpersonal skills, project and program management, business skills, and ethics are all critical. Graduate students still need expertise in core areas, but they also need to recognize the broader impacts of their research. Personal traits such as the ability to learn, a growth mindset, emotional intelligence, and having diverse and adaptable skills set are critical to success. Students going into academia also need to learn how to teach and mentor students and train their students in these skills. The participating employers identified observed skill gaps in many finishing graduate students, most notably that many graduating students have trouble defining problems that need solving, and identifying and applying possible solutions, though most can solve problems that they are given.

Conducting research is considered an important skill, and many fundamental competencies are enmeshed in doing research, such as critical thinking and problem solving, oral and written communication, knowing the current and future trends in the relevant scientific literature, coding and other technical skills, and project management. Employers also value high-level graduate coursework for helping students develop new skills and giving them practice in defining and solving problems, applying solutions, and improving written and oral communication skills. The general menu of skills needed in master's and doctoral graduates are the same, but the levels of competency differ both by degree and with the type of employment. Over the four-year period from 2018 to 2022, rapid advances in information and computational technology led to striking changes in expectations — what employers in 2018 had predicted would be important in 5 to 10 years have become nearly essential today, particularly in terms of the expectations for skills in data management and data analytics, machine learning, artificial intelligence and computer programing and coding.

Department heads, chairs and graduate program directors identified ways each of the recommended skills and competencies could be developed while conducting research, through graduate courses and co-curricular activities. Students can develop some skills as the natural outcome of their specific research, including time and project management skills, and the effective communication of broader impacts, especially to wider audiences. Students need to explicitly develop a range of skills and competencies, and recognize those competencies that they have. Many of the recommended skills — as an example, written and verbal communication - can be integrated into existing graduate coursework. Stand-alone courses within or external to the department (including online courses) can help students develop skills such as data analytics, computer programming, and business skills. Courses also should focus on problem solving, teamwork, and aspects of project management. Co-curricular activities, ranging from clubs and departmental outreach programs, professional organization activities, international experiences, internships and interactions with alumni and employers, short courses, online courses, and targeted professional development courses, all provide excellent ways for students to gain skills not readily attainable through their research or formal curricula.

A key recommendation for all graduate programs is to have their students develop Individual Development Plans (IDPs) early in their academic careers, in conjunction with their advisor and other mentors. IDPs allow students to explore their own skills and career aspirations, identify those skills they need to develop, and lay out a roadmap for achieving their goals. IDPs are useful for more than just developing skills needed for a specific career path. They also help provide more structure to advising and mentoring conversations, to help keep students on track, and they help guide students in their progression through their degree programs to completion. One recommendation was to consider offering an onboarding experience or course for all new graduate students, where they develop an IDP. Such a group activity would also help programs develop student cohorts, and could cover other pertinent topics such as ethics in science, leadership, time management, emotional intelligence, the professional importance of diversity, equity, and inclusion, and other kinds of professional development.

Effective and successful mentoring is critical to geoscience graduate student success and should not be ad hoc. Students benefit from receiving mentoring from more than one individual, and from others in addition to their advisor and thesis and dissertation committee members. Training faculty in best practices for mentoring, and providing incentives for improving mentoring practices, may be needed.

Geoscience graduate programs need to define the learning outcomes that they expect all master's and all doctoral students to achieve while in their programs. These expectations and how to obtain them need to be clearly communicated to graduate students. All coursework, whether required or not, should list expected learning outcomes. Some faculty will find it easier to incorporate key skills into their existing classes, while others may prefer to team-teach with faculty who have different, complementary skillsets, including faculty in other departments. Information on external professional development and co-curricular opportunities should be compiled and made readily available to graduate students. Department websites should post lists of the recommended skills and competencies discussed in the sections below, with links to this report. Toward helping students develop individual development plans (IDPs), departmental websites should include descriptions of their IDP requirement and how they are developed, with links to external resources on IDPs, sample IDP forms, and/or their own versions.

Departments should seek to leverage input from their alumni and the employers of their master's and doctoral graduates, as both can actively assist graduate programs in meeting these challenges. Many faculty are unaware of the dynamic changes occurring in the geoscience workplace and what skills are most needed by graduate students when they have completed their degrees.

Alumni and employers can provide important career awareness testimony. They should visit departments and give talks about their careers and the skills they needed for success. Alumni and employers can also provide mentorship to students, serve on thesis/dissertation committees, and help with student professional development in terms of building attractive resumes, applying and interviewing for positions, and professional networking. They can serve on program or departmental advisory boards and can teach or co-teach courses. Employers can also provide internships, externships, other kinds of financial support, access to large geoscience datasets, and/or real-world problem case studies for students to work on in classes.

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Professional societies should work with their membership to support graduate geoscience programs by developing short courses and/or workshops targeting key recommended skills, and setting up certification or accreditation programs that students can use to formally document their competencies. This includes expanding mentoring opportunities for graduate students through support of professional networking, providing resources for making departmental and curricular changes, and helping to disseminate the results of this initiative to ensure that their members are aware of this report.

Funding agencies can influence the direction of graduate education and training by establishing explicit requirements for graduate student training and mentoring as conditions of support, as recently added by NSF in 2023, and by providing financial support to departments (as appropriate) in support of implementing changes to graduate programs.

Transformative change to graduate programs is needed, but faculty need to be convinced of this need and be incentivized to make change. It is important to recognize that most faculty are already overloaded with responsibilities and requirements and generally do not have the bandwidth to take on additional work. Many faculty, like their students, are struggling with mental health, motivation and work/life balance issues related to the COVID-19 pandemic. They may need further professional development training, as well as other incentives that decrease their other time commitments. They need to understand that, in the end, these changes will benefit them as well as students and programs.

Faculty incentives and rewards for excellence in teaching, mentoring, student professional development, developing new courses, integrating key skills into existing courses, and working on curricular changes all depend on individual situations. This can range from monetary achievement awards, merit raises or bonuses, teaching releases, summer support, extra teaching credit and other ways of creating flexibility in faculty workloads. Making these considerations part of yearly merit reviews and promotion decisions will emphasize their importance.

The primary factors departments use to measure success are the employment of their finishing graduate students and degree completion, followed by publications and research for doctorates. Thus, developing the skills and competencies necessary for future success and mentoring students through their degree to completion is the primary motivator for change to graduate geoscience programs. A department's success depends on this change.

Other effective approaches are to leverage the external pressures. The impacts of low geoscience graduate enrollment and retention issues on financial and upper administration support, and the importance of student success and program rankings, are some of the factors that can be used to encourage change. The threat of department closures or shrinking departments is real and happening in some geoscience fields, while some specialty areas, such as data analytics and the application of AI, are experiencing dramatic growth in student interest and job opportunities. Administration and faculty need to be made aware of these changes and develop plans to evolve programs toward success.

Those departments that reported progress on action plans that they developed as part of our 2019 Summit highlighted a variety of successes (summarized in Section 7: Fostering Change in Academic Communities: Case Studies). The introduction and use of IDPs was the most successful, followed by the integration of many key skills into courses, developing new courses, and even developing a cross-college certificate program. The advice they provided ranged from taking things slow and starting with changes that had minimal impact on faculty, to engaging the whole faculty in open debate and discussion of program goals and student learning outcomes.

Culture change in departments is difficult, but the long-term health of the geoscience profession demands change. Graduate students are entering a wide variety of professions and careers that are different than in the past. They will need both a larger and different menu of skills and competencies to be successful in the future workforce. This report provides a roadmap for change and is intended as a resource for department heads and chairs, graduate program directors, faculty, students, alumni, employers, professional societies, and funding organizations interested in shaping the future of graduate geoscience education.

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RECOMMENDATIONS

Transformative changes in graduate geoscience education are needed to ensure the long-term health of geoscience graduate programs and professions and to produce geoscientists with the skills and competencies needed to address global societal challenges.

Geoscience employers and the academic community have achieved consensus on the portfolio of critical skills and competencies needed by Master's and Doctoral graduates in Earth, Atmospheric and Ocean Sciences to lead successful, fulfilling careers. These should be broadly disseminated and used to guide graduate students, faculty, and departments.

- Graduate education should encompass these skills and competencies through research, courses and co-curricular activities, and students should be encouraged to develop them, with the depth dependent on their degree and career goals.
- Graduate students need to take ownership of developing these skills and competencies during their graduate education.
- Graduate students should have increased practice in problem identification and approaches to finding solutions, as well as solving problems, in courses and their research.
- Skills related to data analytics, coding, and computer programming should be embedded in theses and dissertations and coursework.
- Scientific communication skills — verbal and written — should be honed for both scientific and more diverse audiences.
- Graduate students should prepare "elevator speeches" — a brief statement of what they have accomplished in their research and why it is significant — that they practice and revise throughout their graduate career.
- Graduate students need to develop a leadership and innovation mindset as they pursue their education.
- Research is the central property of a graduate program and should be treated as both an intellectual and pedagogical construct.
- Graduate supervisors need to encourage their students to broaden their skillsets through coursework and co-curricular activities.
- Geoscience graduate programs should consider ensuring that all doctoral students gain experience in teaching.

Students should be required to develop Individual Development Plans (IDPs) early in their academic career, in conjunction with their advisor and other mentors. These plans provide structure to advising, a roadmap for achieving student goals, and help keep students on track towards completion of their degree.

- Departments should consider requiring that faculty to provide a mentorship plan in order to admit students into the graduate program, and for all graduate students to have a mentoring plan.
- Discussion around mental health and work/life balance should be normalized.

Department heads/chairs, and graduate program directors must take leadership roles in creating and incentivizing change. It requires convincing faculty and upper administration that there is a need for change and providing a proposed path to doing so.

- Department heads, chairs and graduate program directors should leverage external pressures to convince faculty of the need for change, such as their student legacy, decreasing enrollments, lack of diversity, rankings, financial support, expanding geoscience careers, and changes in the nature of the geosciences.

Recommendations, continued on next page

Recommendations, continued

- Graduate program and departmental culture needs to become more inclusive and supportive of diversity in demographics, thought, and career paths.
- Departments should market geoscience graduate degrees as a means of developing the knowledge, skills and competencies needed to solve societal issues and to increase diversity and overall enrollment.
- Departments need to develop program-wide student learning outcomes for their master's and doctoral students, and individual faculty should establish learning outcomes for their graduate courses. Graduate students should be made aware of these learning outcomes and receive guidance on where they can be obtained both within and external to the department.
- Graduate education needs to be student focused, using the broad spectrum of identified skills and competency opportunities available through research, coursework, and co-curricular activities to meet educational and career goals.
- Departments should consider offering an onboarding course or experience for all new graduate students to form a cohort, develop Individual Development Plans, and be introduced to ethics in science, leadership, time management, the importance of emotional intelligence and of diversity, equity, inclusion, and justice.
- Departments should take advantage of the experience and advice of colleagues who have begun to make efforts toward transformative change their graduate programs.
- Faculty should have the benefit of further training and support in effective mentoring, teaching, and supervising their graduate students to provide an education that results in successful students.

Heads/Chairs, faculty, employers, alumni and professional societies need to communicate, collaborate and offer opportunities for graduate students to successfully develop these skills and competencies.

- Alumni and employers should consider and be encouraged to participate in the graduate education effort through giving lectures on careers, mentoring, providing help with professional development, serving on master's and doctoral committees, and offering internships, externships, datasets and/or financial support.
- Departments should consider establishing external advisory councils or boards that meet annually or biannually to provide advice on their graduate programs.

Professional geoscience societies should be proactive in disseminating the results of this initiative, including a link to this document, and post a list of resources the society offers to support preparation of graduate students. They should consider offering inexpensive short courses or workshops focused on these desired skills, setting up certification programs, and increasing mentoring opportunities.

Funding agencies should establish explicit requirements for the inclusion of graduate student support in awarded grants, such as requiring plans for student mentorship and career development using IDPs. As well, funding agencies should find ways to provide support for departments seeking to implement changes to their graduate programs.

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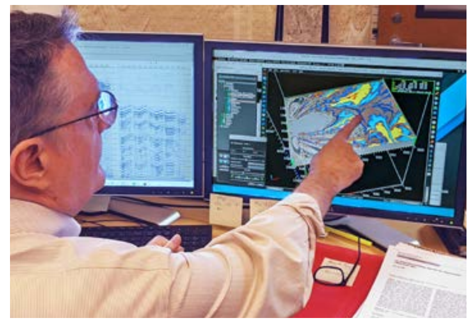
Section 1. Call for Action

Geoscience graduate programs are often narrowly focused on academic research and preparing students for academic careers (e.g., National Academies of Science, 2018). As a result, there is a mismatch between graduate education in the Earth, Ocean, and Atmospheric Sciences, and what graduates need for future careers in these fields. Most doctoral and master's students do not continue into academic careers. It is imperative that we educate our students for future success regardless of their chosen career path. This call for action is motivated by many factors, ranging from students' ability to become successful professionals, to the long-term growth and future of the geoscience profession.



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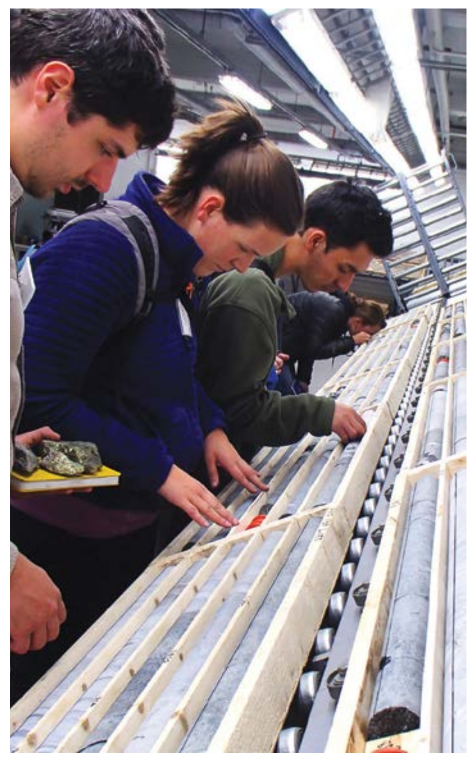
Graduate students need to develop expertise, depth, knowledge, and technical skills in a core area and hone their problem solving and critical thinking skills with additional practice on multiple, different geoscientific problems. They also need to develop all the professional and personal skills valued by *both* academic and non-academic employers, such as communication, teamwork, project management, social dynamics, and leadership. Graduate programs need to integrate these professional skills into their students' graduate education without losing a strong research emphasis. Departments need to make many of these non-core research skills part of their program culture.

Geoscience enrollments and degrees granted have been generally decreasing at all levels as measured in AGI's annual Directory of Geoscience Departments survey (American Geosciences Institute, 2023). Between 2015 and 2019, geoscience undergraduate enrollments dropped by ~30%, and degrees awarded by ~20%; that said, they have rebounded since the pandemic. While there is a lag between undergraduate and graduate enrollments and degrees, since 2019 graduate geoscience enrollments overall have dropped 46.6%, master's degrees granted have declined by 32.3% and doctoral degrees granted have declined by 48.4%. The long-term health of geoscience graduate programs is in jeopardy unless recruitment, admissions, and retention of graduate students improves.

The geoscience workforce (e.g., number of employees whose work responsibilities include using geoscience knowledge and skills) is increasing, and the types of careers that geoscientists can pursue are expanding. Currently most employed U.S. geoscientists have master's degrees, followed by bachelor's graduates, and then those with doctoral degrees. However, as of 2022, 22% of all U.S. geoscience employment was held by non-geoscientists, and the percentage of geoscience and non-geoscience doctoral degree holders in such employment was roughly the same. Unless we can increase the number of



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geoscience graduates, and improve their skillsets, this trend of geoscience positions being filled by non-geoscientists will likely continue, and an increasing number of geoscience positions will be filled by non-geoscience graduates.

The geoscience profession has changed, and geoscience employment has become more diverse, including many career options that did not exist a decade ago. Finishing graduate students need to have a solid base of transferable skills, and they need to be prepared for a dynamic and changing future. The geosciences have evolved from a subdiscipline-oriented profession to one in which multi- and interdisciplinary science is the norm, and it is rapidly transitioning into a transdisciplinary science, driven by the need to meet major societal challenges. These changes already pervade the research being conducted in non-academic government labs/agencies, research institutes, and industry, which is influencing the applied approaches commonly taken in industry, consulting, professional services, and other private sector professions. Being successful in this new and dynamic environment requires different skills, particularly professional and social skills, teamwork, and communication. We must recognize that if successful, our students will lead diverse and varied careers, requiring a range of skills and competencies necessary for success in both academic and non-academic occupations.

The focus on societally important research has increased in the geosciences and is central to many geoscience applications. The societal and natural impacts of earth processes, and the need for solutions focused on mitigation and prevention, have grown. Geoscience knowledge and skills are critical to those addressing challenges in natural hazards, in environmental issues, in the impacts of a changing climate and its effects on the oceans, and in the varied mineral, natural and energy resources needed with a growing world population. The need to be able to do systems thinking, as well as temporal and spatial reasoning when looking at an Earth system where all the parts are interlinked and interact, is critical. Geoscience graduate students need the skills and competencies to work on a range of problems at the interfaces of the Earth and humanity and the ability to interact effectively with social scientists and non-scientists in addressing these issues.

The methods and technologies used in geoscience research have changed markedly in recent years. In non-academic occupations, these changes have been equally, if not more, rapid than have been seen at most academic research institutions. The use of large, global, sensor-driven datasets, advances in computational methods, data analytics, machine learning, artificial intelligence, Earth system modeling, remote sensing, and technological advances in chemical, physical and biological analyses, and much more, all require graduate students to become adept in the use and creative application of a portfolio of technological, computational, and quantitative tools and resources.

The demographics of the future workforce are changing. The professional world is more diverse and global, and the geoscience fields need to keep pace with these trends. Diversity in the geoscience workforce, in terms of racial, ethnic, socioeconomic and cultural backgrounds, is low, as in all STEM fields. We need to change the cultures of our graduate programs to be more inclusive, and we need to train and graduate students who value diversity of thought. We need graduate students who are diverse in demographics, backgrounds and cultures, and who can work together as teams of colleagues to solve geoscience problems. They need to understand ethics and the need for equity and justice in making geoscience decisions. Our graduate students must thus develop strong interpersonal and communication skills regardless of their future careers.

Geoscience graduate students need more and more current information to help them identify career options and develop the necessary skills and competencies for success in their chosen career paths. They need more effective mentoring during their graduate tenures to reach their career and professional goals. Taking more control of their future directions through individual development plans for their academic and professional development, with the help of one or more mentors, will support them in preparing for their future careers and developing a customized roadmap for the completion of their degrees. This preparation will provide them with the skills and competencies to succeed, both inside academia and in the broader geoscience professions.

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This document is intended to provide a roadmap for academic leaders, graduate degree programs, faculty, students, alumni, employers, professional societies and funding agencies toward making positive changes to graduate geoscience instruction and advising. Over a four-year period from 2018 to 2022, over 300 geoscientists, including ~100 non-academic geoscience employers, discussed the skills and competencies that are recommended to be a part of the graduate education of doctoral and master's students in Earth, Ocean, and Atmospheric Sciences. They have investigated the best means of developing these skills and competencies in master's and doctoral graduates and identified a variety of implementation strategies for graduate geoscience programs nationally. This effort seeks to help bridge the gap between employer expectations and the ability of the academy to prepare students for successful future careers. Further interactions to improve employer-university relationships, and support from professional scientific societies and funding agencies, will both greatly benefit the graduate education of master's and doctoral students in Earth, Ocean, and Atmospheric Sciences. We as a profession must act.

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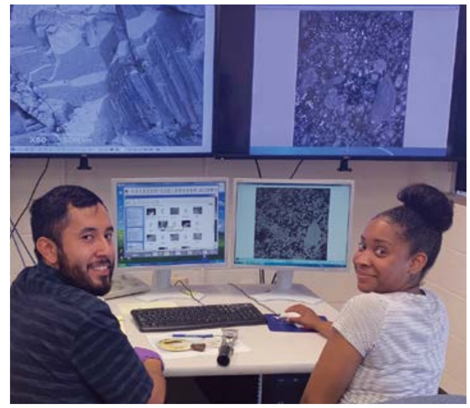
Section 2. Process Summary: Summit, Workshops, Survey

The National Science Foundation (NSF) sponsored initiative on "Universal Skills for Geoscience Graduate Student Success in the Workforce" focused on what skills and competencies master's and doctoral students in Earth, Ocean, and Atmospheric Sciences need to be successful in future careers. The initiative builds on a previous undergraduate effort, published in the *Vision and Change in the Geosciences: The Future of Undergraduate Geoscience Education* (Mosher and Keane, 2021), regarding what students need to be successful in the workplace and to discover how these translated to graduate geoscience education. The graduate effort covered the breadth of the geosciences and geoscience careers, including academia, whereas the undergraduate effort primarily, though not entirely, focused on Earth Sciences. For this reason, establishing a critical suite of concepts was not included in these discussions. Participants were predominantly, but not exclusively, from the U.S. and Canada.



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The project goals were to:

- Identify the skills and competencies that should be part of graduate geoscience education for doctoral and master's students in Earth, Ocean, and Atmospheric Sciences.
- Investigate the best means of developing these skills and competencies in graduate geoscience programs nationally.
- Work with Heads/Chairs and Graduate Program Directors on implementation strategies to develop the skills and competencies identified by the geoscience employers' workshop and other studies.

In October 2018, a Geoscience Employer Workshop brought together 52 participants representing a broad spectrum of geoscience employers of doctoral and master's students in the Earth, Ocean, and Atmospheric Sciences. These industrial, non-profit and other organizations covered weather and climate, energy and natural resources, oceans and fisheries, environment, geology, reinsurance and hazards. Also represented were NASA, NOAA, federal labs and other government agencies, and research labs within universities and professional societies. The participants spent two days discussing and providing feedback to academia on the skills and competencies needed by doctoral and master's students for the current and future workforce. Their discussions were informed by presentations derived from the results of the Future of Undergraduate Geoscience Education

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(FUGE) initiative, the National Academy of Sciences report on Graduate STEM Education for the 21st Century, and the Council of Graduate Schools report on Professional Development Shaping Effective Programs for STEM Graduate Students. The workshop format was similar to the previous FUGE Summits and workshops, where small working groups addressed a series of specific questions and presented a summary of their results to all participants for a group discussion. By the end of the workshop, geoscience employers had defined geoscience skills and competencies needed by master's and doctoral graduates, discussed methods for developing these skills and competencies and the employers' role in this endeavor, and the balance between preparing for the workforce, research, and more general educational goals. It is noteworthy that despite the broad differences in disciplines and employment sectors, there was strong agreement on the skills and competencies needed by graduate students in the Earth, Ocean, and Atmospheric Sciences.

In May of 2019, a three-day Summit of academic leaders brought together 74 participants, primarily department heads, chairs and graduate program directors of Earth, Ocean, and Atmospheric Sciences programs, representing 59 doctoral granting and 5 masters'-only granting universities or colleges. Ten participants represented industry and professional societies. Participants received the same background information as the geoscience employers plus a summary of the results from the 2018 Geoscience Employers workshop. Additionally, there were three panels: two employer panels, one focused on skills and competencies needed to prepare graduate students for future careers in the geosciences, and the other on employer roles and expectations, plus a professional scientific society panel focused on their roles. The format for the rest of the summit was the same as for the geoscience employers' workshop and previous FUGE summits and workshops. The participants discussed the input from geoscience employers and other studies on skills and competencies needed by doctoral and master's students for the current and future workforce, methods for developing these skills and competencies, and the balance between preparing for the workforce, research, and general educational goals. The academic leaders in general agreed with the employers in terms of what skills and competencies graduating doctoral and master's students have acquired and what they lacked. Additionally, participants discussed implementation strategies for integrating these skills and competencies into graduate programs and developed Action Plans for their institutions. Fifty-three institutional plans were submitted.

A 3-day workshop was also held at the Earth Educators Rendezvous in 2019 (44 participants; in-person) and in 2021 (61 participants; virtual) where we integrated the results of the graduate and undergraduate initiatives, and gained additional insights and feedback from department heads, chairs, and graduate program directors.

Progress reports on each Action Plan were requested in the fall of 2020 and of 2021 and spring of 2022. The onset of the COVID-19 pandemic in the spring of 2020 had a significant impact on progress in implementing changes. However, by 2022 we had received reports from 30% of the action plans, and half of those programs submitted two reports, one to two years apart. In 2021, a subset of employers who participated in the 2018 Geoscience Employers workshop provided insights into what had changed since 2018, with the primary focus being the effects of the pandemic. In 2021 and 2022, employers were also contacted to find out what changes had occurred in the workplace that impacted the previous results, with seven employers providing substantial input.

In 2022, we held two workshops that were specifically designed for administrative leaders who could make and lead change, and the employers of doctoral and master's students in Earth, Ocean, and Atmospheric Sciences, who are involved in making hiring decisions or setting priorities for their organizations. The specific objective of these events was to connect geoscience academic leaders and employers to encourage further dialogue about what skills and competencies graduate students needed to be successful in the future workforce regardless of their career path, and to discuss how graduate programs can effectively develop these skills and competencies for their students.

Our goal was to develop strategies for transformative changes in geoscience graduate education. Both workshops had working groups with both academics and employers, and at these workshops, the academics also participated as employers. The format was similar to the other events, though with several presentations: results of the 2018 Geoscience Employers workshop augmented by the employer updates on what had changed since 2018; the outcomes of 2019 Heads/Chairs/Graduate Program Directors Summit and implementation successes; and a summary of 2019 Heads/Chairs/Graduate Program Director Action Plan Reports. Discussions focused on similar questions as addressed at the earlier Summit and workshop events and explored what changes had taken place since 2018/2019. The May 2022 workshop had 43 participants comprising 23 academics and a somewhat different mix of 20 employers, including the World Bank, Smithsonian Institute, NASA, a

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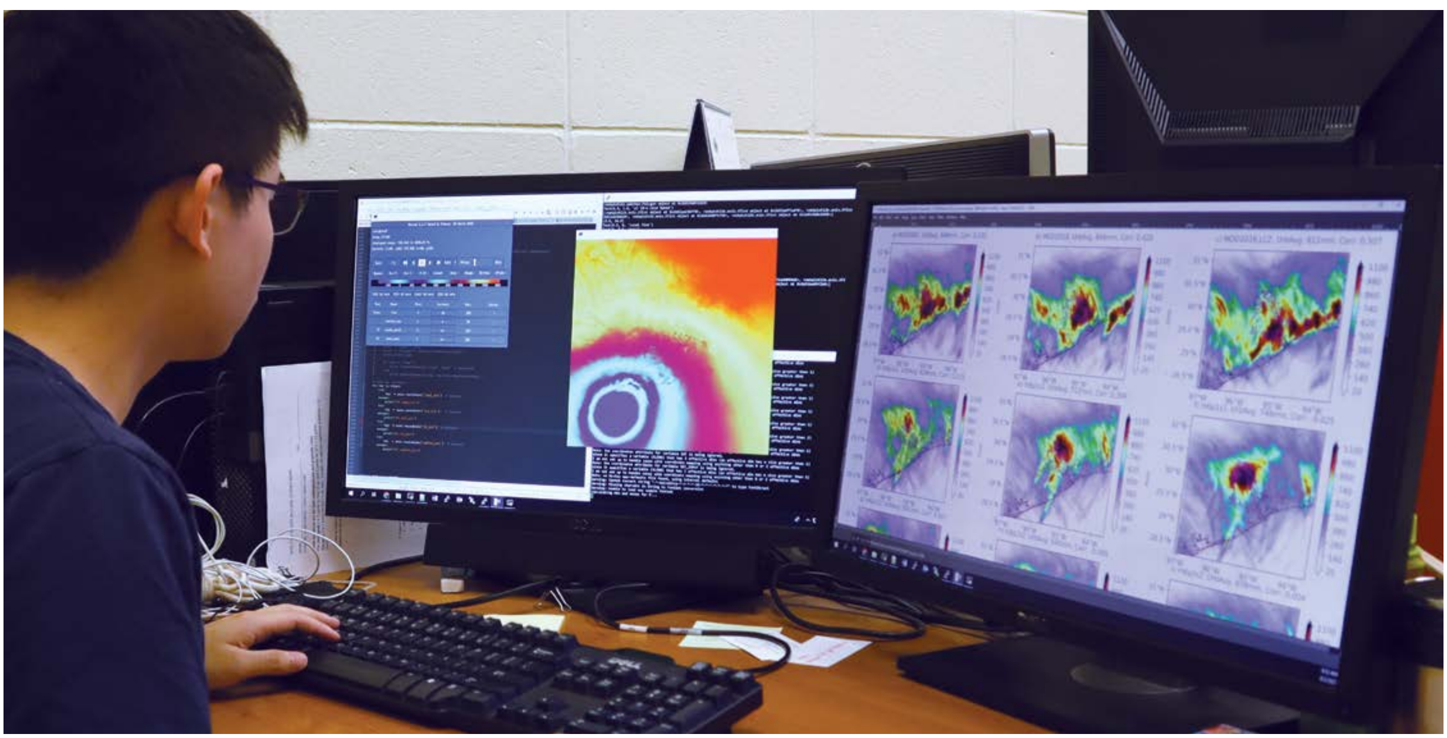
space/geophysical research institute, state and federal government regulatory agencies, oil and gas, USGS hydrogeology, American Meteorological Society, and the National Association of State Boards of Geology (ASBOG). The August workshop had 33 participants, 19 academics and 14 various employers, including several types of consulting, reinsurance, oil/gas, construction, Google, and national labs. A couple of graduate students also attended the May and August workshops to provide student perspectives.

Overall, we received input from over 300 individuals, of which ~100 were geoscience employers, with essentially all types of geoscience employers represented.

The American Geosciences Institute (AGI) also conducted several surveys in support of the project. All surveys were conducted utilizing the LimeSurvey online platform hosted on AGI owned servers. No options for paper or phone responses were provided. Additionally, all communications soliciting responses to these surveys were directed to the identified chair or head of U.S. geoscience departments.

Through a subaward, AGI conducted a study of the structure of geoscience graduate programs. AGI sent survey requests to all 377 U.S. graduate degree granting geoscience departments as identified in the 2018 Directory of Geoscience Departments. The respondent on behalf of the department was delegated by the chair or head. Complete responses were received from 146 departments, giving the survey a response rate of 39%. Of those responding departments, 27% were terminal master's programs. The results were then analyzed against the underlying framing of degree level and whether the degree programs were structured as a cohort or non-cohort. The complete analysis results are available on the project website **https://graduate.americangeosciences.org**.

AGI leveraged its support of activities from this project to relaunch its National Survey of Recent Geoscience Graduates Survey. This survey is sent to all departments for distribution to their graduating students at the bachelor's, master's and doctoral levels. The respondents were the graduating students. The two most recent iterations of the survey received 442 responses (2020–21) (212 were from master's or doctoral graduates) and 519 responses (2021–22 (233 were from masters' or doctoral graduates), representing an estimated 15% and 16% of graduate degree awardees, respectively. Both surveys utilized identical instruments for measuring employment, research experiences, and skills and concept exposure. The full results of the National Survey of Recent Geoscience Graduates are available on the AGI website (Keane et al., 2022; **https://www.americangeosciences.org/static/files/GraduateSurvey2021.pdf**).



Courtesy of the Jackson School of Geosciences, University of Texas at Austin

Courtesy of the Jackson School of Geosciences, University of Texas at Austin

Section 3. Graduate Programs and their Interface to Geoscience Work

GEOSCIENTISTS IN SUPPORT OF SOCIETY

A healthy and vibrant economy and society depends on the steady production of graduate degrees. The production of new master's and doctoral degree graduates consistently predicts increased growth and innovation (Aghion, et al., 2009). With growing challenges such as climate change adaptation, issues of resource availability, and natural hazard reduction and mitigation, maintaining a productive pipeline of master's and doctoral graduates in the geosciences is critical to our future. Though public perspectives on higher education center around the bachelor's degree, this is only the foundational step for driving science innovation and problem solving. Bachelor's graduates in the geosciences (and other STEM fields) who stay in the profession either continue into graduate programs or pursue careers in specific technical roles that apply innovations and discoveries made primarily by doctoral level geoscience professionals.

Courtesy of the Jackson School of Geosciences, University of Texas at Austin

Success in the geosciences will be defined by the ability of master's and doctoral graduates, and the graduate degree programs that produce them, to tackle emerging challenges and advance the geosciences. Graduate programs must monitor and recognize the changing needs and applications of the geosciences, and must be agile with curricula, instruction, and student opportunities. They also represent an incubator for the future of the discipline by developing the next generation of educators, researchers and thought leaders. Although about half of geoscience doctoral graduates pursue careers in academic research and teaching, they only represent a small fraction of the total geoscience workforce (8%) (AGI analysis of U.S. Bureau of Labor Statistics). With current pressures on academia related to enrollments and funding post-pandemic, according to the U.S. Bureau of Labor Statistics, the total number of academic positions are not expected to grow over the next 10 years. But with ongoing retirements and changing societal needs, the next generation of academic geoscientists will need a new portfolio of skills and strategies for success as they will be responsible for educating the future workforce. This core function of graduate degree holders is pivotal for the discipline's success. Success will require this next generation of educators and leaders to work across the discipline to maximize opportunities in the evolving professional space with a myriad of new opportunities, such as the increasing role of professional services companies across the Earth, Ocean, and Atmospheric Sciences with their application and advancement of the science.

THE OPERATIONAL FRAMEWORK

One of the greatest strengths of the U.S. higher education system is the ability of institutions to innovate their own approaches to degree programs. This creativity is especially evident at the graduate level, where degree innovations have flourished beginning with the MBA in 1908, and many new approaches since that time, such as the Professional Science Master's degree.

Within this diversity of degree programs are dominant structural frameworks in which graduate programs fall. Central are the two fundamental degree levels: master's and doctorate. A second dimension is the nature, purpose, and expression of research in the degree program. The third structural dimension is the organizing principles of the programs: whether students progress through programs in a cohort or individually, or some hybrid approach.

Based on the AGI survey of geoscience graduate program structures, 73% of U.S. geoscience departments granting graduate degrees offered doctoral programs, while 27% only provided terminal master's degrees. All doctoral granting programs also award master's degrees. Almost all master's programs awarded Master's of Science degrees, with only 8% reporting awarding Professional Science Master's degrees.

MASTER'S AND DOCTORAL DEGREES

Geoscience employers and academic participants in the workshops agreed on the distinct purposes and expectations of the master's versus the doctoral graduate. Importantly for the graduate, the degree received affected the hiring decisions of employers, including academic employers. Employers agreed that the types of skills needed for master's and doctoral graduates were the same, but the level or depth of competency differed both with degree and with the type of employment. Employers expected that master's graduates have developed a broad skill set, and that doctoral students have a greater depth of competency, and more expansive technical skills.

Fundamentally, master's graduates are expected to know how to solve problems but are less likely to have experience defining research questions or fully articulating the broader relevance of their research. Doctoral graduates are expected to have broader backgrounds and to have conducted self-starting research. They should know how to identify and think about problems and how to solve them, and they have more experience and practice.

ROLE OF RESEARCH

Research was consistently recognized by academics and employers as central to any graduate program in the geosciences. Importantly, the research process was seen as a primary method for students to develop a wide range of scientific, technical, and core professional skills, such that research was not viewed as just an end in itself. Employers especially viewed evidence of research experience and accomplishment as critical in their hiring processes.

Doctoral research was universally recognized as being independent and as building a student's ability to conduct novel investigations, and to plan, manage, and execute these activities. They need to define the question, design the project, create a proposal, and justify doing the research. They have a longer timeframe to solve problems and to reach higher levels of accuracy. They are the driver of their research and receive less direction from their advisor than would a master's student. Those advisor interactions are centered more on reviewing progress and results throughout the project. What distinguishes a strong doctoral researcher is a deep dive into one subject, the ability to discover, own and solve a problem independently, and a high level of creativity and innovation.

Doctoral research may be viewed by some non-academic employers as too specific to be directly impactful on their business, so it is critical for doctoral students to clearly demonstrate their deeper understanding of the technical and core professional skills developed through their research, in addition to content and research-related skills. All employers are seeking leadership, innovation, out-of-the-box thinking, and mentoring skills. They recognize that tinkering is an important and critical luxury of a doctoral degree that is central to fostering these creative capabilities. All U.S. doctoral programs have a strong emphasis on research, and as such need to ensure that key professional skills are well integrated into the effort and clearly demonstrable by the student without losing a strong research emphasis.

Academia is a critical employer for doctoral graduates with about half of these graduates employed in some form of academia. At the 2022 workshops, preparing doctoral students for academic positions was discussed. These students need to be exposed to the fundamentals of academic institutions as a business, to understand the larger picture at the institution, and to know what to expect in their role as an academic beyond the expectation of research. Doctoral students need to know how to mentor students and how to teach effectively. They should be given opportunities to mentor undergraduate or less senior graduate students, to teach classes, to experiment with different teaching styles and to be constructively critiqued and evaluated on their instructional practice. Doctoral students also need to understand the broader professional and stakeholder community and have a global perspective. They need to develop an understanding of the kinds of innovative research they can propose that will be funded, and get practice in writing compelling, concise proposals and constructing realistic research budgets.

Being successful as an academic or in industry or government involves differences in mindset and it is important to learn the cultural and practice differences, and how to shift between these, whether they make a shift in employment sector, or work collaboratively with non-academic partners. Having doctoral students rotate through and work in different labs or with different research groups will expose them to different styles of management and mentorship.

Master's programs may offer thesis and non-thesis options. Often programs that require a thesis are both doctoral preparatory or, as noted by employers, also workforce preparatory. Non-thesis programs are normally terminal master's degrees where graduates expect to enter the non-academic workforce. However, across the board, non-thesis does not mean no research, but rather that they engage in different modes of research, with different intents.

Master's research projects are narrower than doctoral projects. Master's students are commonly provided with a research problem, and they work under the direction of their advisor, learning the research process as much as conducting research activities. They learn how to solve problems, work on a shorter time scale, and ideally know when their results are sufficient. Master's programs with a non-thesis option are not the same as coursework-only master's programs. Universally, the non-thesis option programs require either a capstone project or a case study, and almost universally require public presentation of their results and an oral defense of their work. These non-thesis options tend to be more limited in scope, however they still provide opportunities for students to develop research-related skills, including, for those pursuing non-academic careers, core professional skills. Employers indicated a preference for students who have completed a master's thesis because of the expected skills development from the research experience. Thus, it serves non-thesis programs well to focus on ensuring that the research experiences within their programs also develop this suite of skills in a demonstrable manner so students can showcase their accomplishments in an e-portfolio or through interviews.

Master's students are more likely to seek employment on completion of their degree, but their level of expertise can carry over into a doctoral degree program, especially for thesis-based master's students, they develop skills and initiate and complete a body of research that could form the basis of a doctoral dissertation. They have developed some awareness of what has been done before, conducted a critical evaluation of the literature, and may have identified where there are gaps and further work needs to be done.

Employers recognized that master's students may initially need more direction and support once hired as they are still developing their independence.

Employers recommended that master's students be introduced to problem identification and approaches to finding solutions in courses, and that more instruction and practice in critical thinking skills be embedded into these courses. They also felt that master's students would benefit from more leadership training, and the insertion of some business skills into their geoscience coursework.

COHORT AND NON-COHORT PROGRAMS

When looking broadly at U.S. STEM graduate programs, even among the broader models, there are two fundamental structures being used: individualized programs (non-cohort) and cohort-based programs. Within the geosciences, cohort programs are a more recent development as compared to other disciplines, and are mostly relegated to master's programs, whether in terminal master's departments or as separate programs within doctoral-granting departments.

Individualized, or non-cohort, programs are what most geoscience academics will recognize as the traditional approach, where a student, working with an advisor and likely a program and/or research committee, will craft a coursework plan that meets departmental requirements but also addresses their research needs. A student's progress in research is usually managed by the advisor and committee members. This approach allows students flexibility in terms of their coursework and research focus. Students can tailor their educational experience to their specific interests, goals, and schedules. This model is well-suited for students who have a clear research focus, require flexibility due to work or personal commitments, or prefer working independently.

As of 2018, 59% of doctoral departments and 55% of terminal master's departments exclusively used the non-cohort model across their graduate degree programs.

Advantages of individualized programs:

- Greater flexibility in course selection and research focus
- Ability to work at your own pace
- Potential for interdisciplinary or unique research projects
- Opportunities for self-directed learning and growth
- More individualized guidance from advisor and/or committees

Cohort-based programs group students together based on the time of enrollment or a specific program within a department, so they proceed through the program together, taking the same courses and working on projects or research in parallel and sometimes collaboratively.

Beyond coursework, cohort programs can also include common comprehensive exams, opportunities for group or collaborative research, and opportunities for group advising and dialogue with faculty, providing a broader exposure to the scope of research within the department. Additionally, 70% of cohort programs offer additional specialty certifications (e.g., GIS, energy or IT management, etc.) either within the cohort program or for general access both by students within the program or externally. The presence of these certificate programs aligns with the preponderance of cohort programs producing terminal master's degrees.

This model can provide efficiencies for departments with large numbers of graduate students, especially if those students are not in traditional thesis programs. For students, cohort programs can foster a sense of community, support, and networking, which can be highly beneficial for both academic and professional development.

In the geosciences, 23% of doctoral departments reported having programs (usually master's) that used cohort structures, and 25% of terminal master's departments in geosciences reported programs using cohort approaches exclusively. The remaining departments, 18% for doctoral departments and 20% of terminal master's departments, had a mix of programs that used cohort and non-cohort structures.

Enrollments in terminal master's cohort programs were steadier over time than in individualized programs. For doctoral departments, a similar pattern was observed, with cohort programs having substantially steadier enrollments and individualized programs experiencing enrollments varying two to three times as much as cohort programs. It is also worth noting that cohort programs, which almost all co-exist in departments with traditional programs, have very different business models: many of the students in these programs are self-funding, and all departments with cohort programs report receiving support from private foundations, as compared to 62% of doctoral and 42% of terminal master's departments utilizing non-cohort models. Also, the pedagogical approaches of cohort programs facilitate effective graduate education for a broader population of students.

Core advantages of cohort-based programs:

- Stronger peer support and collaboration
- Networking opportunities with fellow students
- Structured curriculum and more definitive timeline
- Enhanced group learning experiences

GRADUATE PROGRAM CULTURE

Beyond the observable structure differences, graduate programs across the country have different academic cultures. Master's only programs commonly enroll graduate students focused on diverse professional outcomes, including graduates going elsewhere for a doctoral degree. In a subset of programs, most graduates go on to employment in a specific sector, and the coursework and theses are designed to develop the knowledge and skills needed for that profession. This entangles the success of the program with the health of the targeted economic sector.

Employers and academics briefly discussed professional, usually non-thesis, master's degrees and whether they facilitated students achieving their career goals. Professional Science Master's degrees focus on real-world problems and are done in conjunction with an employer. These degrees and dual degrees with business (MS-MBA degrees) or other interdisciplinary degrees that blend business and/or law with STEM fields aim to prepare students for the private sector. Their advantages include that they help develop business acumen in students (Moran, 2021; Moran et al., 2009), often take less time to complete, and usually don't require a research-based thesis. However, employers were forceful in saying that they still valued the importance of conducting research, as it strengthens the students' ability to think critically, solve problems, present research in writing and orally, and complete a major project.

Programs exclusively or primarily focused on doctoral degrees are research-focused and a common (if often unstated) expectation that graduates will go into academia, or potentially government labs or federal agency research positions. Doctoral programs heavily focused on these outcomes need to increase their awareness of the professional paths outside of academia, as about half of doctoral degree recipients pursue non-academic paths (Figure 3.9b). The recent growth in large start-ups, advancements in artificial intelligence (AI), and the private sector developing their own modeling capabilities provide a much wider set of opportunities for finishing doctorates. Doctoral programs at institutions that also have strong terminal thesis-oriented master's programs are generally more aware and accepting of different professional outcomes and scaffold skills between degrees.

The trajectory of students in a graduate program directly impacts the eventual outcomes for those students. Given a rapidly changing geoscience profession, it is important to utilize pedagogical approaches that integrate core knowledge with the key skills needed both in academia and in industry (see Section 4: Skills Framework). It is also important not to allow different expectations to develop for academic and non-academic professional directions, as student career choices and the field itself often change over the longer duration of doctoral programs.

Another cultural issue impacting graduate programs is that the ability to do doctoral research is dependent on the extramural funding that faculty can generate and on the available institutional facilities, which are themselves a product of both institutional resources and longer-term faculty research success. Resource-rich graduate programs, whether through endowments, strong institutional investment, or highly successful PI's, can often support curiosity-driven, blue-sky research. At less internally resourced institutions, or those supported by specific industries, student research commonly has a more targeted and/or applied focus.

Program research and associated career opportunities also vary within the geosciences. Vibrant graduate programs will recognize the opportunities as ways to foster specific skills and scientific advancements that not only enrich the post-graduation opportunities for the students but represent amplifiers for their graduate programs. The increasingly important role of professional services companies in the Earth, Ocean, and Atmospheric Sciences are creating a myriad of unique opportunities. For the earth sciences we see an increased focus on applied science in the field and the need for increased development of novel data and analytic techniques. In the atmospheric sciences, the role of machine learning and artificial intelligence has exploded, and these companies are often at the forefront of new application spaces for the science and leveraging these new advances. Ocean science is seeing new opportunities in advanced data acquisition and analysis and machine learning opportunities in the search of subsea resources and analysis of ocean dynamics for environmental and climate monitoring.

GEOSCIENCE DISCIPLINES

Geosciences includes Earth, Ocean, and Atmospheric Sciences, with earth sciences being the largest in terms of degrees awarded and geoscience employment with 1481 master's degrees and 890 doctoral degrees awarded (2020 Directory of Geoscience Dept. Survey). According to NSF (2021), the atmospheric sciences had 217 master's graduates and 156 doctoral graduates in 2019. Ocean Sciences has 144 master's graduates and 136 doctoral graduates in the same year.

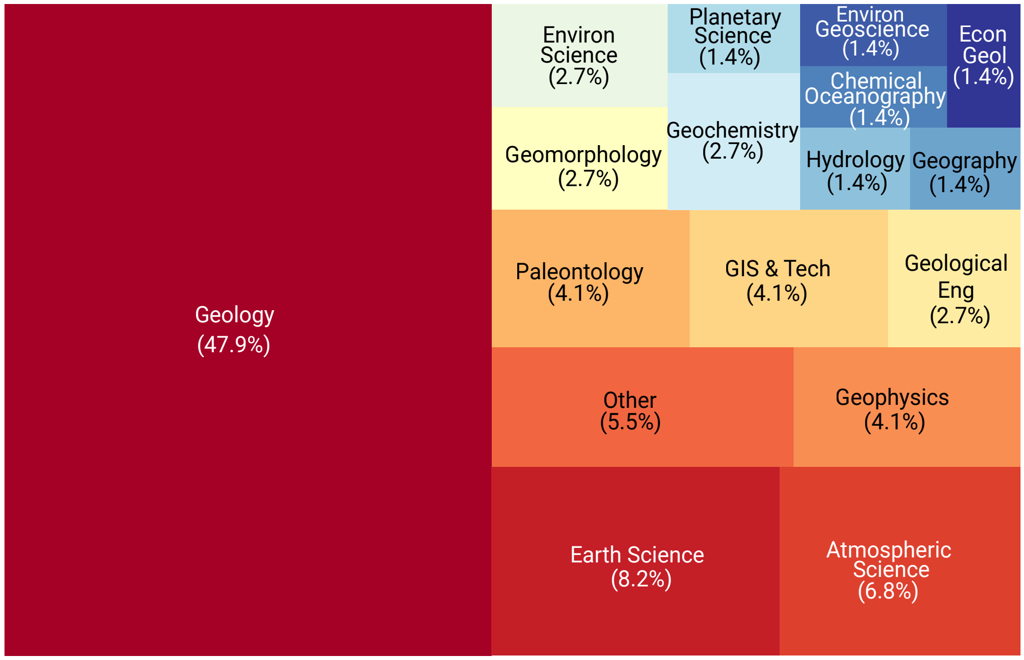
In the results of the survey of recent geoscience graduates, the respondents overwhelmingly come from earth science-oriented programs, but many of those are also multidisciplinary with active atmospheric and ocean science activities. From these results, we see some general trends in specialization between the degree levels (Figure 3.1a,b). Geology is the largest sub-discipline, constituting about half the master's degrees, and about a fourth of the doctoral degrees. Overall master's degrees are more application oriented (e.g., GIS & tech, geological engineering) than doctorates. For doctoral degrees, planetary sciences, Earth sciences and hydrology show the largest increases relative to master's degrees, and degrees in climatology, petrology and physical oceanography are also awarded. Regardless of the geoscience discipline or subdisciplines, employers and academic participants agreed on the skills and competencies needed by graduate students to be successful in the current and future workforce. These geoscience disciplines are employed in a wide variety of occupations (Figure 3.2).

THE SUCCESSFUL GRADUATE DEPARTMENT

Ultimately the driver for change is to make graduate programs more successful, which means understanding what constitutes success. The survey of graduate granting departments asked how a department defines success for themselves as an entity, and separately, how they define a graduate student as having been successful. These definitions of success (Figures 3.3, 3.4) likely extend not only from the internalized values and expectations of educators, but also from external pressures such as deans and alumni.

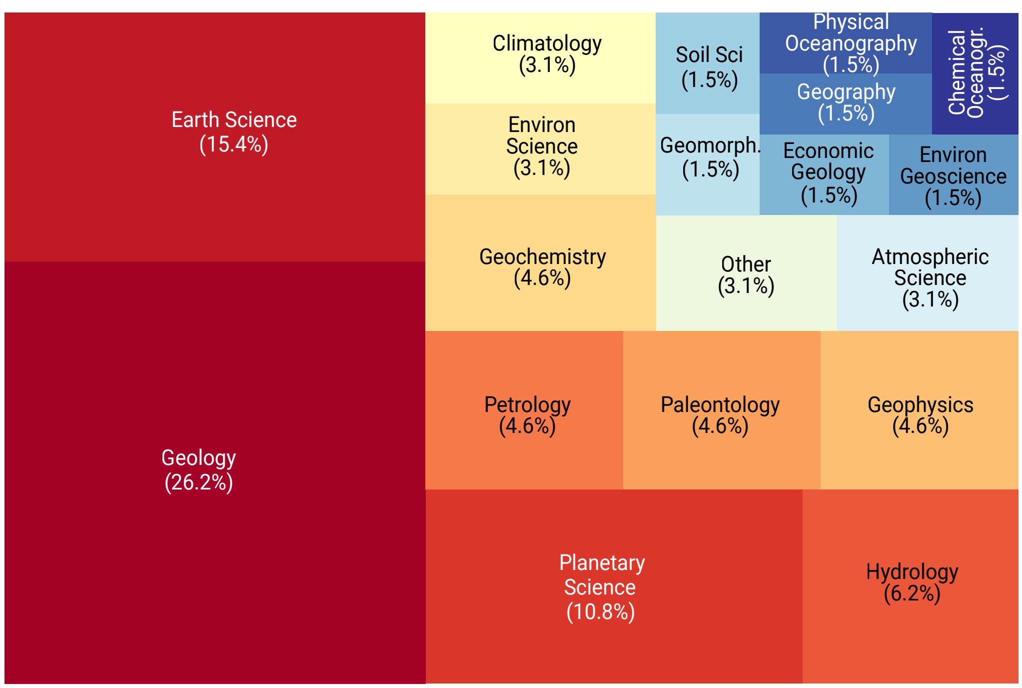
Departments define their own success largely by the outcomes of their graduates (Figure 3.3). The identified measures of

Figure 3.1a: Field of Degree, Master's 2021–22



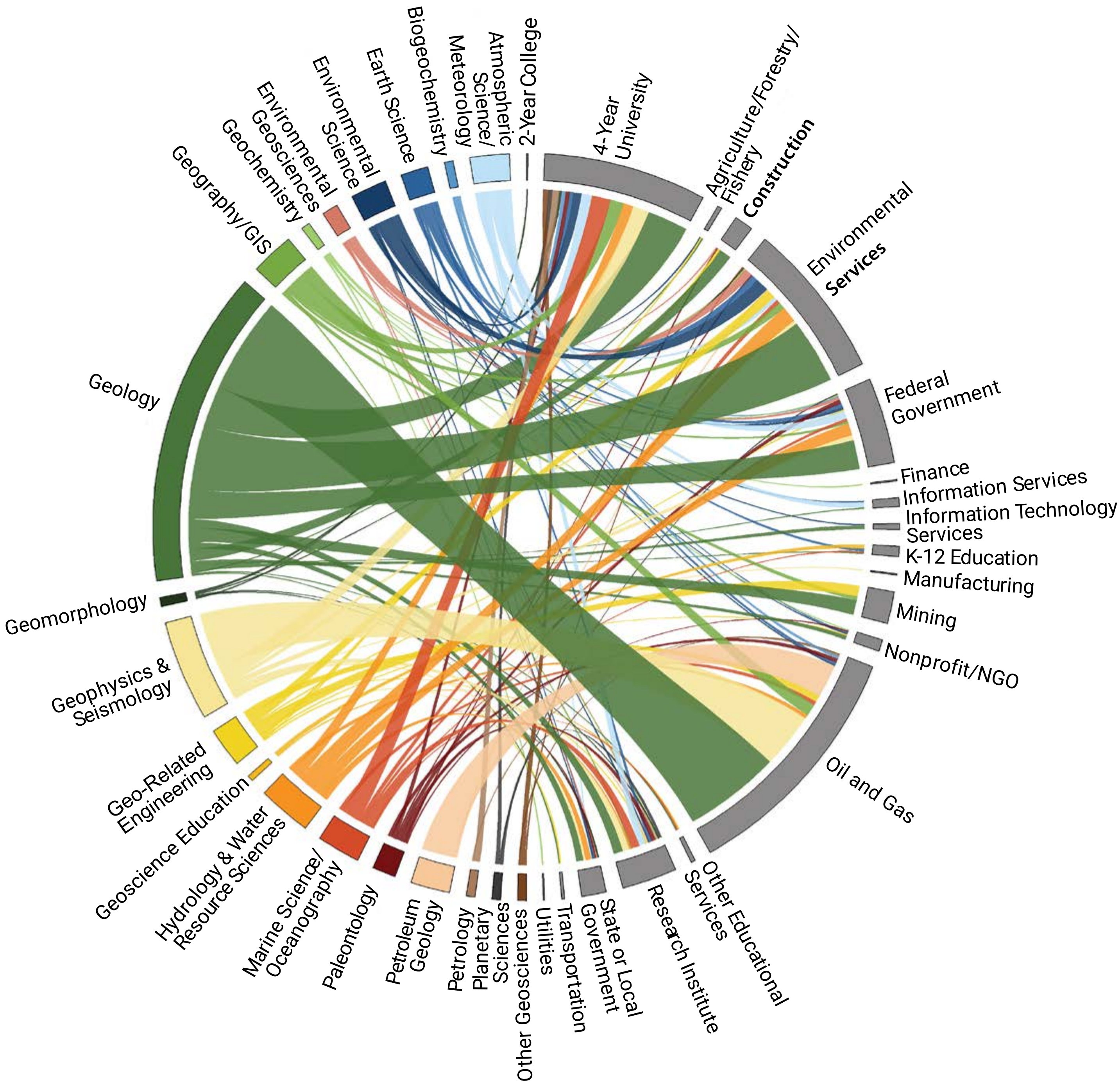
Reported field of degree of geoscience Master's U.S. graduates for the 2021–22 academic year.
American Geosciences Institute. Source: Data from the 2021–22 AGI Survey of Recent Geoscience Graduates.

Figure 3.1b: Field of Degree, Doctorate, 2021–22



Reported field of degree for geoscience doctoral U.S. graduates for the 2021–22 academic year.
American Geosciences Institute. Source: Data from the 2021–22 AGI Survey of Recent Geoscience Graduates.

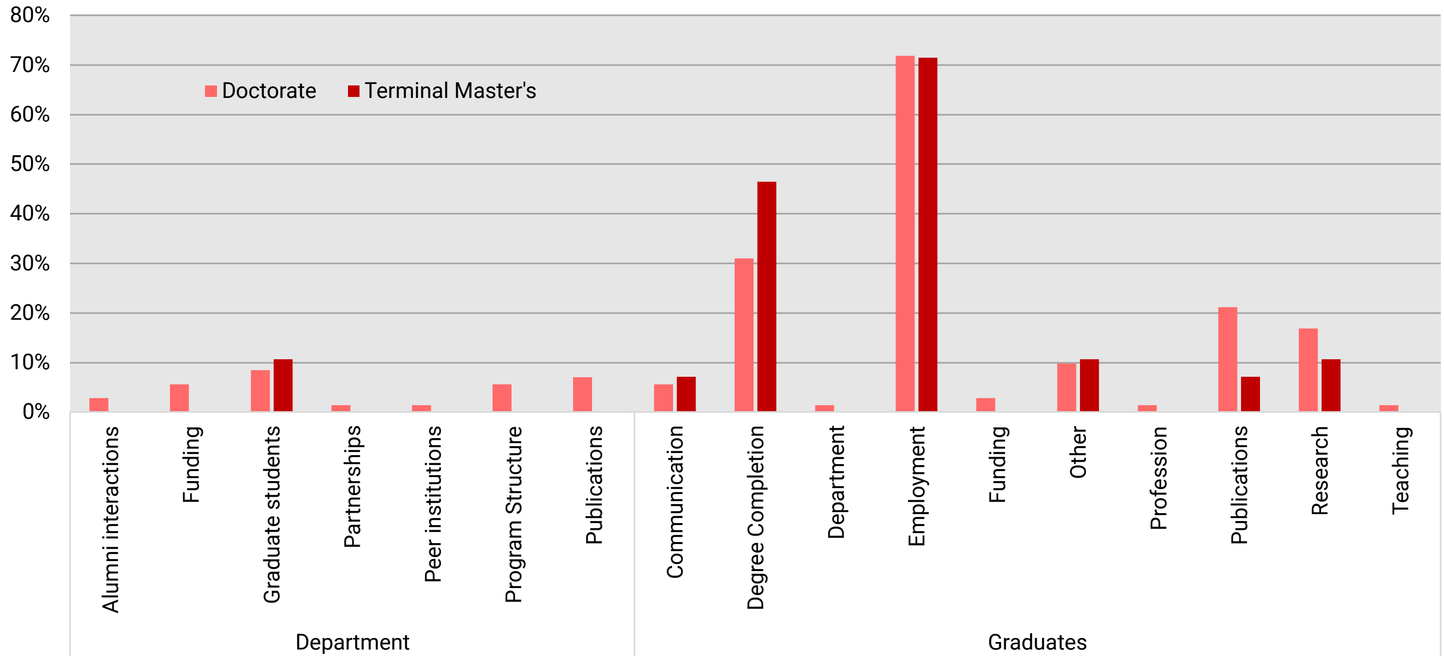
Figure 3.2: **Degree Topic to Employment Pathway of Geoscience Graduates, 2013–2018**



Sankey diagram of the pathways from the subject of geosciences degrees awarded between 2013–2018 in the United States and the employment sector of their first post-graduation job.

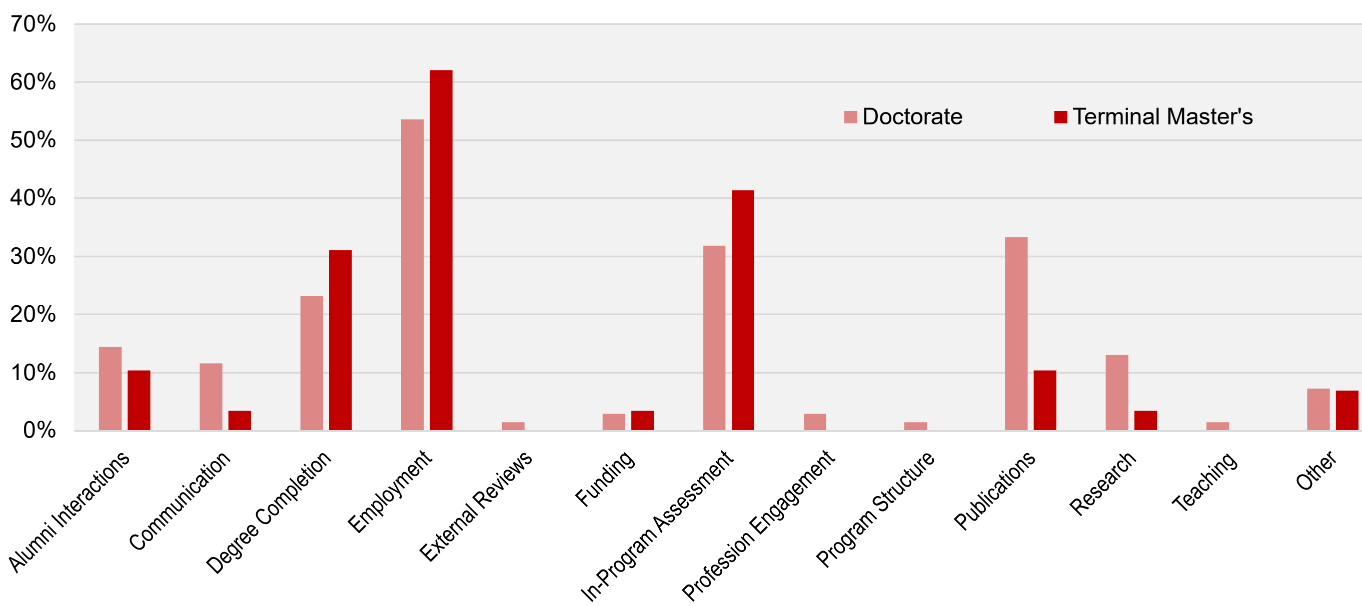
American Geosciences Institute. Source: AGI Status of Geosciences 2018

Figure 3.3: How Do You Define Success for Your Program?
Percent of respondents



Graduate programs reported what factors they considered when evaluating the success of their program. Some of the metrics are related to the actual department and its function, and others related to activities of the graduate students themselves.
American Geosciences Institute. Source: AGI Survey of Graduate Program Structure

Figure 3.4: How Do You Define Success for Your Graduate Students?
Percentage of responding departments



Graduate programs reported on the metrics they use to evaluate whether a specific graduate student has been successful within their program.
American Geosciences Institute. Source: AGI Survey of the Structure of Graduate Programs

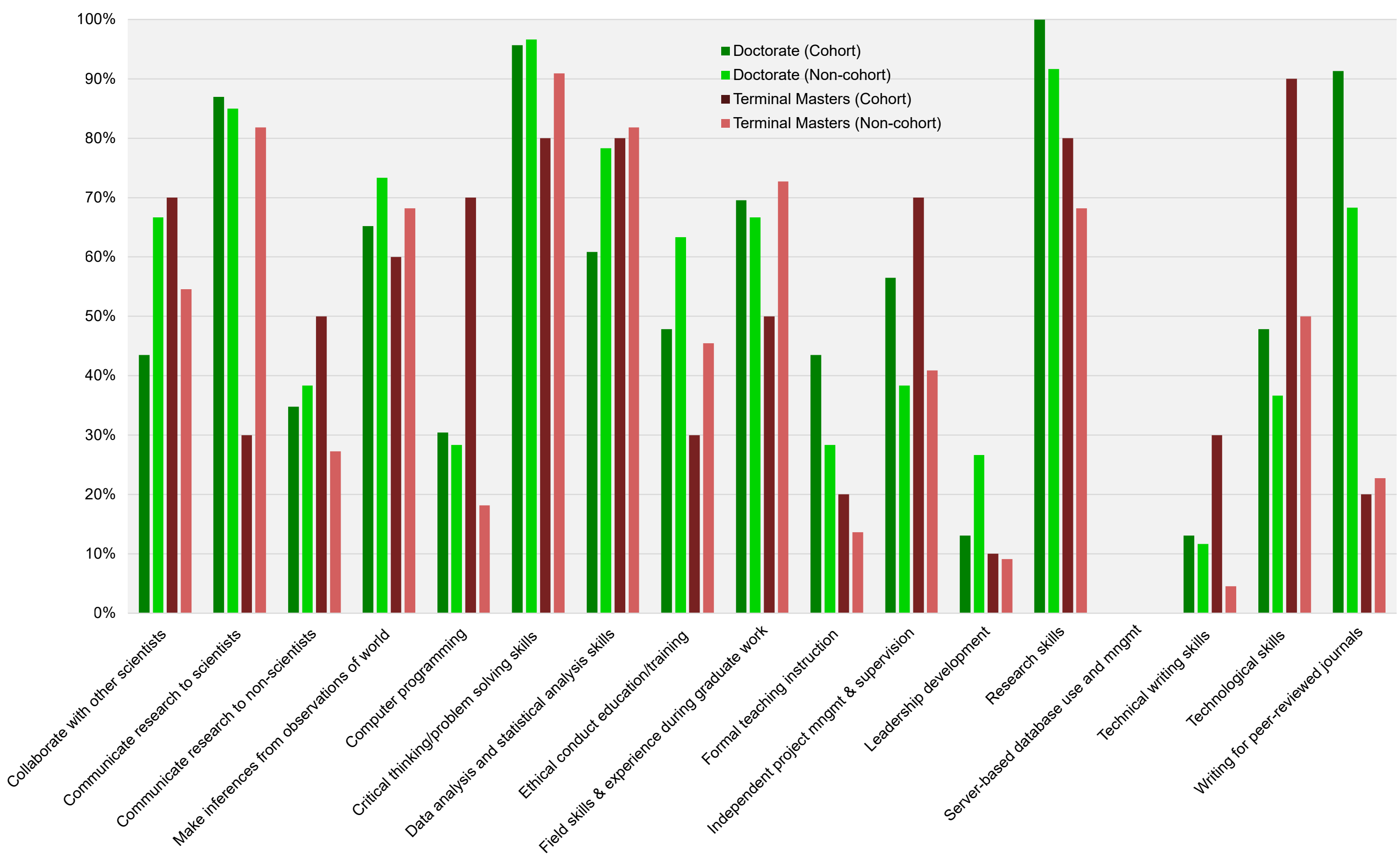
graduate success are primarily employment and degree completion, and to a lesser extent for doctoral programs, publication in peer-reviewed journals, the ability to conduct independent research, and contribution to the geoscience profession through involvement in professional societies. Some departments also noted specific internal metrics, such as departmental funding, the number of papers published in high-profile journals, the number and amount of grants awarded to faculty, a positive departmental culture, and a strongly connected alumni network.

The most prominent measure by which departments define their programs' success is based on whether their graduates secured meaningful employment. This common and singular success metric creates a clear connection between the graduate programs and their need to understand and respond to the ongoing evolution of the role of geoscience in the workforce.

Departments also reported a suite of metrics they used to evaluate whether, or not, an individual student has been successful in their program (Figure 3.4), including passing comprehensive exams during the course of the degree program, and conducting research and publishing. Research success via publishing in peer-reviewed journals during their studies or shortly after graduating was mentioned more frequently by doctorate-granting departments as a success metric.

Interestingly, although degree completion was important, it was not the most common success factor mentioned by departments. Instead, it was whether the student

Figure 3.5: Skills that Departments Expect Graduates to have Expert Proficiency by Graduation
Percent of respondents



Graduate programs have certain expectations of skills their graduates will have developed by the end of their program. Variance in those expectations are seen both by degree level and whether or not a program is cohorted.
American Geosciences Institute. Source: AGI Survey on Graduate Program Structure

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had gained meaningful employment. In-program assessments were the second most common factor, likely reflecting that such assessments, like comprehensive exams, are one of the few common factors across all students in a graduate programs, as well as pressures from accreditors and institutions to identify some suite of uniform, in-program assessment measures.

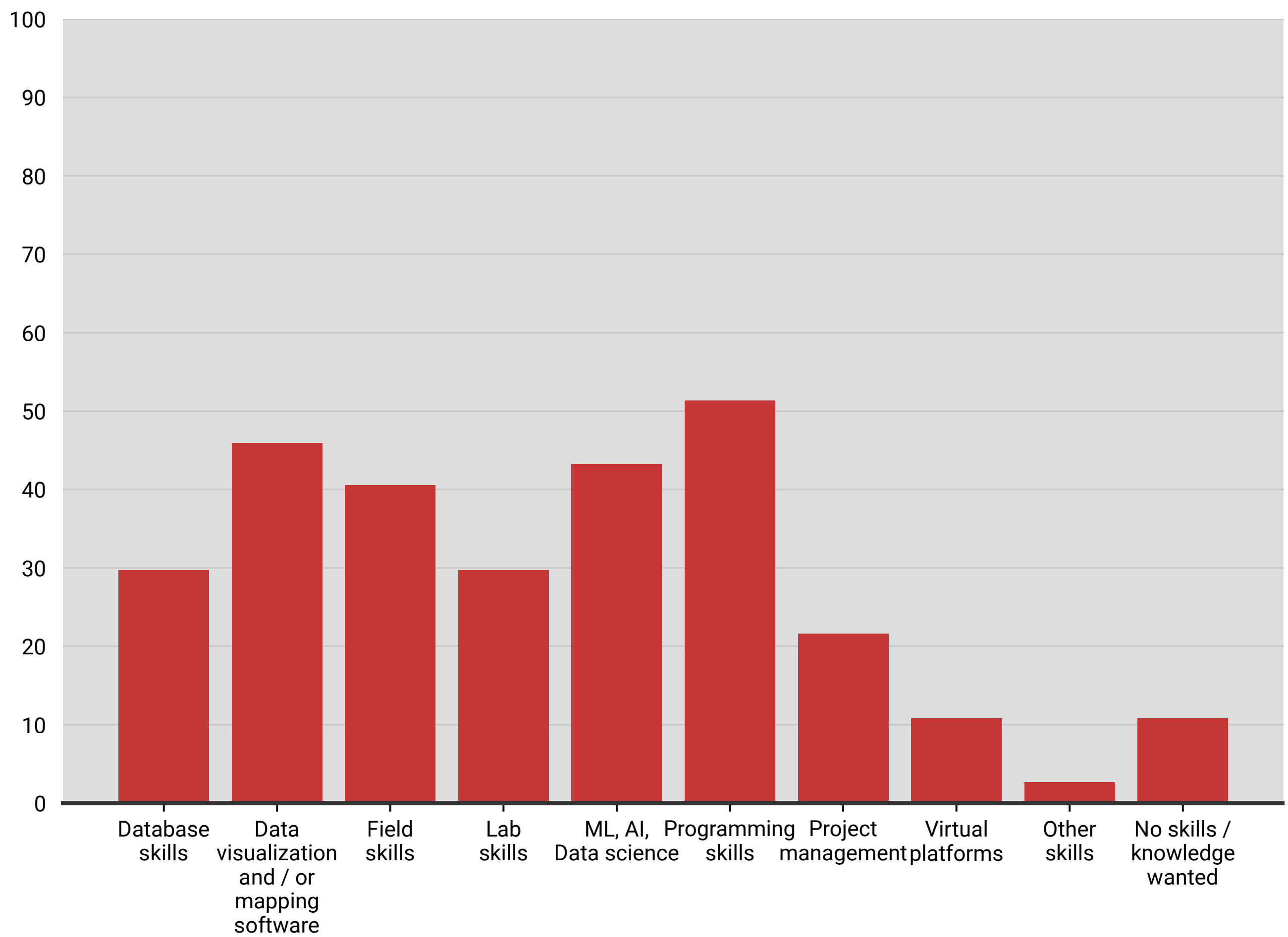
With meaningful employment of graduates central to ideas of success of graduate programs and their students, ensuring the programs are well-grounded in the spectrum of ways geoscience expertise is used in society is important. Understanding the current dynamics of geoscience-related workforce needs can provide graduate programs with a roadmap.

EXPECTATIONS FOR GRADUATE DEGREE RECIPIENTS

Both doctorate-granting and terminal master's departments value critical thinking/problem-solving skills, research skills, communicating research to scientists, and data analysis and statistical analysis as the top skills expected from their graduates (Figure 3.5). It is worth noting that computer programming is not widely emphasized as a required skill for doctorates and non-cohort master's, despite data analysis and statistical analysis being among the top five where computer programming skills may be inferred.

Skills that are not heavily emphasized include communicating research to non-scientists, ethical conduct/training in terminal master's programs, formal teaching instruction for non-cohort doctorates and master's, leadership development, database use and management, and technical

Figure 3.6: Skills and/or Knowledge Deficiencies Identified by Recent Graduates
Percent of recent employed graduates



The percentage of recent graduates reporting on specific skills they have needed in their employment and wish they had learned during their formal education.
American Geosciences Institute. Source: AGI Study on the Impacts of COVID-19 on the Geoscience Enterprise

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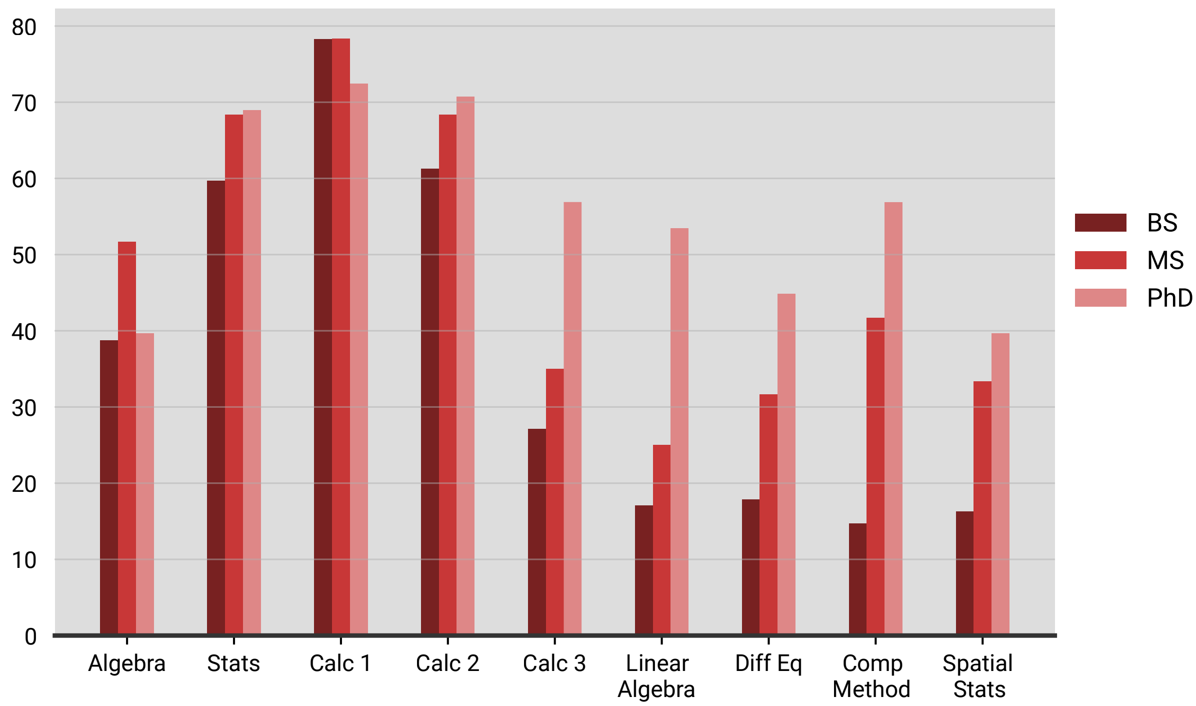
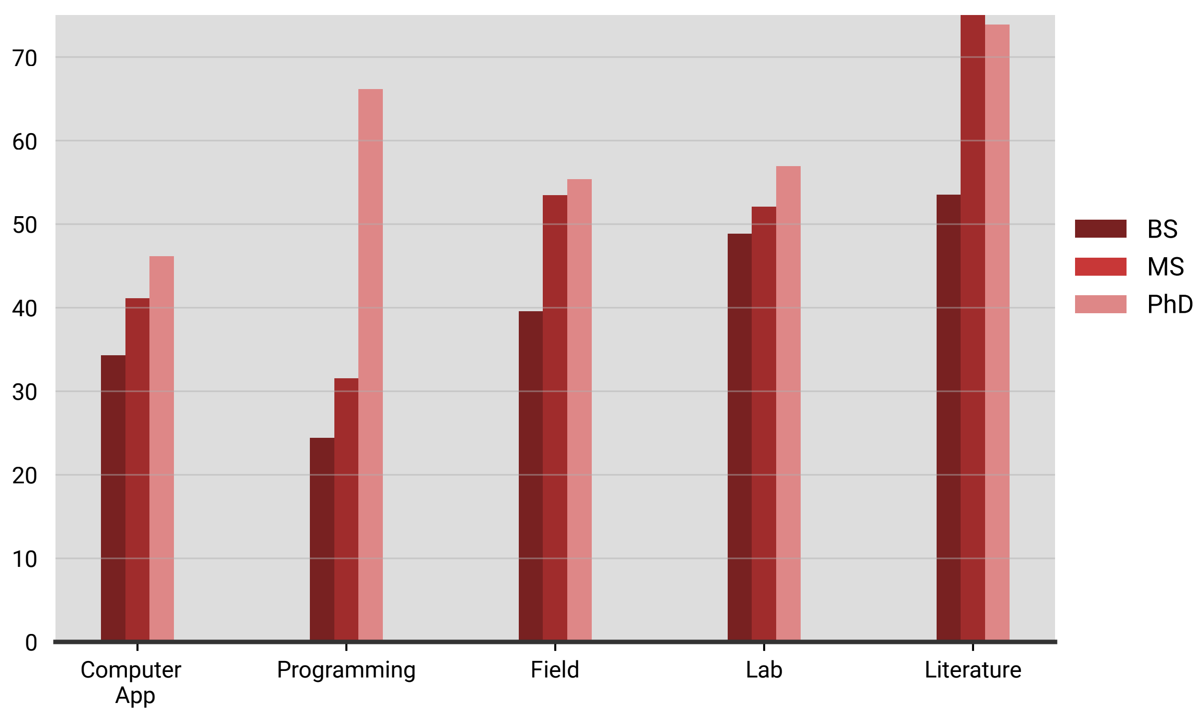
Figure 3.7: **Quantitative Skills by Degree Level, 2021–2022**
Percent of graduates by degree level



The percent of U.S. geoscience graduates by degree level who have taken a course in specific quantitative topics.
Ameircan Geosciences Institute. Source: AGI Survey on Recent Geoscience Graduates, 2021-22

Figure 3.8: **Research Methods Used by Degree Level, 2021–2022**
Percent of graduates



The percent of recent graduates who report using specific research methods during their graduate program.
American Geosciences Institute. Source: AGI Survey of Recent Geoscience Graduates, 2021-22

writing skills. As the workforce is moving towards data, automation, and greater interaction with non-scientific communities, the lack of emphasis on these skills is a cause for concern. The impact of these shortcomings is also reflected in recent AGI surveys where early career geoscientists name data management and other data-related skills (Figure 3.6), writing, and business issues as key skills they wish they had focused on in during their education along with field and lab skills.

With the increased need for quantitative and computational skills expected by employers (see Section 4: Skills Framework), it is interesting to note which skills geoscience students have obtained, and how much they are used in conducting research (Figures 3.7, 3.8). In general, doctoral graduate students have the most quantitative, computational and programing skills and experience. Although about 70% of graduate students have had statistics, only 40% or fewer have had spatial statistics which is important for the geosciences.

STUDENT DEVELOPMENT

All graduate programs report providing a range of specific student development activities, from core courses and seminars to explicit writing and quantitative skills courses. All modes of student development are available in at least half of graduate programs, with doctoral programs more likely to have seminar-related activities and terminal master's programs more likely to have common core courses and enhanced writing courses. Although almost all doctorate granting departments offer seminars, 65% require attendance at these events. For both doctoral and terminal master's programs, 80% of programs encourage students to engage with external development activities such as attending conferences and short courses. Diversity programs and events are more prevalent in doctorate granting departments than in terminal master's programs[1].

Additionally, for all program levels in doctoral departments, a number of co-curricular experiences were identified as being pursued by current students:

- Presentations at local and national conferences (76%)
- Internships (63%)
- Outreach activities at local K–12 schools (47%)
- Giving public talks and lectures (30%)
- Active with student clubs and organizations (27%)
- Engaging with science fairs (20%)
- Traveling to professional meetings (17%)
- Community service (16%)
- Participation in field trips (14%)
- Pro bono work for local non-profits (11%)

GEOSCIENTISTS IN THE WORKFORCE

Since 2015 geoscience employment in different sectors has changed radically for master's graduates and significantly for about half of the doctoral graduates (Figure 3.9a,b). Prior to around 2017, the majority of new master's graduates were employed in the oil and gas sector, with a peak of 67% in the mid-2010's dropping to 4% in 2022. Growth employment areas since 2017 have been in state government, mining, and other unspecified areas; federal government employment increased after 2015 but has gradually declined since 2017. For doctoral graduates, employment in academia has stayed at about 50% since 2017 with a small decline. The largest increases for doctoral graduates since then have been in federal and state government and professional services (Figure 3.9b).

Current structural changes in the domestic labor market and rapid technological advances are driving disruptive change within all science and engineering fields. As the United States emerges from the pandemic, the labor market has changed, with current labor shortages recognized as structural and expected to persist into the future, (Abraham and Rendell, 2023). For technical fields, accelerating retirements are creating a skills mismatch between supply and market needs, with the labor participation rate of workers 65 and older declining 10.6% between the start of the pandemic and January 2023, according to the U.S. Department of Labor. (U.S. Bureau of Labor, 2023)

Part of this mismatch lies in the issue of replacing experienced workers with new entrants, which has been especially complicated in that the pandemic has impeded the usual knowledge transfer and mentoring experiences for new workers. Additionally, the reported skills of new graduates are not aligned with market demands, as technology and the problems being addressed are changing rapidly. Industry is attuned to pivoting quickly, but

1 Note that this survey was conducted in 2019 and does not reflect post Black Lives Matter efforts and the expansion of diversity efforts on U.S. campuses.

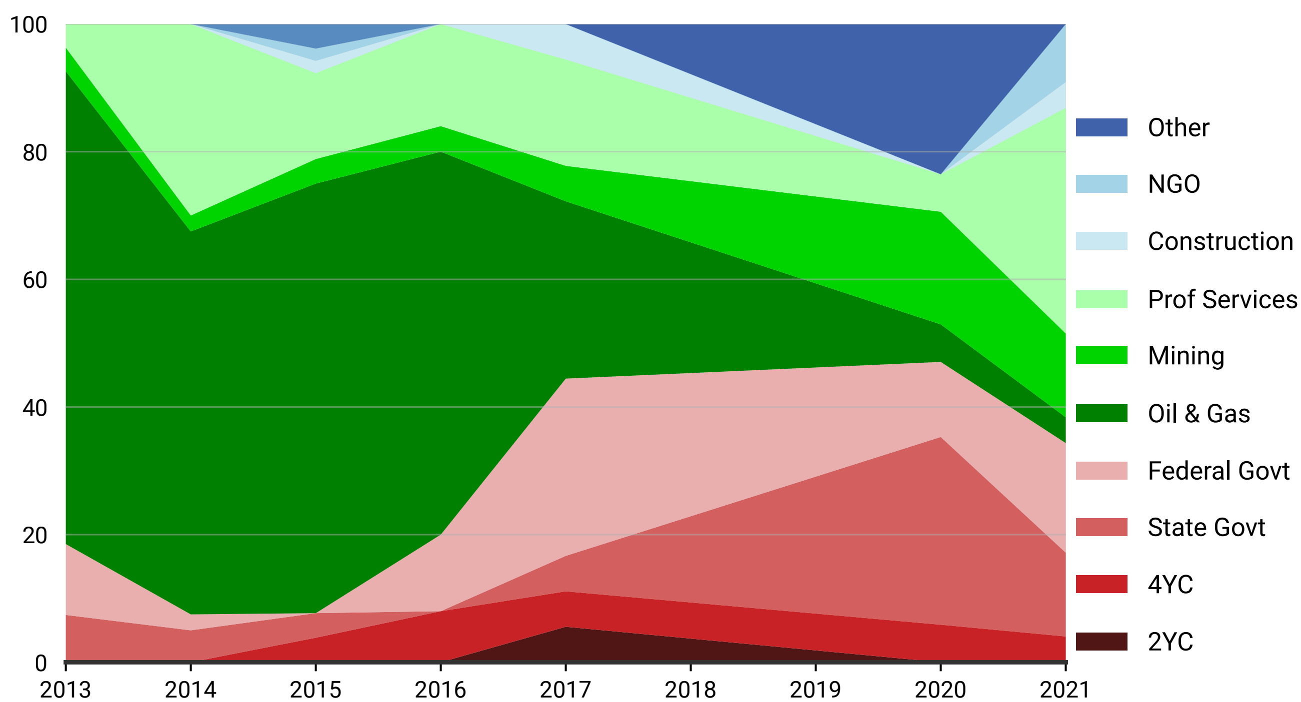
academic programs traditionally change much more slowly, resulting in part of this observed gap. A response to this critical skills gap by academia is needed, but, even so, there will still be a time lag before current and incoming students with these skills graduate.

The market itself adjusts rapidly to disequilibrium, and as a result of these people- and skills-supply gaps, jobs are being re-envisioned and workers are expected to bring substantially increased productivity to accommodate fewer colleagues sharing the burden.

While technology is helping to fill some of the labor gap, it has also disrupted traditional roles for geoscience graduates at several degree levels. A sharp shortage of people for technician and similar entry-level positions has created a strong employment draw on the bachelor's degree population, while the desperate need for highly skilled geoscientists in analytic and professional positions is driving a substantial increase in the expected skill level of new hires as they replace experienced workers. The labor market has changed faster than academic programs can adapt, and at all levels there are both a shortage of appropriately skilled individuals for available positions and a shortage of opportunities for graduates with comparatively traditional capabilities.

Traditionally, bachelor's level geoscience graduates who do not pursue advanced degrees have entered the professional services or state/local government employment sectors. Those with a master's degree, which is historically considered the default employment degree in Earth and atmospheric science, have tended to enter resource companies, professional services, or government (Figure 3.9a). Doctoral graduates have largely sought opportunities in federal research or academia (Figure 3.9b). This distribution of sectoral destinations is likely to experience sudden and frequent shifts in response to changing market needs. For example, for the graduating class of 2020–21, master's students saw a doubling in hiring by state governments driven by healthy budgets, and a tripling of hiring in the mining sector driven by demand to support the transition to electrification and sustainable energy (Figure 3.9a). Yet in 2021–22, state government hiring returned to normal levels, having effectively filled their structural demands, and hiring in mining dropped to only double their

Figure 3.9a: Employment Sector of Master's Graduates, 2013–2021
Percent of employed graduates



The employment destination of master's geoscience graduates in the U.S. continues to change as the dominance of the oil and gas industry wanes.
American Geosciences Institute. Source: Report on the Survey of Recent Geoscience Graduates 2021

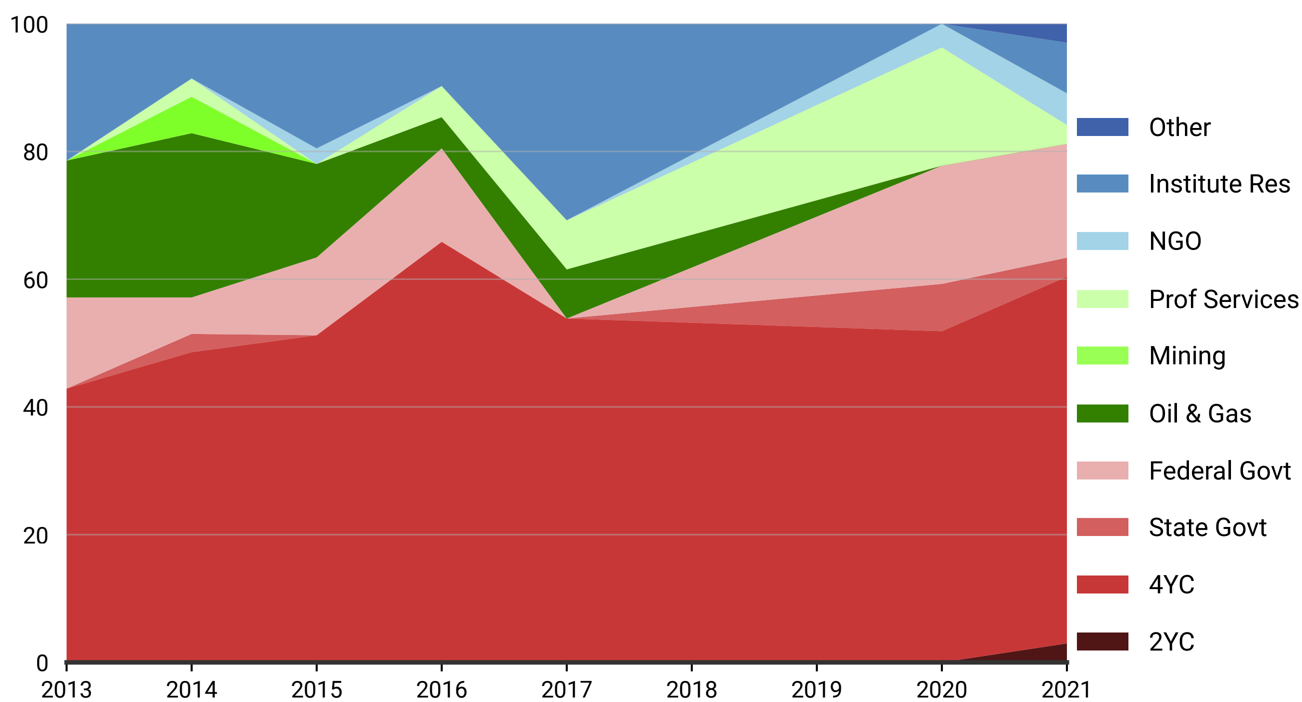
long-term hiring trend, as they reap the benefits of their prior aggressive hiring. These dynamic changes necessitate that graduate programs focus less on specific employment destinations but rather on fully developing with their students the portfolio of employer-sought skills, and nurturing the necessary creativity and intellectual flexibility to help today's students navigate a rapidly changing labor market. Students in geoscience sub-disciplines have a diversity of employment options (Figure 3.2).

Interestingly, another shift is occurring at the doctoral level concerning graduates' career paths (Figure 3.9b). Traditionally, most geoscience doctoral recipients immediately enter academia, postdoctoral research, or government research, with fewer joining the resources industry. However, starting in 2017, there has been an increase in doctoral recipients seeking and securing positions in the professional services. This sector had been reluctant to hire doctoral graduates due to concerns that these individuals might be overqualified, be under-stimulated, and eventually return to academia to pursue research careers. However, the need for higher-skill individuals has pushed more professional services firms to actively recruit at the doctoral level (Keane et al., 2022).

The change may also reflect an evolution of the role and view of the doctoral degree in the geosciences. Employers are seeking doctoral recipients as viable employees because they often graduate with a stronger technical skill base in using data and in data analytics than master's graduates. As seen in surveys of geoscience graduates by the American Geosciences Institute over the last several years, the skills differential between a bachelor's and master's has become narrower while the skills differential between a doctorate and a master's has grown substantially. Additionally, with increases in automation, more and more work in the geosciences is focused on higher level problem-solving and the shepherding of advanced technical and analytic techniques for which many of the doctoral graduates have exposure and experience.

However, these changes may not be entirely driven by the relative advanced skillfulness of doctoral graduates, but also by external pressures, which include the willingness of private sector employers to hire doctoral recipients given the lack of available and qualified bachelor's or

Figure 3.9b: Employment Sector of Doctorate Graduates, 2013–2021
Percent of employed graduates



Doctoral employment has seen recent increases in professional services, but higher education remains the single largest destination of new doctoral recipients in the United States.
American Geosciences Institute. Source: Report on the Survey of Recent Geoscience Graduates 2021

master's recipients, as well as a decline in the interest of doctoral recipients in pursuing academic careers because of the disruption and uncertainty within the academic sector, both related to the pandemic and to more recent pressures driven by the decline in college enrollments and the political pressures being applied to faculty and universities (Keane et al., 2022).

CULTURE OF HIRING AND EMPLOYING GEOSCIENTISTS

At the 2018 Geoscience workshop and the two 2022 combined academic and employer workshops, and from other survey responses of employers during this initiative, much discussion centered on hiring practices for different employer segments and sizes. A brief synopsis is given below.

In hiring, the relative weighting of specific skills depends on the job opportunity, the sector of geosciences, and the type of employer. The level of required competencies is important, but hiring often comes down to the very specific position being filled at the moment. In some cases, master's level skills are sufficient, and a doctorate is more than required. In choosing between a master's or doctoral level applicant, an important consideration is often which applicant's background is more appropriate for the position. Another is whether a doctoral graduate's focus area is overly specific and thus not as transferable as that of a master's student. Hiring at the master's level tends to be more holistic, and the specific topic of the master's research is less important. Doctoral hiring, by contrast, is driven more by technical expertise. Current hiring methodologies, and the need for specific extant skills and competencies, do not favor generalists. Hiring is frequently done by non-geoscientists, and especially with larger employers, algorithms may be used in initial screenings. In these cases, the use of well-selected keywords to describe one's expertise and skills is essential, as is addressing the specifically identified qualifications for the position.

Many employers also consider the long-term career potential of candidates. Is the employer more interested in someone who is solution oriented, technically capable and can carry out specific tasks, or someone who is integrative, thinks critically and has the potential for leadership and strategic vision? The depth and range of experience is generally higher with a doctoral graduate than a master's graduate, and that deeper experience level allows for earlier transitions to higher-level positions. As such, the doctorate brings potential for more rapid professional advancement. Even if the job advertisement requires a doctorate, other aspects of the position may result in the master's applicant being hired because they tick more boxes, especially if the position is highly skill focused. Some employers advertise for a set of skills, others for degree level, but documented experience can trump both.

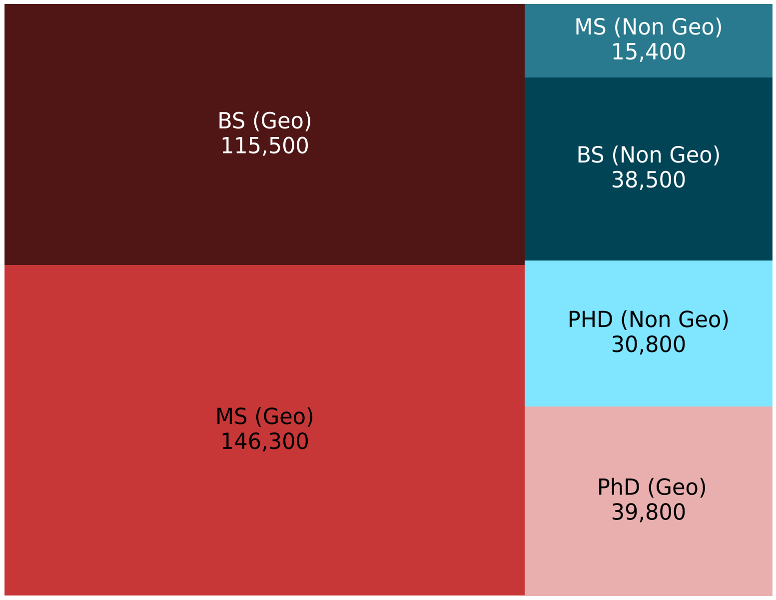
The participating organizations noted that there were differences between large and small employers, even within the same field. Larger organizations can afford to hire graduates with more specific skills and research experience, while smaller ones need employees with broader talents who can make an impact immediately across several responsibilities. Major large industries/corporations and academia can economically afford to hire doctoral graduates to think critically, creatively, and innovatively. For smaller and less capitalized organizations, this is often not an option, as every minute is money. That said, an increasing number of small firms have a single geoscientist, and doctoral graduates with good workforce skill sets are generally preferred in such positions.

State agencies who hire master's and bachelor's graduates are generally looking for more generalist research training with better "skills", and for people who can successfully work in a "political position." As such, students seeking such positions need networking and team skills, and the ability to communicate with land-owners and other invested parties.

National labs hire both master's and doctoral graduates. They expect incoming doctorates to have more research depth, but these individuals won't last if they can't work in teams, network, or bring in their own projects. At the master's level they are expected to have the appropriate research skills to do the work they are assigned but are not expected to bring in new projects or funding. National labs need to be able to respond to funding opportunities across a spectrum of domains and thus require more breadth than is required in academia. Specific skills needed include baseline competencies in laboratory skills (especially safety), being able to work collaboratively and in a self-guided way, people skills (e. g. being personable), time management, and possessing a "growth mindset."

Science divisions in federal agencies (e.g., NASA, NOAA, USGS) generally only hire doctorates, while other divisions hire people with other degree levels. Doctoral graduates are directly recruited for projects, and the skillset and content understanding are more critical than the actual degree. Even in federal agencies, however, doctoral-level science division employees are expected to generate their own funding as PIs within 3 years, which is why they prioritize doctoral applicants with leadership potential. NASA and NOAA attrition rates are very low (2%) compared to industry (10–12%).

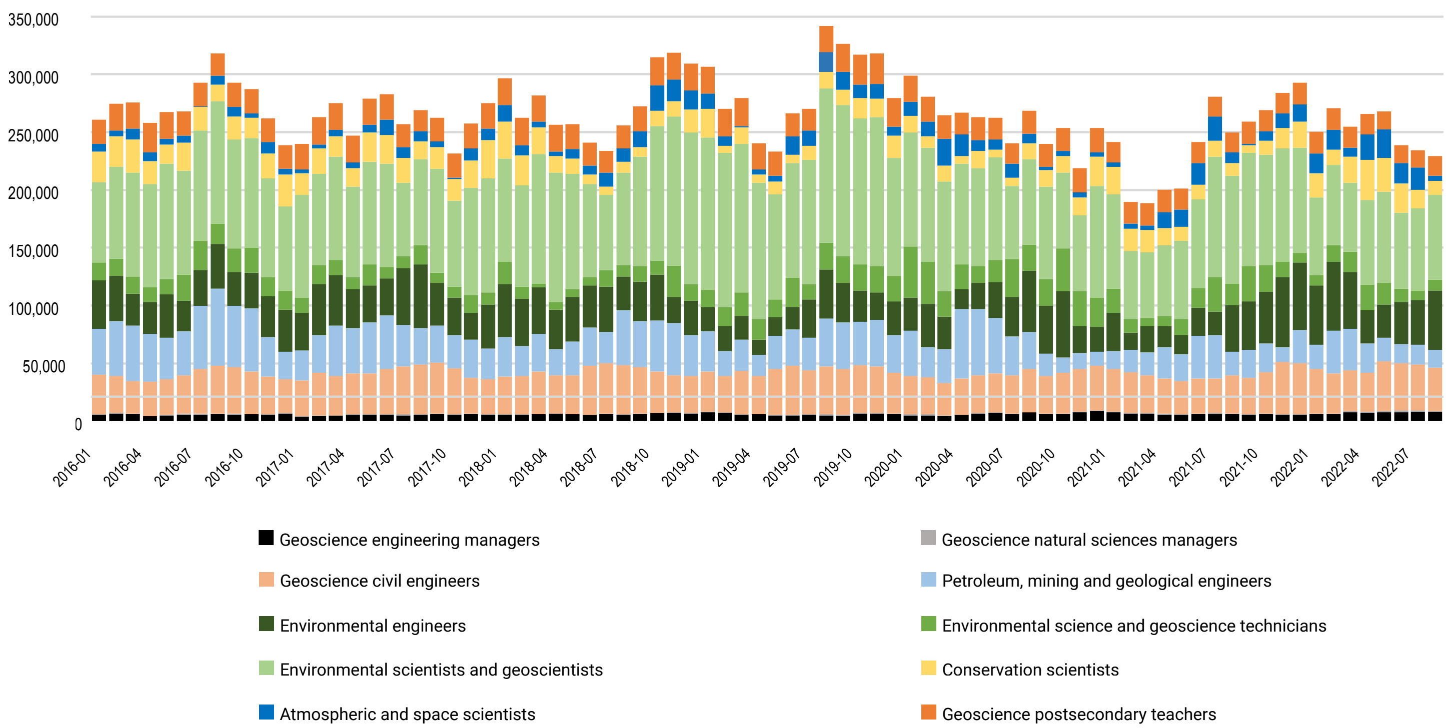
Figure 3.10: Terminal Degree of Working Geoscientists in the United States, 2017



Most working geoscientists in the U.S. have either a bachelor's or master's degree in the geosciences, but many also have non-geoscience terminal degrees.

American Geosciences Institute. Source: Status of the Geosciences, 2018

Figure 3.11: Monthly Geoscience Employment in the United States



Geoscience employment can fluctuate monthly based on primary activity of workers, seasonality of employment and overall economic conditions. As seen, geoscience faculty represented as "Geoscience postsecondary teachers" is consistently less than 10% of the total U.S. geoscience workforce, even though it is relatively stable in size.

American Geosciences Institute. Source: US Bureau of Labor

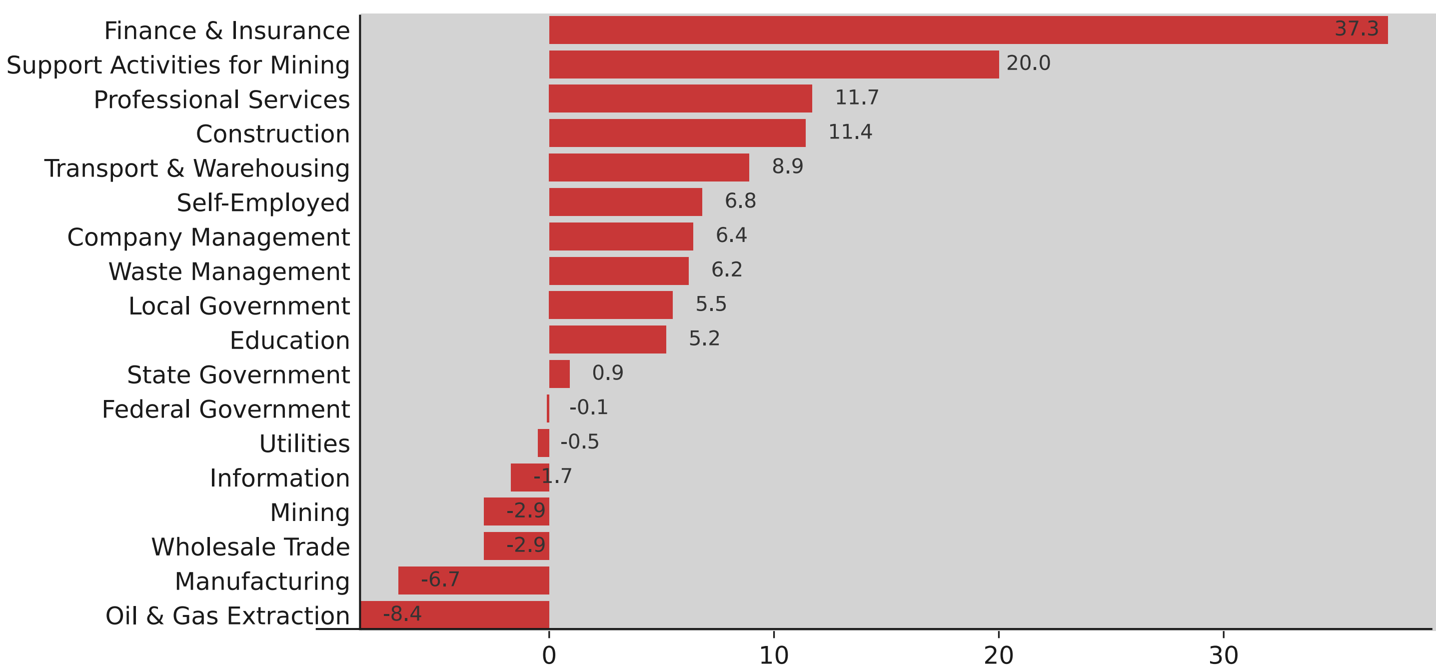
In professional services, employers also look for management skills, self-sufficiency, and non-technical skills (e.g., empathy, awareness, emotional intelligence, self-reflection). Proficiency is expected, but some of the necessary technical skills can be learned on the job.

Doctoral students applying for most faculty positions are expected to articulate their short- and long-term plans for research, and their philosophies on teaching, graduate supervision, mentoring and (more recently) diversity. Although for research-oriented faculty positions, their research and potential for publishing and grant success are critical, an increasing focus is now placed on other educational aspects of the position. The skills and competencies that help ensure success in business or industry are also valuable in the academic setting. Search committees are interested in the applicant's view of the department, and in what motivated them to choose their department over others. Non-tenure track positions for Professor of Practice or Instruction and Lecturers have become more common in academia, and candidates need to know what will be expected of them in such roles for success. In these cases, prior industry experience and well-developed professional skills may still be a positive.

THE WORKFORCE TODAY

The geoscience workforce in 2023, those whose work responsibilities include using geoscience knowledge and skills, in the United States comprises approximately 250,000 working professionals, of which 78% hold a terminal geoscience degree (Figure 3.10). Approximately 60% hold a graduate degree, with about 70% of those holding a terminal master's degree. Only 40,000 of approximately 70,000 doctoral geoscientists have their terminal degree in the geosciences. Overall geoscience employment over the 7 years has been relatively stable, although U.S. government data shows some seasonality driven by reporting methodologies (Figure 3.11).

Figure 3.12: Projected Change in Geoscience Labor Demand by Sector between 2018 and 2028
Percent change from 2018 levels



Many employment sectors for geoscientists are expected to grow through 2028 in the United States, with some of specific growth constituting shifting of geoscience jobs from specific industries to professional services.
American Geosciences Institute. Source: U.S. Bureau of Labor

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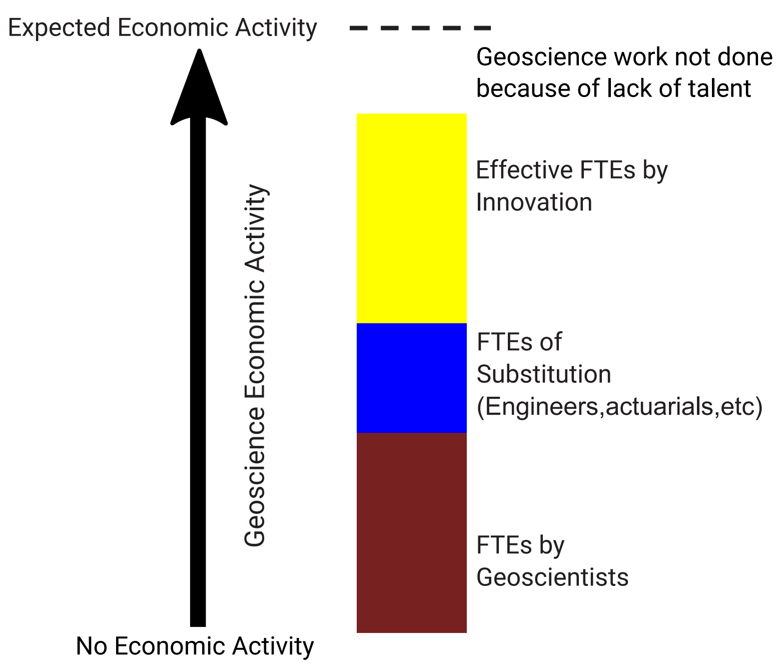
The COVID-19 pandemic led to a temporary plateau in total employment, helped because 88% of geoscience employers received some form of governmental aid such as Paycheck Protection Program (PPP) loans (Keane, 2022). These static employment levels stayed consistent from March 2020 to January 2021. However, over the subsequent four to five months, an estimated 100,000 geoscience workers were forced out of their jobs, largely due to the expiration of PPP loan protections. Despite this setback, the discipline has shown resilience as the nation began to recover from the pandemic, with employment rapidly bouncing back to around 250,000, indicating much of the churn was not structural but rather pent-up job changes during the hiring/firing restrictions of the PPP loans. One sector which has not seen recovery is the oil and gas industry, where total employment has decreased.

SPECIFIC PATTERNS OF SELECTED SECTORS

Though geoscientists work across almost all sectors of the economy, several sectors employ large numbers of geoscientists and help define the general destinations for new graduates. A major consideration is that individuals are not only less likely to work for a single employer for their entire career, they are also not likely to work in the same employment sector throughout their career. The skills and knowledge of well-educated geoscientists are highly transferable and, for agile workers, the ability to move across employment sectors is enhanced. Given the historic economic cycles that have plagued the geosciences, the nimbler our professionals are, the healthier the profession will remain. Building on core competencies and developing creative, innovative individuals who can continue to learn will lead to a future of resilient geoscientists.

The recent shifts in employment patterns underscore a continuing trend, where more than 90% of working geoscientists are employed outside academia (U.S. Bureau of Labor Statistics, 2023). When analyzing future workforce needs by industry, as projected by the US Bureau of Labor Statistics, sectors like professional services and finance are expected to expand significantly, beyond expected economic growth (Figure 3.12). Meanwhile, sectors like government and education are likely to see the total number of jobs remain steady, effectively shrinking relative to the overall economy. Additionally, the projection shows declines in employment by primary employers in the resource industries (e.g., mining, oil and gas) by 2028, but what this reflects is the shift of geoscience work to professional services companies (Figure 3.12).

Figure 3.13: **How Projected Labor Demand is Met**



Labor demand projections are based on expected economic activity and how much of that work an average person in that field can do in a year. To met that demand, you can have specialists, substitution by non-specialists, or innovation that improve the efficiency of workers. If the sum of those does not reach the projected demand, then total growth will be lower than expected.

Christopher Keane. American Geosciences Institute

An AGI 2021 survey of geoscience employers provides further insight into hiring and the wide net with which employers are seeking talent: approximately 72% of employers were hiring geoscientists at the bachelor's level, around 73% at the Master's level, and 50% at the doctoral level (Keane et al., 2022).

Professional Services

Traditionally, the geosciences have recognized the environmental and engineering consulting sector as a distinct and highly defined community. Through increasingly complex problems being addressed by these companies, industry consolidation, and changes in other sectors, this field has broadened and grown into one of professional service providers. Many of the consulting companies continue to provide their traditional services related to engineering and environmental issues, but others, including new entrants, are providing geoscience expertise to focus on highly defined but diverse problems brought by clients in all parts of the geosciences, including the Earth, Ocean, and Atmospheric Sciences.

This sector has particularly benefited from strategic shifts in the energy sector, where much geoscience work has been outsourced to these consulting firms. A portion of the growth in this sector is actual reallocation of positions that historically would have been in the energy sector but are now in these service companies, even though the work is the same. Thus this has driven a diversification of capabilities in the professional services sector, but also brought strong overall growth, with as of 2022, 42% (U.S. Bureau of Labor, 2023) of all geoscientists working in this sector.

Additionally, an increasing number of professional service companies are forming around developing advanced technologies with geoscience applications, from advanced data acquisition to machine learning methods in atmospheric science to lateral transfer of science across domains, such as the frontiers needing both earth and ocean sciences in deep-sea mining. Many of these ventures work closely with the highly capitalized industry players. But increasingly, the definition of domain scope between the science, technology, and entrepreneurial innovation is becoming less defined.

Based on AGI's Survey of Recent Geoscience Graduates, during 2020–21 there was a notable shift in the hiring patterns within the professional services sector (16% of all doctorates). This sector, which traditionally favored hiring bachelor's and master's degree graduates, witnessed a decline in its hiring at that level, possibly due to being outcompeted by aggressive hiring by the federal and state governments looking to replace retiring geotechnical staff. With the combined external competition at earlier educational levels and an increased need for high-skill labor, professional services firms have started to hire more at the doctoral level. Though the shrinking doctoral graduate pool in 2021–22 lessened hiring of doctorates into the sector, hiring at the master's level rebounded to consume nearly 33% of new graduates.

Raw Materials

We have observed a significant increase in graduate-level hiring within the broader raw materials sector, including the mining industry and state governments, particularly seeking those with master's degrees. The mining industry's growth can be attributed to increased economic activity in the raw materials sector as the economy works through its "energy transition" and ventures into new operational areas such as mining in extreme environments and activity in other parts of the material cycle such as recycling and waste recovery. Like the energy sector, the raw materials sector includes many professional services companies that are working on mineral and materials challenges, sometime in collaboration with mining companies and sometimes independently in different parts of the material cycle. Though the outlook for labor demand in the raw materials sector remains bullish, all resource sectors are highly vulnerable to cyclicity. Transferrable skills remain important, and with the addition of several sought-after skills in the raw materials sector, such as drone licensing and core professional skills to support social license efforts, these new mining geoscience professionals should be able to move between sectors more freely than prior generations.

Government

Large scale retirements at the federal and state levels, coupled with healthy budgets from pandemic stimulus funding, has led to an episode of accelerated hiring. Most recent hiring at the federal level has been at the bachelor's level to fill in geotechnical positions. But we see hiring of master's recipients at the state level, replacing recent retirements of more senior scientists. However, with the 2021–22 graduate employment data, we have seen both sectors moderate their hiring, potentially because they have satiated their immediate demands and will be returning to long-term replacement hires. The Department of Labor does not expect any absolute growth in government positions and with, as of 2023, looming budget challenges, this sector will likely not be returning to significant hiring in the foreseeable future (Figure 3.12).

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Energy

The energy sector has become a more complicated situation relative to the geosciences. With the movement from a fossil fuel-driven economy towards a materials-driven economy, many traditional oil and gas jobs in the geosciences have disappeared. But complicating this dynamic are new energy positions such as work on geothermal, wind and solar energy, carbon capture and even geoscience applications related to batteries and the material cycles for batteries. These new kinds of positions confirm that geoscience expertise is central to the energy sector, but the specifics and necessary skills and competencies are changing rapidly. Between 2013 and 2022 hiring of master's graduates in the oil and gas industry decreased from 72% to 4% (Figure 3.9a). Although the primary hiring may no longer be in the formal petroleum sector, there continue to be diverse employment opportunities for geoscience-related positions across energy applications.

One interesting outgrowth, especially for those coming from the energy sector, has been consistent hiring in "non-traditional" geoscience sectors. For example, from AGI's Survey of Recent Geoscience Graduates, the health care industry has consistently been hiring geophysics master's graduates, mostly in the medical imaging industry. Many of the skills and knowledge developed in geoscience graduate programs are highly transferable.

THE FORCES OF WORKFORCE CHANGE

Projections for future geoscience labor demand are built on two key assumptions: the growth rate of the overall economy, and that per-person productivity remains approximately the same. According to the U.S. Bureau of Labor Statistics, for the geosciences, labor demand is expected to grow slightly faster than the economy. Whether there will be supply to meet that demand both in terms of quantity and capabilities is a key question.

From an economic development perspective, a certain amount of labor is required to produce a given amount of work. Failure to reach that level of work results in unrealized economic activity. Meeting that amount of work in the geosciences, however, can happen both with actual geoscientists and professionals who can substitute in some of those applications, such as engineers or actuaries. But perhaps more importantly, innovation improves professional efficiency and can thus allow a single person to accomplish more work, reducing labor supply gaps (Figure 3.13). Innovation is a major factor in meeting labor needs, changing the traditional productivity curve of geoscientists from a 3% per year rate (Keane and Milling, 2003) to something as yet unquantified, but much higher.

Much of the innovation today is driven through data analytics and machine learning applications being applied to scientific and industrial activities. This shift to a data-centric workflow is profoundly impacting the geosciences and will define the future of work within the discipline. Conversely, these data-centric skills, as well as the increase in AI, are allowing geoscience graduates to obtain non-geoscience positions in other highly technical fields (e.g., information technology). It is interesting to note that of those with a terminal geoscience master's degree, 49.1% are working as a geoscientist and 76.3% in a science occupation. For geoscience doctoral graduates, 69.7% are working as a geoscientist and 87.9% are working in a science occupation (Keane et al., 2022). Not all of these in science occupations are in data or computationally intensive positions, however, the skills and competencies developed by geoscientists in graduate school are clearly applicable to other scientific endeavors.

Machine learning and artificial intelligence are not directly replacing the intellectual endeavor of geoscientists but are rather being applied to tackle the problem that scientists spend ≈80% of their working time identifying, cleaning, and preparing data and only ≈20% of their time analyzing data and generating useful insights and syntheses (Fell, 2018). Several industry initiatives have pursued using machine learning applications to reduce this 80/20 ratio so that geoscientists can spend substantially more time focused on doing science rather than on data manipulation. These efforts have yielded clear successes, both in building efficiencies as well as in automating large parts of the geologic analytic workflow, such as logging, surveying and interpretation (Fell, 2018) and have supplanted many middle-skill geoscience positions doing routine geologic evaluation in the field and in the lab. Today these processes are advanced enough to handle the classification of most routine geoscience information and are also sensitive enough to flag areas that deviate from expected norms which usually indicate points of geologic interest to be analyzed and evaluated by a geoscientist.

Several companies that have adopted these processes insist that they don't intend to replace geoscientists in the workforce. Instead, they aim to create an "augmented geoscientist" (Fell, 2018), following onto the ideas of Kobelius (2017) to use machine learning in computer programming as a strategy to better utilize the intellectual strengths of humans through the reduction of rote activity. The goal is to enable professional geoscientists to spend considerably more time addressing geoscience problems, using their creativity

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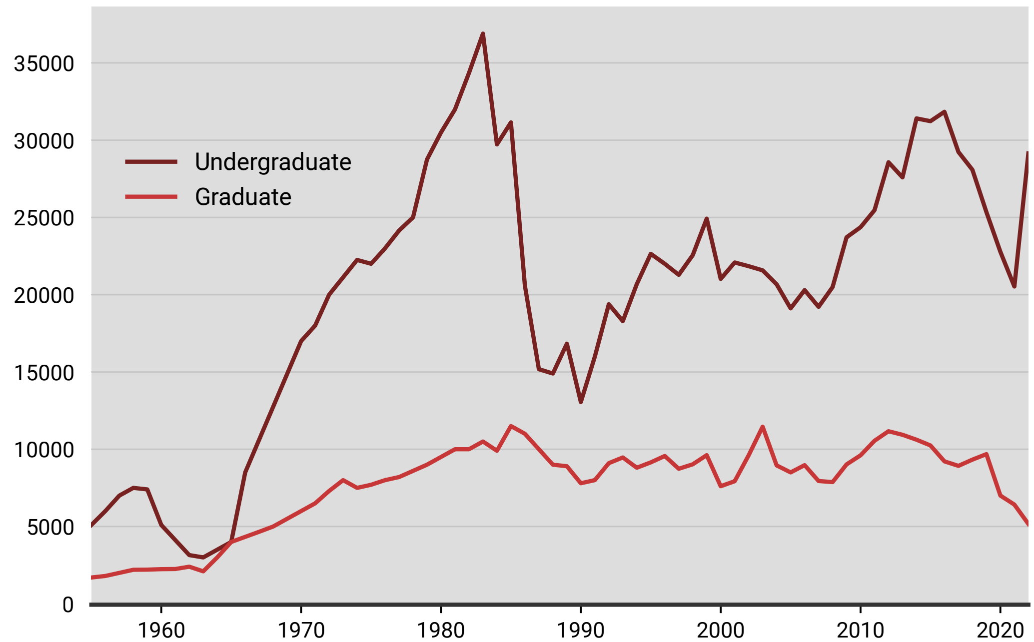
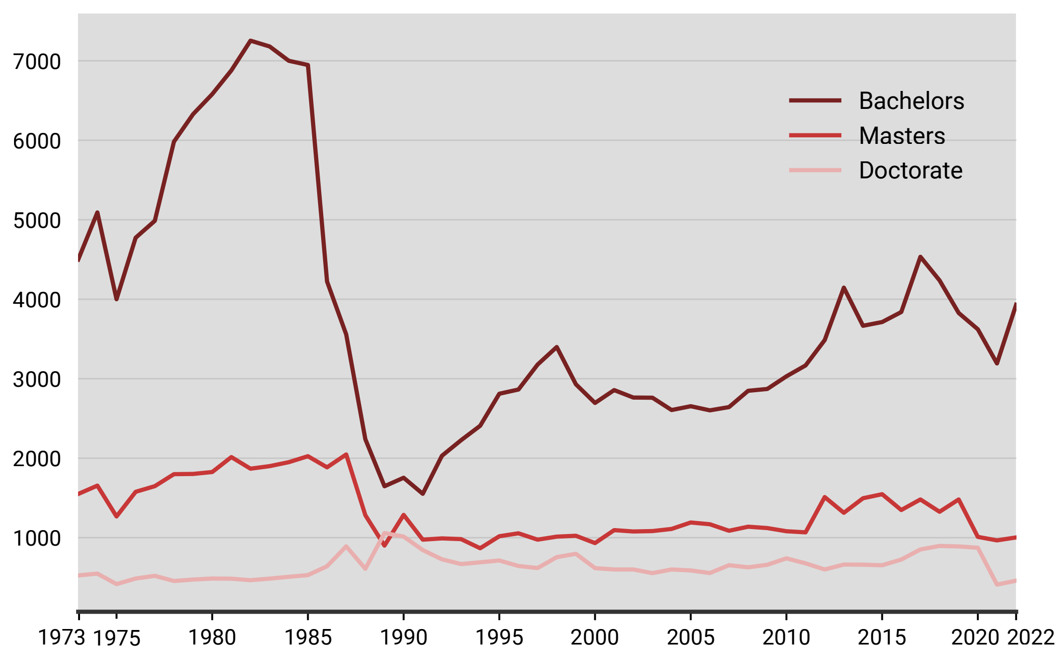
Figure 3.14a: Geoscience Enrollment in the United States, 1955–2022
Students enrolled



Historical timeline of enrollment by U.S. geoscience programs since 1955.
American Geosciences Institute. Source: AGI Directory of Geoscience Departments Survey 2023

Figure 3.14b: Geoscience Degrees Awarded in the United States, 1973–2022
Degrees awarded



Historical timeline of degrees awarded by U.S. geoscience programs since 1973.
American Geosciences Institute. Source: AGI Directory of Geoscience Departments Survey 2023

and scientific abilities to tackle the increasingly intricate issues that society encounters. This idea of "augmented" professionals is also growing rapidly in other fields. The rapid advances in AI applications are making this mainstream, through computing tools like GitHub Co-Pilot.

Another important change in the geoscience profession is the transition of the roles of geoscientists to becoming part of "solution teams". In the last fifty years geoscience work has transitioned from domain-specific specialists working independently to interdisciplinary collaborations in academia, and more recently to the formation in various industries of integrated teams of interdisciplinary professionals. The current trajectory is towards cultivating integrated professionals/individuals who possess a broad understanding of the geosciences and related areas, including engineering and business, while maintaining specific strengths in their technical area. They collaborate with other professionals who have complementary skills, enabling all team members to contribute to every facet of the problem. Numerous large geoscience employers have reported trying to move towards this new team model.

These changes are disrupting traditional models for labor in the geosciences, eliminating many mid-skill roles such as seismic and stratigraphic interpreters. The focus has shifted to individuals who are field and technical-oriented, especially in data collection and production, and to those focused on analysis and synthesis. This shift is leading to a new geoscience labor structure where geoscience expertise is applied to two specific aspects of the discipline (Keane and Wilson, 2018).

We are also witnessing systemic changes in the role of geoscientists within the economy. Traditionally, many geoscientists were employed in the resource sector, including oil, gas, minerals, and water, working for large companies that developed and managed these resources (Figure 3.9a). Today, the challenges are less about traditional resource discovery and more about the production, development, alternative sourcing, and stewardship of these resources with their hosting communities and the environment, leading to the application of geoscience expertise downstream.

Another expanding trend is the solitary geoscientist in the private sector. With the growth in environmental regulations and increased compliance expectations, coupled with market pressure for adherence to ESG (Environmental, Social, and Governance) goals, a growing number of corporations, particularly in manufacturing, finance, and infrastructure, are hiring individual geoscientists. These professionals are tasked with addressing a wide range of questions and fulfilling reporting requirements to meet these goals for their employers.

DYNAMICS OF THE LABOR SUPPLY CHAIN

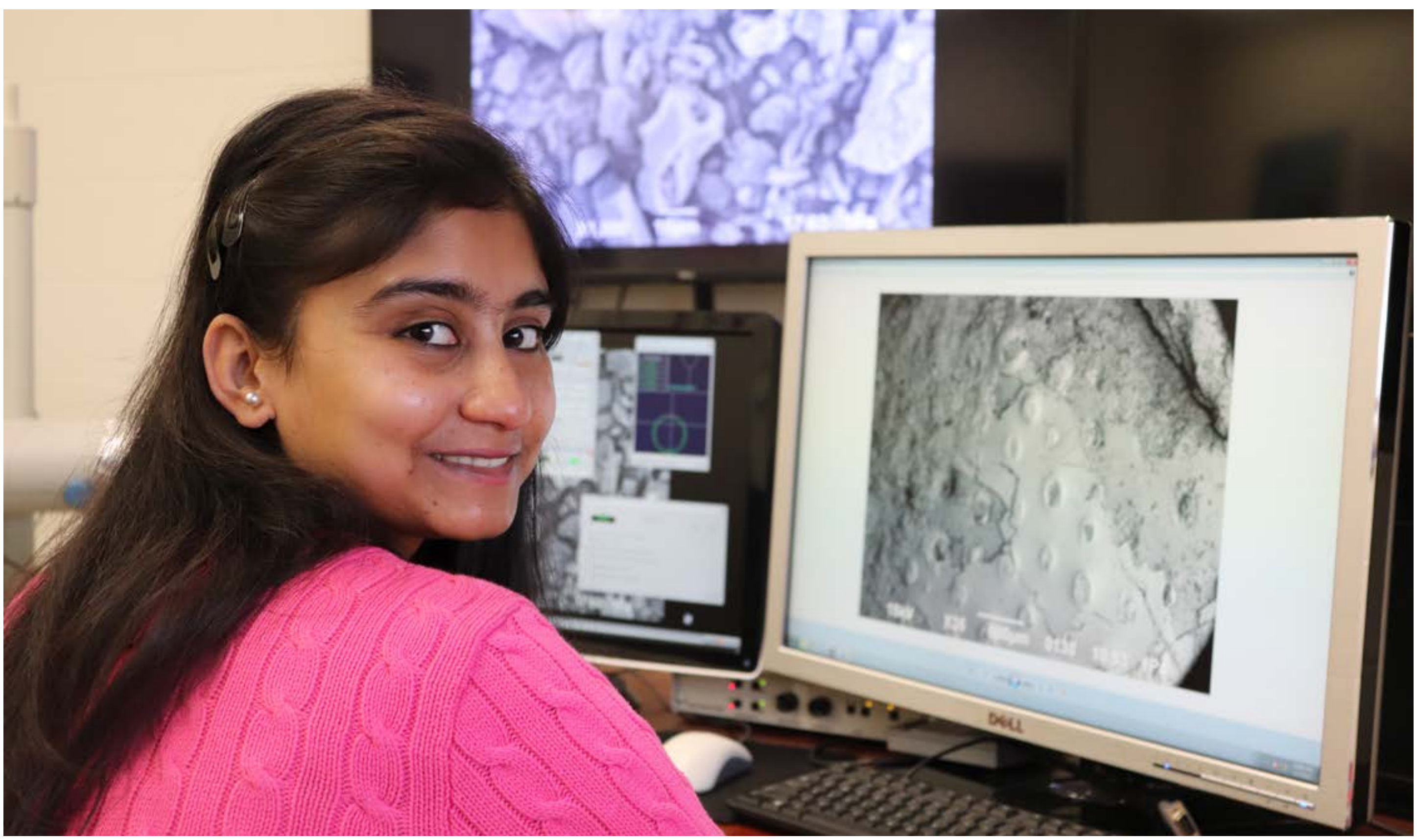
For the first time in nearly four decades, enrollment in geoscience graduate programs in the United States has decreased (Figure 3.14a). This reduction is partially due to the impact of the COVID-19 pandemic, but signs of a weakening in graduate school enrollments were evident as early as 2011. Since 1982, the geosciences had maintained a steady graduate enrollment around 10,000 students, which largely represented the functional carrying capacity of geoscience graduate education programs in the United States.

The decline in enrollment since 2018 has been significant, with only around 5,000 students currently enrolled in geoscience graduate programs as of 2022. According to department leadership in the AGI survey for the Directory of Geoscience Departments, distinguishing between master's and doctoral enrollments is challenging, as many students indicate intent to pursue the doctorate, as that improves the access to funding, but then may leave with a master's degree. The same survey shows that degrees awarded for master's and doctorates have been relatively steady for decades but decreased during the pandemic (Figure 3.14b). Between 2019–2022, master's degrees awarded dropped by 32.3% and doctoral degrees by 48.4%. The post-pandemic rebound in undergraduate enrollment and increase in degrees awarded (Figure 3.14a,b) may result in more graduate enrollment and degrees.

From the surveys of AGI's Impacts of COVID-19 on the Geoscience Enterprise project (NSF #2029570)(**https://covid19.americangeosciences.org**), another trend that has emerged since the start of the pandemic is that many geoscience programs have curtailed their intake of new graduate students as they grapple with how to successfully guide their current students, who may have faced delays due to the pandemic, to graduation. An ongoing steady output of degrees in an environment of decreasing enrollments (Figure 3.14a) suggests that the issue of delayed completion has been a major factor. Moreover, increasing numbers of programs are either choosing not to admit new students or are reducing the number of available spots due to financial uncertainties within the school and lower undergraduate enrollments, which has led to fewer available teaching assistantships.

Looking to the future, 10 years from now, if enrollments continue to decline and the need for geoscientists increases as predicted, what can be done to avoid a large employment gap — which is to say, how do we attract more students to the geosciences? Previously, geoscience employment largely followed oil and gas trends, but by 2005 it had decoupled. Geoscience employment is now being driven by new fields: our participating employers included those from the reinsurance industry, from tech companies, from remote sensing, construction firms, and a wide range of other earth, atmosphere, and ocean science employers. To effectively compete for graduate students, geoscience departments need to highlight how the geosciences allow students to participate in solutions to global and societal challenges. Jobs requiring geoscience skills won't go unfilled, but who gets hired into those jobs may not have the competencies that are needed for them, because they don't have geoscience degrees. We need to make sure the future workforce has geoscience expertise.

Courtesy of the Jackson School of Geosciences, University of Texas at Austin



Courtesy of the Jackson School of Geosciences, University of Texas at Austin

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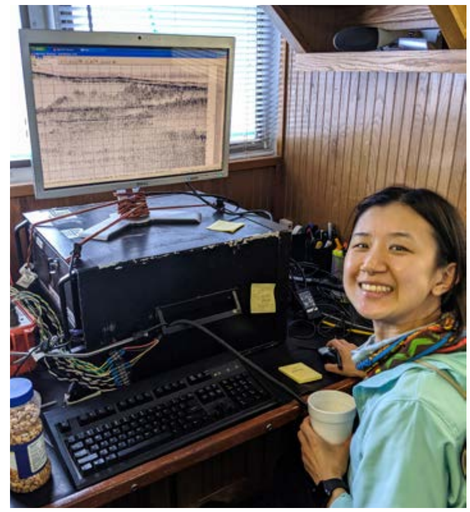
Section 4. Skills Framework

SKILLS & COMPETENCIES NEEDED BY GRADUATE STUDENTS IN EARTH, OCEAN, AND ATMOSPHERIC SCIENCES

The skills and competencies needed by doctoral and master's students to be successful in a wide variety of geoscience careers and how these have evolved and changed over the last 3–5 years are summarized below. These skills and competencies were first identified by employers, including industry, government, and academia as employers, at the 2018 Geoscience Employers Workshop. Academic leaders at the 2019 Summit agreed overall with the importance of these skills and competencies and focused on how to build their development into graduate programs. More depth was provided at the combined employer and academic workshops in 2022, where they also discussed what had changed over the last 3–4 years. In these workshops, the academics also provided input as employers. Supplementary input on changes since 2018 was provided by additional non-academic employers. Many of the identified skills and competencies are the same as recommended for undergraduate students. (See *Vision and Change in the Geosciences: The Future of Undergraduate Geoscience Education*; Mosher and Keane, 2021, referred to below as *Vision and Change* undergraduate report and/or effort.)



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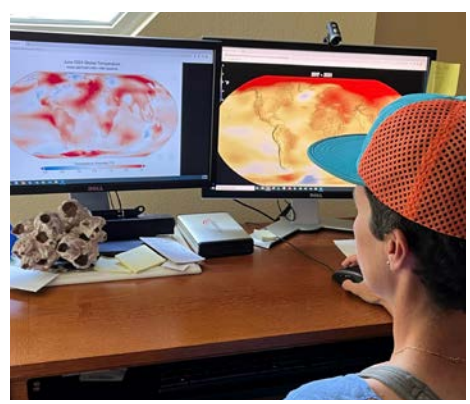
Employers and academic participants recognized that the skills needed for geoscience students are essentially the same regardless of education level, only the depth of competency increased from bachelor's to master's to doctorate degrees. In contrasting their expectations for graduate students relative to undergraduates, and for master's versus doctoral graduates, they distinguished exposure to a skill (discussed/highlighted in coursework with limited practice or application) from proficiency (a level of accomplishment developed through instruction and substantial practice), from mastery (deep accomplishment gained through independent use) and from expert (independent application of a skill and competency). In general, employer and academic expectations were that bachelor's would have exposure and be proficient in some skills; master's graduates would be proficient in most key skills, with evident mastery in one or more areas, while doctoral graduates should show mastery of key skills, with clear expertise in at least one core area. The skills and competencies discussed below (also see Box 4.1) can be developed during a student's graduate education through their research, coursework and co-curricular activities (see Section 5: Organizational Framework for Graduate Programs)



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BOX 4.1. UNIVERSAL SKILLS AND COMPETENCIES NEEDED BY GEOSCIENCE GRADUATE STUDENTS

1. The ability to conduct research
2. Depth of expertise in core areas
3. Critical, geoscientific, and systems thinking
4. Problem solving
5. Communication — to diverse audiences; written, verbal, listening
6. Quantitative skills
7. Computational skills — programming, coding
8. Data management and data analytics
9. Teamwork and collaboration
10. Social dynamics and people skills
11. Leadership
12. Project, program and time management, business skills
13. Ethics and science
14. Diversity, equity, inclusion, and justice
15. Broader impacts
16. Professional development
17. Networking
18. Personal skills

1. THE ABILITY TO CONDUCT RESEARCH

The participating employers and academics were unanimous in highlighting the importance of research in the graduate education of geoscientists. Employers want graduates who have done a deep dive into a geoscientific topic, through which they developed both an investigative mindset and a research toolkit they can apply to different projects. The successful conduct of research necessarily involves higher level critical thinking, identifying and solving problems, project management, and completion of a project. Other specific research-related skills discussed by employers included field, laboratory, and computational expertise. Field experience was seen as invaluable in providing real-world context for models and interpretations of data.

At the 2022 workshops, employers and academics discussed the value of conducting research versus developing specific skills. The overwhelming agreement was that conducting research is a skill itself. No mutual exclusivity exists between "skills" and research; they inform and rely upon one another. Research involves technical and non-technical skills and requires content knowledge and the capacity to extend that knowledge. Conducting research shows student motivation and the ability to think critically. For academic employers, conducting research is more important than developing a specific set of skills, while the opposite is generally true for industry and business.

Many research skills transfer readily to industry. Particularly useful in supporting this transfer is structuring research in a project-based style that includes the writing and vetting of a research proposal, project management, project boundaries in terms of scope and time, concrete project deliverables, and management of project costs, including time and labor. Gaining experience with this suite of project components is equally important as preparation for those going into academia or other research-oriented positions. Students need to demonstrate the ability to execute and complete a project, and to define the context of the project — what needs to be done and why — rather than just collecting and analyzing samples and making conclusions based on the results.

2. DEPTH OF EXPERTISE IN CORE AREAS

Graduating doctoral and master's students should have a deep understanding of the scientific fundamentals of their core research areas and the mechanics of the various techniques and methods they have used. This depth of expertise in their core disciplinary areas leads to both good judgment and professional confidence. The Earth, Ocean, and Atmospheric Sciences employers who took part in workshops and summit were unanimous in noting that graduates should be highly accomplished in the core technical skills of their areas of expertise. Potential employers expect doctoral graduates to be experts in their research area with specific specialized research skills, whereas master's students have the requisite skills and content in their core area. Overall, the employers agreed with the idea that the geoscience graduate students finishing in the 2019–2022 timeframe have very strong technical and research skills, including laboratory and field skills, with a solid base of knowledge in their areas of the geosciences.

Employers stressed the need for good foundational knowledge and skills, specifically a strong grounding in the geosciences with requisite breadth across the sciences, and for a solid coursework background in their chosen field, even if students had switched fields after their undergraduate degrees. They noted that many geoscience and science skills are valuable regardless of career choice, including non-geoscience careers. The basic knowledge and concepts associated with the geoscience disciplines provide a firm foundation for future use.

Geoscience education has an hourglass shape — undergraduates start as generalists, and then in graduate school develop narrow expertise. As professionals, graduates then broaden out, diversifying away from their original narrow area and use the expertise they have gained in graduate school to address a range of different problems.

When queried during our 2022 workshops, the participating employers noted that the desired foundational core competencies had not changed since 2018. Many of these core competencies depend on the career path, e.g., oil and gas, mining, environmental, oceanography, climatology, weather and meteorology, hydrology, etc. As the occupations of graduates change, most of the skills they needed for success in their original area were transferable to others. For example, expertise needed for oil and gas is the same as that for carbon capture and sequestration or for geothermal energy.

3. CRITICAL, GEOSCIENTIFIC, AND SYSTEMS THINKING

As highlighted in the *Vision and Change* undergraduate report, critical, geoscientific and systems thinking are seen as core competencies for geoscience graduates, at the bachelors, master's, or doctoral level. Critical thinking was identified as one of the two most important competencies, regardless of geoscience specialty or employer type. Graduate students need to be able to think logically, and to be pragmatic, open-minded and flexible in their thinking. They should be able to critically evaluate the literature and recognize credible sources. The expectation for finishing graduate students is that they be independent critical thinkers in their specialty areas. Doctoral students should be expert, creative critical thinkers, while master's students should show mastery.

Geoscientific thinking forms the basis of geologic reasoning and synthesis. Geoscientists need to think about processes on geologic and current timescales, on different physical scales and in three and four dimensions. Geologic processes occur instantaneously or over thousands to millions of years, and the age of geologic structures and features can span minutes to billions of years. 3D/4D and spatial visualization skills are necessary to understand and interpret structures and features in the Earth and in other planetary systems. The processes and features studied by geoscientists occur on the scale of atoms to that of the universe. Working across time and space requires the ability to think and work on multiple scales, and to understand non-linear behavior.

Employers agreed that competencies in systems thinking was essential for all types of systems, and finishing graduate students needed to be able to deal both with highly complex systems that have many interacting parts, as well as with the interactions among systems. They stressed the need to consider entire systems and recognize that any part in isolation may act differently than when considered within a system. Thus, it is important to start at the system level and evaluate the interactions, feedback, and limitations of its different parts. In solving problems, employers were looking for those who could look at and grasp the big picture first, then drill down to details evaluating the reinforcing and balancing processes, and then bring that information back up to the system level.

The Earth is a complex, non-linear, open, interactive, dynamic, coupled system. The interrogation and learning of atmospheric, ocean, and solid earth concepts provide a concrete framework for systems thinking. Graduates need to understand the processes that are acting in the different parts of the Earth system and the interactions between them. In addition, understanding the interconnections between the atmosphere, hydrosphere, lithosphere, pedosphere (Earth's surface), and biosphere (including humans) is essential for geoscientists. Graduates should be able to incorporate the human element and understand how human society impacts the Earth system, as well as how geoscience processes impact society. In some specialties, coupled solar system-Earth interactions are additionally important. The participating employers

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indicated that doctoral students should have achieved mastery, and master's students' proficiency, in knowing how the parts of the Earth system interact, work together as a system, the driving forces for change, and their effects.

4. PROBLEM SOLVING

Problem solving, also discussed in the *Vision and Change* undergraduate report, is the second important competency identified by employers regardless of specialty or employer type. The expectation was that finishing graduate students, particularly doctoral graduates, should not only be independent critical thinkers, but also adept in independent research, as self-sufficient, and self-motivated problem solvers. They should be able to identify and define problems, develop appropriate approaches to solving problems, and be able to apply those solutions. For both finishing undergraduate and graduate students, employers expected that they could understand the context of problems, identify the appropriate questions to ask, data to collect, and methods to use. They are expected to be able to collect those data, evaluate data quality, interpret the results, and make sensible predictions from limited data. Graduate students were expected to recognize gaps that need addressing and opportunities for new advances. Being flexible and able to adapt to changes, using different methods, or interdisciplinary approaches was seen as important.

The ability to distill important information quickly and accurately was seen as essential in new graduates. Central to research success is knowing where to find answers. Also, learning how to identify misinformation or disinformation and how to recognize trusted information is a necessary skillset for geoscience graduates. In addition, they need to learn how to articulate to others why specific information is trustworthy or not. Employers also said that knowing when to ask questions or request help was important, but that such asks should not be open ended. There is a balance between being independent and self-sufficient and requiring specific direction to accomplish a task. Knowing the right questions to ask, or bringing forward possible solutions or approaches for discussion, maintains that balance and fosters collaborative problem solving and innovation.

Finishing graduate students not only should be able to identify and define problems, but also develop and implement appropriate solutions with solid analysis and technical skills. It is important that they can define a sufficient solution to a problem, as opposed to only the precise and complete solution, and know which type of solution is needed or appropriate. In a workplace environment, there is often neither the time nor need to find comprehensive solutions, so it is critical to know whether the chosen solution is sufficient. The result should be the delivery of a product.

> "Screw the two decimal places! Just give me something I can make a decision with!"
>
> — Quote from government administrator about making a decision using scientific results.

Students also need to recognize that delays, errors, and failure is a normal part of research and should learn to minimize disappointment when things don't go as planned. Not all problems can be solved.

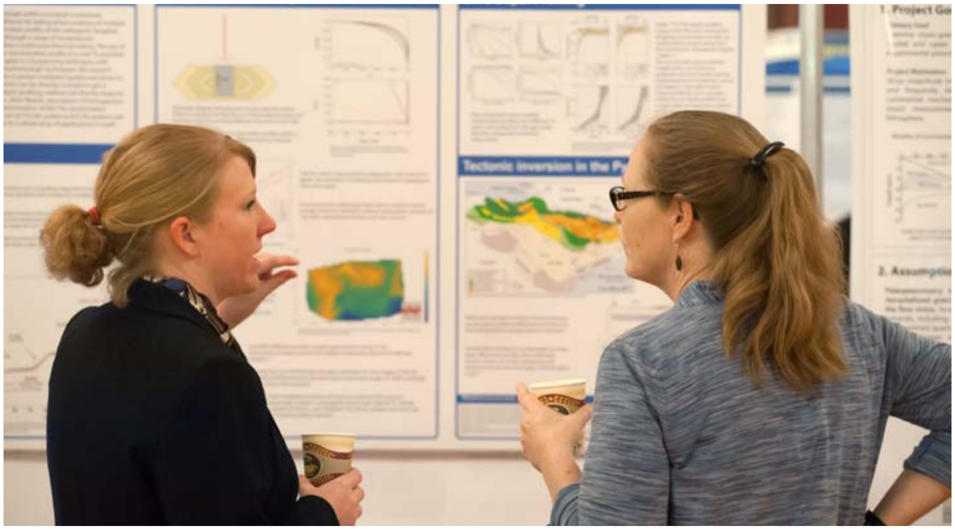
Employers pointed out that many finishing graduate students struggle with defining problems. Many also had difficulty after solving a problem in identifying how to apply a solution, another critical skill.

Employers found that recent graduates could readily solve problems that were given to them. However, the definition of problems and knowing what to do with the answers are skills expected of doctoral graduates and most master's students.

5. COMMUNICATION

Employers at our 2018 and 2022 workshops stressed the need for communication skills, similar to those expressed in the *Vision and Change* undergraduate report, but with an even greater emphasis on this need for graduate students. Effective communication was seen as vital, regardless of the profession, and it is a skill that geoscience employers generally find lacking in finishing graduate students. The inability to express technical content successfully, both in writing and verbally, to diverse audiences is seen as a common obstacle to success across the geoscience professions. Specific points that were emphasized include:

- Modify and tailor content and style of verbal and written communications to match audience.
- Express ideas accurately and logically.
- Be concise. Short one-to-two-page documents with bulleted lists are effective.
- Provide brief, compelling executive summaries with any written report. In many cases, this summary will be the only part read, though the rest may be used by those more directly involved in any implementations.
- Keep presentations to the allotted time.



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- For non-technical audiences, including public, policy makers, government officials, politicians, and the press, convey complex material in a simple way, without technical jargon or acronyms; make the key points without "dumbing down".

- If using slides or visual aids, it is important to maximize the impact of your work by making the data both visually appealing and accessible to all.

- Use colorblind-friendly color palettes, easy to read fonts, non-distracting backgrounds, and, if possible, closed captioning for those with hearing limitations.

- When presenting, provide a simple statement of what is shown on the slides; this helps audiences unfamiliar with the subject or when slides are hard to read (e.g., this graph plotting temperature versus depth shows…).

- For effective posters, organize the layout and create an attractive visual appearance; this can play as large a role as the science presented.

For an audience in one's own specialty or in related science fields, one can assume a certain amount of background knowledge. But for engineers and other non-geoscience technical personnel, or for upper-level audiences, such as CEOs, managers, upper administration and/or sponsors, explaining the purpose of the science should be the focus. Whatever background or data that is required needs to be provided concisely. In many situations, being able to effectively communicate the societal and/or financial impacts of a problem or project is just as important as presenting the science itself.

The employers in our 2018 and 2022 events emphasized that communicating across different disciplines, and even across different cultures, has become increasingly important in geoscience professions. The ability to work and collaborate with social scientists is a growing need as geoscientists are involved in addressing significant societal issues and problems. In many cases, social and environmental/geological problems are entangled, and knowing the history surrounding the issue and the science is imperative. Also, in today's global world, being able to effectively communicate with people whose first language is not English is also necessary.

Developing editing skills to both critically evaluate and revise written work, and to accept and use criticism of their own work is important. Graduate students need to learn how to respond to arbitrary and negative feedback.

The combined employer and academic workshops in 2022 highlighted the need for students to learn how to write short, polite professional emails, in addition to cover letters. They also discussed the growing need for knowing how to use social media effectively, including writing blogs, generating videos, and using other digital outlets (e.g., YouTube, Instagram, Twitter/X, etc.). Part of working in social media is knowing how to deal with arbitrary critiques, trolls and negative reactions. Being able to effectively use different formats and platforms for communication has become increasingly important in the geosciences. Employers highlighted the importance of being aware of the professional impact of one's virtual presence, both on professional and personal media channels.

As in the *Vision and Change* undergraduate report, employers also stressed listening skills as a critical competency. Being sensitive to one's audience (i.e., reading the room), is important in gauging the appropriate level for effective communication, and in recognizing when one's audience is engaged and understands what is being said. Being attentive to what others say is important, both verbally and through facial expressions and body language. Listening carefully when questions are asked is especially important. Many presenters either don't listen or assume they know what the question will be and answer a different question than the one asked. If unsure, ask for clarification and/or confirmation from the questioner.

6. QUANTITATIVE SKILLS

Employers agreed that students entering graduate school should have competency in the basics of statistics and in higher-level math as undergraduates, including calculus, differential equations, and linear algebra. Particularly important is statistics, for communicating certainty. If not, they need to acquire these competencies in graduate school. The employers involved in the *Vision and Change* undergraduate effort had also strongly emphasized these high-level quantitative skills for undergraduates, with an emphasis on statistics. Depending on the type of employer, different higher mathematics competencies (i.e., differential equations, linear algebra and/or applied statistics) are the most needed. For example, differential equations are most important for those working with fluid flow, whereas linear algebra for working with complex multivariate systems to understand how they behave and how multiple variables and dependences between them can generate multiple solutions. Applied statistics is used in constructing and evaluating predictive models, including extremes, the probability of an event being more extreme that previously observed, which is important for weather, water, and climate (**https://www.atmos.albany.edu/facstaff/andrea/MindTheGap/MindTheGap2.html**)

7. COMPUTATIONAL SKILLS

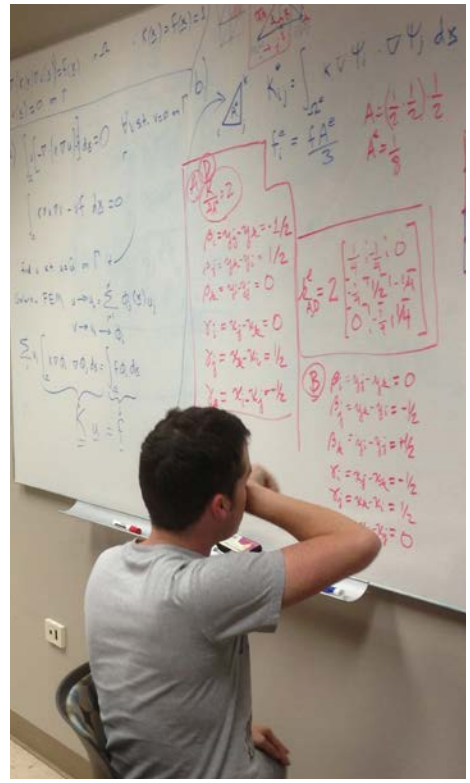
Computational and quantitative skills are essential within all types of geoscience employment, and in our 2018 and all 2022 workshops, employers stressed computational skills as necessary. At the 2018 Geoscience Employers Workshop, employers also discussed expected advances over the next ten years in these areas. Four years later, most of the advances discussed in 2018 (i.e., machine learning, robotics, blockchain, AI, and immersive virtual reality data exploration, and transition from supercomputing to cloud based, high performance computing - HPC) had occurred. By 2022, competency with machine learning was considered a mainstream need, and AI was on its way to being one as well. The post 2022 advent of ChatGPT, Bing AI Chat, and Google Bard AI clearly demonstrates AI's current and future importance.

Employers and academics at 2022 workshops all recognized that the professional importance of these digital skills had increased dramatically. The changes between 2018 and 2022 exemplify the rapid change in computational skills being employed by geoscientists, which are expected to continue, and highlight the need for the development of competencies in these areas. Many geoscience graduate students may find employment in dominantly computational occupations, but essentially all, regardless of employment, will need familiarity and some expertise with these digital skills.

By 2022, employers and academics at the combined workshops also agreed that in the geosciences today, the use of GIS (*geographic information systems*) for geospatial analytics, computer programing, quantitative analysis, and data handling and analysis is a necessity. Across all geoscience disciplines, graduate students need to be able to do statistical analyses and understand the correct statistical tools to apply for any specific problem.

> "Using GIS is more than making pretty maps! True geospatial analysis is required!"
>
> — 2022 workshop employer participant

At the 2018 Geoscience Employers workshop and the two 2022 workshops, employers across the spectrum stressed the need for all geoscience (and STEM) students to learn some basic programing in scripted languages and be able to code (a key skill), even if it is only simple scripting, logical algorithms, MatLab, Excel macros, or similar entryways into programming. The ability to translate older code to newer code and more effective systems was seen as important, as is being aware of different styles of programing and programming paradigm shifts (e.g., object-oriented vs. functional, compiled vs. interpreted). Familiarity with version control (e.g., Git, Github) to tracking and managing changes to software code, is important for data intensive disciplines, such as atmospheric sciences (see **https://www.atmos.albany.edu/facstaff/andrea/MindTheGap/MindTheGap2.html**)



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The ability to analyze algorithms and use R and/or Python has become critical with the increase in machine learning and AI. However, as programing languages change over time, understanding the basics of

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programming and problem-oriented logical thinking is the important competency. Students need technological versatility and some basic skills, but they don't need to be an expert in everything, as tools change over time. Students also need familiarity with informatics, the study of computational systems for data storage and retrieval.

Other desirable skills include being able to develop, analyze and evaluate computational models and to develop and use computer simulations to predict how a system or process performs under different conditions. Understanding how to upscale and downscale to connect models to reality and the uncertainty involved is also important.

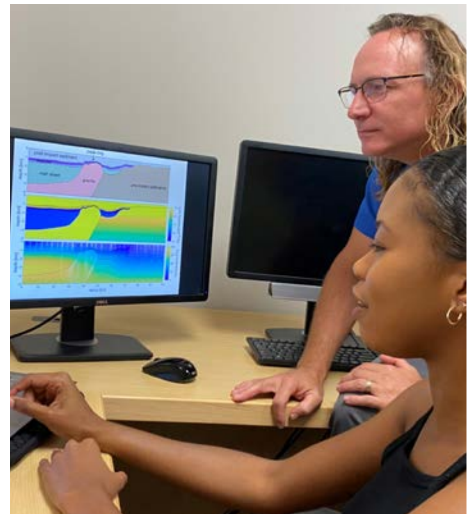
Master's students specifically need to have and demonstrate computational skills. Software skills are expected for many types of entry-level jobs today, with being able to write computer software a requirement, followed by understanding geosciences as context for that software. For doctoral and some master's students, many employers are interested in those who have embraced technology as creators and could engage in genuine innovation. Having such skills is important as many geoscience employers said that they also hire non-geoscientists with some geoscience courses or background, because they have more experience and skills in computer science or engineering.

8. DATA MANAGEMENT AND DATA ANALYTICS

Employers across the geoscience spectrum strongly emphasized the critical and growing importance of data management and data analytics skills in all geoscience careers. In 2018, geoscience employers expected finishing graduate students to be familiar with data analytics, its applications, and with processes for using data. The depth expected at that time varied with employers and the geoscience discipline, but by 2022, the depth and type of these skills expected had grown markedly across all employment sectors. Employers agreed that skills in data analytics, data management and machine learning were now critical, and that skills in AI applications would become critical in the future.

This very strong emphasis on "big data" skills is a new development since the *Vision and Change* undergraduate effort (focused primarily on Earth sciences) and became more important in the eyes of all geoscience employers over the course of the current project. Behind this change is the growth in geoscience information collected through various kinds of sensors (airborne, satellite, land-based) which has expanded rapidly and to an overwhelming degree (Baumann et al., 2016; Guo, 2017). For the atmospheric and ocean sciences, modeling and big data has been a primary focus (Bauer et al., 2015; Brunet et al., 2023) and increases in computing capacity has meant greater private sector involvement in using their own modeling capability. With the AI revolution, the private sector is moving into the area of estimating the changes in the frequency and impact of damaging weather and climate events. The rapidly increasing amounts of available data and the rapid growth in computing power have made these skills necessary.

Graduate students need to learn to work with multiple large, complex datasets, with the skillsets to integrate and merge different types of data and information to solve complex geoscience problems. They need to be able to examine datasets to draw conclusions about the information within them, which may provide answers to the problem being addressed, as well as to other questions not yet defined.



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Regardless of their involvement in data collection and acquisition, it was seen as essential that graduates understand the processes. Datasets can be the result of observations, experiments, or simulations, or can be derived from combining and processing existing raw data. It has become important to understand the different sources and types of data, and to be able to assess data credibility. Graduates should understand how data were acquired (gathered, filtered, and cleaned) and/or manipulated (i.e., changed or altered to make it more readable and organized). They need to know how to evaluate data quality and be able to make effective use of data of different qualities.

Participants at the combined academic and employer workshops in 2022 stressed the importance of understanding how to work with and process large volumes of sensor data, and being able to interpret such data using spatial statistics (GIS, EarthChem, IODP data, geophysical data sets, Ocean Observing Initiatives (OOI) for cabled sea floor data; EARTHScope, volcano monitoring data), geoscience data that comes from a variety of perspectives (e.g., air, ground, underwater, etc.). To analyze and manage data effectively, graduates need

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to be proficient in synthesizing various types of data from these different perspectives. They should be familiar with the available tools for accessing, organizing, analyzing, and interpreting geoscience data. For atmospheric sciences, students need to understand the characteristics of these models including how subgrid scale processes may be parameterized.

Data analytics is an expanding field, and developing and learning new ways to manage, analyze and synthesize data will be needed. With a rapidly growing influx of new observations, data assimilation and sequential updating of model forecasts will become routine. Also crucial are the ability to model from data and know the limits of the modeling, and to create visualizations and/or simulations for display and exploration of data. Another skill of growing importance is understanding how to monetize data, or data valuation.

Finishing graduate students should be able to integrate diverse, interdisciplinary big datasets, access, store, and process data, use machine learning (e.g., auto-analyses of data), and be able to run and modify numerical models. They should also know how to visualize and display data, do data validation (QC data), be able to explain the data and connect it to the bigger picture. With the rapid advances in data analytics, machine learning and AI, the ability to keep up with new statistical methods and find reliable and relevant information are of growing importance. Geospatial analytical skills, spatial awareness, image analysis, data visualization, and geospatial reasoning, including statistical analysis of geospatial data, were also considered very important. Another key competency needed by graduates is knowing how to share the results of your data with different audiences and the broader community.

Looking ahead ten years, the 2022 workshop participants agreed with the continuing importance and advancement of data analytics, the ability to synthesize diverse datasets, and competencies in machine learning and AI applications. They predicted that AI would become dominant in the future. They also saw an increasing emphasis on data safety and security, as well as on GIS and geospatial analyses. Although many geoscience careers may focus primarily on addressing the larger science questions, having a good understanding and familiarity with data analytics, machine learning and AI is required to verify the validity of the conclusions.

9. TEAMWORK AND COLLABORATION

Teamwork and collaboration were extensively discussed in the 2018 and all 2022 workshops, substantially expanding on similar discussions during the *Vision and Change* undergraduate effort. Teamwork and collaboration with scientists and other professionals are common in the work environment, where diversity of thought, expertise, and abilities are considered essential. Employers agreed that finishing geoscience graduate students generally lacked experience in these areas and would benefit greatly from more exposure. The ability to work in groups towards a project goal is critical, and people skills are essential. Effective teamwork requires recognizing and valuing the skills and capabilities of the people on your team, as well as knowing one's own strengths and skills. Being able to manage conflict and to get others to work together is important as both a team leader and a team member.

Graduates need to be personally versatile and should be comfortable leading, following, accepting coaching, and taking directions. They should know how to work both collaboratively and alone — and be able to identify which approach is best for any specific problem, as well as understanding when innovation is acceptable and appropriate. Team leadership requires good interpersonal skills and the ability to empower experts on the team.

Skills that enable interdisciplinary and transdisciplinary collaborations are very important. Geoscientists are more and more frequently working across geoscience disciplines (earth, atmosphere, ocean) and across sciences, as well as

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across subdisciplines within geoscience fields. Working successfully with social scientists, economists, and other scientists and professionals is becoming more and more essential toward doing science with improved societal outcomes (National Science Foundation 2021). As well, collaboration with and across different types of institutional entities, such as government, industry, academia and the public is critical to solving global societal issues.

10. SOCIAL DYNAMICS AND PEOPLE SKILLS

People skills related to interpersonal and cross-cultural interactions are highly valued in the geoscience workplace. Employers indicated that finishing graduate students often show limited interpersonal and cross-cultural skills, which can become a barrier to their future success. Empathy and emotional intelligence allow for more successful communication and interaction.

An important skill for graduates is the ability to work with different types of people, including those with different specialties, abilities, experiences, and educational backgrounds. In addition, it is necessary to be able to work with different personalities, emotional makeup, and viewpoints, irrespective of one's affinity for or agreement with them. Personal opinions about an individual are irrelevant to professional conduct and cooperation. The employers contended that the vast majority of 'human dynamics' issues in a corporate environment arise from the inability to work with others who are different. In today's global workforce, understanding and being comfortable with people with different cultures and different languages is also very important. Understanding implicit bias, being aware of it in one's own experiences, and having the ability to overcome it is critical.

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> "95% of the issues in a corporate environment arise from the inability to work with others who are different."
>
> — Quote from business executive.

"Corporate" skills were also deemed to be very important; academia, industry, government and business all involve different work cultures and expectations as to acceptable behaviors. Knowing how to transition between these different institutional expectations is necessary for finishing graduate students and for those seeking collaboration with different institutional entities. For example, a required "corporate" skill is being able to distill down all that you have done to make it digestible and relevant to a CEO, manager, program director, client, or the public.

In 2022, employers and academics noted that since the pandemic, intrapersonal skills have become more important, including resilience and the ability to handle change and stressful situations. Remote work has become much more common and acceptable in the workplace, and with it the need for interpersonal interaction across different social modalities. A consequence is the loss of live interaction with coworkers, which requires learning new ways to communicate effectively and establish successful working relationships.

11. LEADERSHIP

Effective leaders define a vision for the future and inspire and motivate others to work towards that vision. It requires setting goals, communicating the purpose, identifying, and implementing a strategy, and being committed to the outcome. Successful leaders take responsibility for the outcomes, good or bad, and learn from mistakes and successes. They show empathy, cultivate interpersonal skills, and are good listeners, paying attention to those they are leading. To be effective, leaders need to be competent, have a passion for

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developing and growing potential talent, and appreciate the viewpoints and accomplishments of others. They need to solicit "out of the box" thinking, be open to new ideas, and take initiative and risks. Employers said that evidence of leadership abilities were generally lacking in their new geoscience employees, and strongly encouraged graduate programs to work with their students on developing these skills.

In general, only a few of these abilities are developed by the end of graduate school. However, making students aware of them, and of other important qualities of a good leader, is essential. For example, they should have a good set of values and principles and understand the need for integrity, authenticity, honesty, empathy, humility, and ethical behavior. They should seek to develop their communication skills, cultivate their ability to grow and help others grow, including both accepting and providing constructive feedback. They also need to understand themselves, assess their own gaps and weaknesses, and find ways to address them. All students need to be aware of the importance of diversity of thought, inclusive practices, and engaging and supporting diversity. Students also should be encouraged to try things outside their comfort zone and take risks, recognizing that learning from failure is as, if not more, valuable than from success.

Employers expected that master's' students should be aware of what it takes to be a good leader, and doctoral students to be proficient in some aspects of leadership. Leadership abilities are as essential in science and education as they are in business, public policy, and politics. Regardless of graduates' career directions, the ability to lead organizations, groups and/or teams is an important competency. Over the next ten years, employers and academics agreed that leaderships skills would grow in importance. As the geosciences play an increasing role in addressing societal issues, we need geoscientists in more leadership positions that may or may not be geoscience industries or organizations. The need for systemic development of leadership skills in the geosciences is evidenced by the limited levels of geoscience presence in terms of national leadership, especially relative to other STEMM fields.

12. PROJECT, PROGRAM AND TIME MANAGEMENT, BUSINESS SKILLS

Managing projects or programs is a critical career skill for success regardless of occupation and one geoscience employers often found lacking among new employees. Skills needed to manage programs are very similar to those needed for projects, but on a larger scale. Both require an understanding of the economics of geoscience work and some business acumen, including planning, operations, finance, and strategy, all integral for organizational success. They noted that two key limiting factors of geoscience graduates related to future success in managing projects and programs were poor communication and social skills. Innovation and entrepreneurship also play major roles in business success, but unlike in business and engineering departments, geoscience degree programs generally offer little training in these areas.

Overall, the participating employers thought that exposure to the basics of business and business operations and some improvement in student business skills were needed. For project and program management, only awareness was expected for master's' students, while doctoral students were expected to show proficiency or mastery.

Leadership, teambuilding, effective communication, professionalism (staying focused and not distracted), and understanding the importance of diversity of thought are all part of the process of effective project and program management. Those overseeing multidisciplinary projects need to be conversant with the different fields and capable of facilitating communication between participants.

Important management skills include being able to run effective meetings, including developing agendas; managing people, time, and resources; and obtaining funding for the project or program. Business skills include understanding budgets and project financials, accounting, and cash flow, economic, data-driven decision-making, risk analysis, and uncertainty quantification. It is critical to know the sources of geoscience funding, be they within the organization or external through grants and contracts, and what factors drive the decision-making process. Employers and academics also agreed on the need for awareness of time-value concepts, i.e., that money today is worth more than the same amount of money in the future.

Time management for oneself and one's team is critical, particularly given the fast pace in industry. Planning should be structured for different levels and time periods. Making a timeline for weekly, monthly or longer time periods for different aspects of one's project or work, followed by self-reporting, can keep a project on track for completion (e.g., using a GANTT chart). Learning to be efficient so that one spends most of one's time on important actions is very beneficial. Periodically evaluating time usage with a time management quadrant can be useful, as it allows one to see how much time gets spent on busy work such as answering emails, as opposed to meeting project deadlines or strategic thinking. During the pandemic, students and employees had more independence and had to learn to be more self-sufficient in terms of time management skills.

For many occupations, an awareness of policy and regulations, permitting requirements and procedures, and logistics is needed. These skills are usually learned during employment, but knowing how to read and understand policy, rules, regulations, and statutes are valuable skills for all finishing students. In consulting and in many government agencies, important skills include the writing of technical reports, scope of work or guidance documents to implement rules, reviewing such reports to determine if the work complies with the rules, and identifying how well the work was done.

13. ETHICS AND SCIENCE

Integral to being a scientist is understanding and practicing the scientific process, including observing, characterizing, understanding, modeling, simulating, predicting and verifying results. Employers overall expressed satisfaction with these competencies in their new doctoral and master's geoscience employees. Students also need to recognize that research integrity is essential, and understand plagiarism, self-plagiarism, proper attribution to true sources, and the ground rules for scientific citation and research.

Finishing graduate students should have a firm grounding in and mastery of personal and research ethics. Core values, such as having integrity and being trustworthy, honest, and fair, are critical. They need to know and abide by the rules of professional conduct and ethics.

Ethics has become more central to geoscience activities. Geoscientists need to work and co-design work with local communities. It is no longer considered appropriate to do "parachute science/projects", particularly using artificial intelligence (AI), without local input and discussion.

14. DIVERSITY, EQUITY, INCLUSION AND JUSTICE

In the 2022 workshops, employers and academics addressed the question of what competencies students need to be successful working with diversity, equity, inclusion (DEI) activities and environmental and social justice issues. The consensus was that students needed to be aware of the societal effects of geological decisions or hazards, such as water strategy, emerging contaminants, "social licensing" for mining, land use, and other issues of environmental justice, that can differentially impact those of different cultures, races, ethnicities, socio-economic statuses and/or countries. Students should develop an equity lens on the effects of their research activities. In their interpersonal relationships, they need to recognize language and cultural barriers, implicit bias and microaggressions. Also discussed was the ethics of increasingly open science, new forms of publishing, and co-production of knowledge.

15. BROADER IMPACTS

At the 2022 combined workshops, academics and employers discussed the importance of research having a purpose, often one with a societal component. The prevalent view expressed was that all finishing students should be cognizant of the broader impacts or societal connection of their research and any societal purposes of their results. Being able to recognize and communicate those impacts and the importance of their outcomes was considered critical, particularly at the doctoral level.

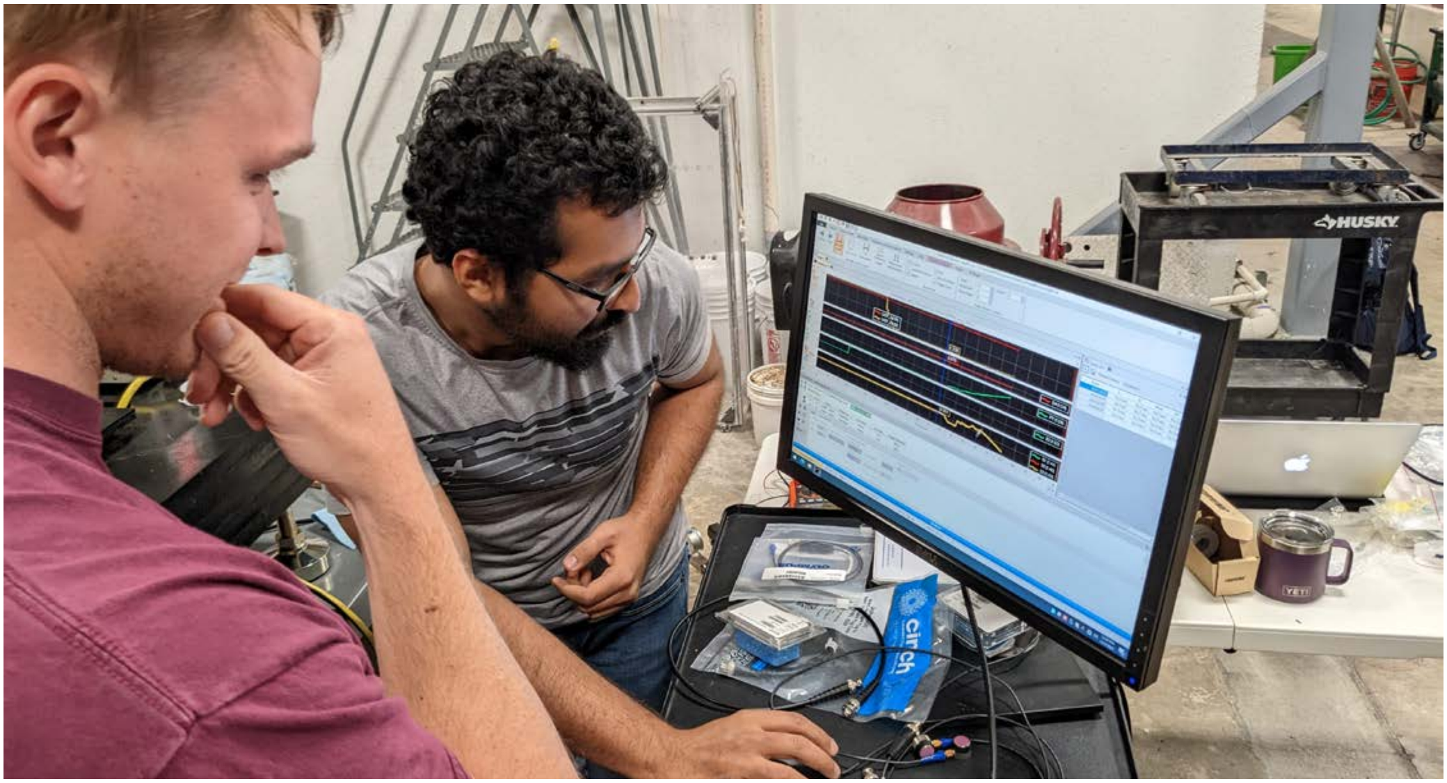
They recognized that the impacts of geoscience research and its applications continues to increase in importance on global and societal scales. Increasingly, robust and meaningful broader impacts are central to the role and purpose of many graduate student research projects. Research topics with application-driven questions are more readily linked back to broader impacts. Such research projects with defined broader impacts or societal meaning help attract students to the geosciences and build students' confidence in the importance of their work.

The geosciences, as a largely place-based science, requires a location-specific, local context for understanding the broader impacts of the science. This can be gained by listening to local cultures or communities. Some geoscience research (e.g., atmospheric, climate, and ocean sciences) may instead have global-scale broader impacts, and all societies, ecosystems and environments need to be considered, which requires a global perspective.

Employers said that recent graduates often struggle to understand the broader impact of their research and recognizing that research needs to have a purpose. Defining a research problem for impact leads to expanded opportunities. A finding in the physical sciences is usually not the end, but rather the societal outcome facilitated by that finding. Graduates also need to recognize the kinds of decisions that could be made using their findings.

16. PROFESSIONAL DEVELOPMENT

Professional development should be ongoing throughout a student's education and beyond. As discussed in Section



Courtesy of the Jackson School of Geosciences, University of Texas at Austin

5: Organizational Framework for Graduate Programs — Individual Development Plans, the use of Individual Development Plans (IDPs) can allow students to develop a roadmap and learn what skills, knowledge and competencies they need to acquire to achieve their desired employment. Professional geologist licensure (PG) is needed for some types of geoscience employment in many states. Specific coursework is generally a prerequisite to eligibility for the PG license.

Although helping students obtain employment after graduation is not the specific responsibility of geoscience departments, how successful your students are in obtaining meaningful in-discipline employment is a measure of programmatic success. To get employed, students need to know where to search for job openings, how to apply, and what information is needed on a resume, a cover letter or an application for different types of employment. Students benefit from help with interviewing skills, including how they need to prepare for online, phone or in person interviews, and experiences with typical questions that may be asked. Importantly, they also need to understand what is unique about their expertise, and how to market themselves effectively. Employers (including academics) when interviewing are looking for people with the ability to move up and transition within an organization. Learning about these opportunities in an organization and asking about them in an interview demonstrates a growth mindset.

17. NETWORKING

In 2022, employers and academics stressed that networking skills are essential to career progress. It involves being able to express interest in the work of others, ask intelligent questions, discuss issues constructively and present oneself effectively. Professional society participation was seen as one of the most effective networking processes, enabling career advancement and access to alternative contacts and information that are hard to obtain in other ways. Such participation also provides access to the forefront of knowledge in the field, and to the people developing that knowledge.

Students should have a prepared "elevator speech" — a brief statement of what they have accomplished in their research and why it is significant — to use in a variety of networking situations. They also should learn and practice networking, including what is and isn't effective and where to be or not be seen.

Also discussed was the increase in professional networking through social media (i.e., LinkedIn, ResearchGate, Slack, etc.) and the need to learn how to network effectively online. In addition, it was noted that how one appears on social media (one's virtual presence or brand) can affect one's ability to obtain and keep a job. Online networking is expected to grow and evolve, and as such our participants recommended more and better incorporation of online engagement as part of students' professional development. They also noted the need to develop a balance between digital and in-person interactions.

18. PERSONAL SKILLS

Personal traits and skills that are important for success were discussed by employers in 2018 and reinforced by employers and academics in 2022. Chief among these was the ability to learn. Students need to learn how to learn in graduate school so they can continue as life-long learners for the rest of their careers. A growth mindset, where you do things so you can learn, gradually improve, and apply, was viewed as a valuable trait. They felt graduate students should seek to become independent and well rounded, seeking out and scaffolding their professional and academic experiences to build confidence.

It was also noted that how people obtain and vet information is evolving, and that new graduates needed to know how to search for information electronically and through other means. Importantly, they also need to be able to critically assess the information they are obtaining.

Students should be ready for dynamic job experiences. They need a diverse and adaptable skillset with the potential for transfer and evolution. Being able to transfer their skills to different problems and situations was considered more important than having specific skills. Much of the discussion on this topic focused on the importance of overcoming fear of failure, and of adopting new technology to address major problems.

> "It isn't about having everything perfect; it is about getting something great done."
>
> — 2022 employer participant

Traits discussed above were reinforced during discussions of what kinds of students employers were likely to hire. Responses included: empathy and emotional intelligence for more successful communication and interaction with more people; versatility, adaptability, flexibility, agility, and being nimble were all stressed. Employers agreed that they look for those with a desire for excellence and an internal drive to do well. In addition, the need for awareness of risk and impact, and having a good grasp of uncertainty and the scalability over space and time were seen as critical. Geoscientists generally have excellent integration skills, and these skills should become well-developed during their graduate education. Employers are looking for future employees with an interest in the enterprise, who will step out of their comfort zones and demonstrate enthusiasm.

In 2022, several new issues arising from the impacts of the COVID-19 pandemic were addressed. It was felt that students needed to develop a healthy work/life balance as a component of their time management. Also, etiquette in virtual settings, such as focused participation in online meetings, turning on your camera, muting to exclude extraneous noise, and dressing professionally, had become issues of importance. Another issue discussed in 2018 and reinforced in 2022 was the need to establish a virtual presence or brand, and to develop awareness of the professional impacts of one's social media presence.

ADDITIONAL KEY SKILLS FOR ACADEMIC CAREERS

About half of geoscience doctoral students end up in academic careers (Figure 3.9b), in programs that range from small liberal arts colleges to large research-intensive universities. The skills and competencies needed in these careers, and to gain employment in different academic settings are similar, but with some distinct differences.

In seeking academic employment, evidence for academic currency is needed in terms of publications, innovative research, and depending on the position and institution, citations and grantsmanship. In teaching-intensive institutions like liberal arts colleges, documented experience in teaching and evidence for a scholarly approach to teaching are often expected. Once hired, regardless of institution, teaching and the application of effective pedagogies are necessary skills.

Courses and/or instruction in effective teaching methods are critically important for graduate students, and even those not ending up in academia will find these experiences useful. Actual experience in classrooms is important for those students wishing to continue in academia. Some geoscience graduate programs require, or strongly recommend, that all doctoral students serve as a teaching assistant for at least one semester, or during a summer session. Effective communication is critical to faculty for explaining their ideas and results from their research, as well as to teach in an impactful manner.

The skills listed by employers as important for non-academic employment are also needed by those who would become faculty. Critical thinking and research skills, including problem identification, problem solving, experimental (or project) design, data integration and synthesis are equally important in academic and non-academic jobs. Additionally, faculty need good interpersonal skills to be effective working with their students, as well as with their staff and faculty colleagues. The ability of faculty to work together and to positively interact with and educate students is central to program success. Toxic academic work environments result in the loss of students, the departure of staff and faculty, and even more serious problems. Faculty also need project and time management skills, as well as financial skills, including developing and managing budgets. These skills are generally related to grant and/or contract research and funding; however, becoming department chairs or heads, deans, professional society presidents, or members of society boards or councils all require a working understanding of budgets and organizational finance. For all of the latter, business acumen and being able to understand financials and budgets is imperative. Additionally, faculty who lead or are part of large research teams or projects need to be able to collaborate and work in a team environment. Teamwork among faculty colleagues builds strong departments and programs and benefits everyone.

Graduate programs should include a focus on ensuring that future faculty have the necessary skills and experience in these areas. In general, newer faculty are coming in with many of these skills and are better at collaboration. Many younger faculty have postdoctoral experience which has provided time for the additional development of their research skills, as well as experience in project management and budgeting. Graduate certificates in various topics including pedagogy, data analytics, machine learning, etc. can help document the skills attained. Faculty mentoring teams, especially for new faculty, are highly valuable.

SKILLS OF CURRENT FINISHING MASTER'S AND DOCTORAL STUDENTS

Employers at the 2018 Geoscience Employers Workshop, during the combined 2022 workshops, and based on additional input in 2020–21, discussed not only the skills that students needed, but also which skills students generally lacked. They discussed how these skills should be addressed during graduate school and how graduates could demonstrate to employers which skills they had attained.

Employers agreed that geoscience graduate students have great research skills and strong technical skills appropriate to their degree and research area. Their technological versatility was seen as lacking, however, though many had learned specific instrumentation skills that could be applied to other instruments for troubleshooting. It was also noted that these students were good at visualizing data, making observations to use in context to draw conclusions (a common field skill), and in writing reports. However, many graduates seemingly lack the ability to express technical content effectively, both in writing and verbally, to diverse and non-technical audiences.

Quantitative and computational skills, including collaborative coding skills and use of community code, were found lacking in most graduates, though some employers in 2022 noted improvements in these areas. The inability to work with large datasets ("Big Data") and to do data analysis and data analytics discussed in 2018 was still seen as an issue in 2022, though in some specialties graduates had more mastery. Additionally, most graduates lacked proficiency with coding, programming and newer technologies (e.g., machine learning; AI). Employers noted that although the programming languages were changing fast and which were needed depended on the type of work, learning any language was helpful in preparing students to learn other languages. These skills are the same ones noted by recent graduates as ones they wish they had gained in their education (Figure 3.6)

Some employers in 2022 noted that basic geospatial and GIS skills had permeated most geoscience fields, and they found that graduates' skills in these areas were generally well developed. Other employers highlighted a greater need for applied skills in GIS, geospatial analysis, statistical methods, and remote sensing, and questioned student understanding of the underlying principles. Many employers also felt that students needed more field experience, both because it grounds them in reality when they are working with computational models, remote sensing and large datasets, and because many jobs require skills involved in fieldwork.

A particular challenge for students (and faculty) is developing emotional intelligence (EQ) skills: empathy, self-awareness, self-management or regulation, social awareness, and relationship management. The collective competency of teams was deemed very important, and most students didn't have exposure to true teamwork during their education, wherein the team shares their experiences and knowledge to generate a collective approach to a task. Communication between individuals in a team is key, especially early in their careers, and helps to teach conflict resolution. Also, finishing geoscience students generally lack leadership versus team player adaptability (i.e., being interchangeable), which is also pivotal to team success. On the other hand, employers were concerned that few graduates seem to have developed the leadership abilities or the skills needed to become creators, innovators and entrepreneurs (see Section 5: Organizational Framework for Graduate Programs — Preparing Graduate Students to be Leaders, Innovators and Creators).

In completing their theses or dissertations, students acquire some project and time management skills. However, most non-academic jobs involve solving problems in much shorter time frames. Also, managing projects and/or programs requires business acumen, workplace skills, and in many cases intercultural skills which are not commonly developed in graduate school. Helping students learn how to manage time and projects has become more acute with the increase in remote work resulting from the pandemic, which made separating work and personal life more difficult. Coupled with always being available electronically, many students struggle with work-life balance, a skill which also will be needed after graduate school.

Skills that graduate students develop during their educations, such as creative problem solving, critical thinking, and project management need to be reinforced and fostered. Employers found that graduate students generally have all these skills to some extent, but don't recognize them and don't know how to market them.

Employers noted that defining the big picture relevance and societal importance ("who cares") of their work is often a challenge for geoscience graduates, even at the doctoral level. Students generally seem to have limited understanding of the societal, policy, or economic, broader impacts of their research. However, professional geoscientists typically occupy a critical position at that interface of science and policy. So, students need to know their subject, but also need to grasp and be able to communicate its relevance and what its broader impacts are to work effectively with clients and governmental agencies and regulators.

Perhaps the most concerning issue highlighted by the participating employers is that many finishing graduate students have difficulties defining the problems that need solving and identifying and applying solutions. This likely arises from students being recruited into grant-supported research efforts, where the problems have already been defined, and the work of many will be combined to develop solutions. Ways to address this issue are discussed in Section 6: Fostering and Implementing Change — Meeting Learning Outcomes.

Employers also noted that graduates generally don't have a clear understanding of the differences between being in academia and working in the private sector. They are unsure as to how they fit into the company and what the cultural expectations may be. Deadlines and accountability are different in corporate settings and being humble (occasionally) is necessary. Students also need to learn how to say no — in a nice way, acknowledging honestly when they are too busy to do something. New hires often lack the confidence to advocate for themselves and need to learn how to do this effectively. They need courage and confidence in the transportability of their skills and knowledge, and they need coaching and feedback in the early stages of their new jobs. They need to identify clear goals for themselves, and a plan to achieve them and become self-sufficient in their new professional roles.

The graduate program structure survey asked departments which skills they expected their graduates to have expert proficiency (see figure 3.5). Comparing the employers' expectations for master's and doctoral graduates with that of the departments, both have high expectations for critical thinking and problems solving, research skills, and communication to scientists. The high expectations by departments for data and statistical analysis, somewhat above field skills and experience, illustrates the increasing recognition by academia of the importance of data analytics. Departments have the lowest expectations for communication to non-scientists, computer programming (except for terminal master's), teaching, leadership, server-based database use and management, and technical writing, all of which are viewed as important by employers.

How graduate students can document their skills for employers was another question raised in workshop discussions. Employers agreed that having standalone courses listed on transcripts (i.e., technical writing, or data analytics) was good, as were stackable certificates and certifications from external courses, such as through professional societies. However, well-constructed resumes, interviews, and research products (e.g., papers, datasets codes, etc.) also can be used to demonstrate skills development. An e-portfolio or other kinds of professional development portfolios can provide a mechanism for demonstrating a student's learning and acquisition of skills over time. These measures of successful attainment are like those expressed by employers for bachelor's students in the *Vision and Change* undergraduate report.

Courtesy of the Jackson School of Geosciences, University of Texas at Austin

Section 5. Organizational Framework for Graduate Programs

INTEGRATION OF SKILLS AND COMPETENCIES INTO GRADUATE GEOSCIENCE EDUCATION

At **the 2019 Summit** of departmental heads, chairs and graduate program directors, there was an overall acceptance of the need to improve graduate geoscience education. After reviewing the recommendations of the 2018 Geoscience Employers Workshop, they concluded they needed to consider how to integrate the identified skills into graduate programs without losing their strong emphasis on research. Additionally, they thought that training and/or practice of many of the non-core skills could become part of programmatic cultures. The consensus was that each graduate program should identify their core learning outcomes for master's and doctoral students in terms of technical and non-technical skills and knowledge. These learning outcomes and their importance should be communicated to students early in their graduate careers, along with guidance on how to achieve them. In addition to informing graduate students where they can develop these skills, it is important for them to recognize when they have done so. For large graduate programs, individual research groups may have somewhat differing expectations, but each program should identify some overall baseline in terms of core skills and competencies.

Academic participants at the 2019 Summit identified where technical and nontechnical skills could be developed through research, coursework and co-curricular activities. These results, augmented by recommendations of participants at the 2022 combined academic and employer workshops and employers at the 2018 Employers Workshop, are presented below.

RESEARCH

The primary focus to best develop competencies was through research. Regardless of whether courses were required or what courses the program or institution offered, the one common feature among graduate programs and institutions is graduate student research. Disciplinary and technical knowledge and skills are already part of research programs. Depending on the specific research, these may include field, laboratory and/or computational skills. Many research projects today involve dealing with large datasets, requiring data analytics and data management. The 2019 participants recommended that skills related to big data, coding and scientific communication should be built into all theses and dissertations, something that had become common by 2022.

Courtesy of the Jackson School of Geosciences, University of Texas at Austin

Learning how to do research is non-trivial. The geosciences lends itself towards process-based thinking, and research teaches this skill. To solve problems, it is necessary to go deep into a topic and identify high level strategic takeaways. In conducting research, students get intensive practice, develop deeper expertise in core competencies, and become proficient in a range of technical skills.

A major part of research is critical thinking and problem solving. Students need to read and evaluate the literature and learn to identify reliable data sources. They learn to distill important information quickly and accurately and when to ask for help. They are required to analyze and evaluate their data and results, and characterize, manage, and communicate uncertainty. They also learn to think on different scales for both time and space and to further develop 3D and spatial visualization. Much research today is interdisciplinary or multidisciplinary, requiring collaboration, and involves Earth systems thinking.

During the research process, students need to formulate the questions to be addressed in their research. They should be encouraged to articulate why their research is significant, and to connect their work as appropriate to societally important problems and issues. They need to seek out and identify solutions and/or answers to the questions posed by their research. Learning to articulate the impact of research outcomes and translate these into a solution or application is an ideal end result.

In a perfect world, graduate research experiences should encompass all these steps. The academic participants recognized that many students are presented with research problems to address, and often do not fully understand the impact or significance of their research. Research results frequently do not answer the originally posed research questions, and often no specific solutions or applications are identified. Concerted efforts are required to ensure that all students are involved in the complete research process.

Graduate students typically get many opportunities for written and oral communication about their research. Theses and dissertations, publications, and grant proposals all provide students opportunities to learn to communicate in writing with other scientists, and conference presentations offer practice with oral interactions, all typically within the subdisciplinary field of the students' research.

Graduate students should also have practice writing about scientifically complicated material for different audiences. Students can practice by writing short summaries of papers they have read or talks they have heard, aimed at a general audience. Having students write press releases for their dissertation proposals and describing the results of their research before publications can help them express the societal impact of their research to diverse audiences along with additional practice for their written communication skills. The 2022 workshop participants recommended that students be encouraged to write about their research for different kinds of information platforms (i.e., social media, blogs) as well as for varied audiences.

Participants stressed that graduate students also need opportunities to give presentations to different audiences, both at professional conferences and to non-technical audiences in more informal settings where they can articulate the big picture in layman's terms. Having graduate students practice presenting 15-minute conference-style talks helps them learn to communicate concisely and effectively. Longer presentations to research groups, as part of department seminar activities, or to undergraduate classes also provide opportunities to practice oral communication to different audiences. More engagement of faculty and students in these activities where students develop communication skills is essential.

Graduate students also need practice giving short informal talks. It was recommended that students prepare "elevator speeches" about their research that they maintain and revise throughout their graduate career. They should be able to succinctly tell someone with little or no science background what they are doing for their research and why it is important in easily understandable language. There should be the opportunity for practice with these so students feel empowered to give them on any occasion. Another approach is for students to develop a 3-minute thesis presentation focused on presenting research succinctly to a general audience.

Many students write grant proposals to support their research (e.g., Geological Society of America — GSA or American Association of Petroleum Geologists — AAPG research grants, NSF graduate research fellowship program grants — GRFP; NASA and DOE fellowship grants), which requires them to develop a budget and project plan helping them learn project management and business skills. Investigating where is most appropriate to submit a proposal helps students develop an awareness of how research is funded. Additionally, they are required to explain the significance and broader impact of their research, another important skill needed in business and by academics. The 2019 participants suggested it would be valuable to incorporate a requirement for a project plan, budget, and statement of the broader research impacts in qualifying and/or comprehensive exams and thesis/dissertation proposals.

Organizational management skills can be developed as part of graduate research programs. Research or lab group meetings, and even teaching assistant meetings provide opportunities to learn how to run effective meetings. Students should all get the opportunity to set agendas, to manage meetings in terms of time, progress, and documentation, and to manage meeting discussions and keep them relevant to planned meeting topics. Those students working such groups also can learn teamwork, including people skills, conflict resolution, sensitivity to diversity, and how to integrate different ideas, methods, and approaches. Co-authoring papers further develops collaboration skills.

Aspects of project management and time management should be incorporated into dissertation and thesis research projects. Advisors should have their students outline the key project components and establish timelines for achieving specific goals, which should be reviewed and adjusted as needed during their research. Continually keeping track of short- and long-term accomplishments helps move the research toward completion, as well as providing experience with time and project management. One approach is scheduled progress reports back to advisors, doctoral committees and/or research groups. As an example, at weekly research group meetings each student can lay out what part of their semester goals they intend to accomplish in the next week and discuss outcomes from the previous week's results.

The 2019 and 2022 participants found the idea of a time management matrix to be a useful means for helping students, and themselves, recognize how they spent their time. The practice of consciously reviewing the activities one was actually undertaking, and assessing whether these were urgent, not urgent, important or not important, and then assaying how much was being spent on each category of activities/quadrant of the matrix was seen as a potentially valuable organizational tool for students as they become more self-directing in their research efforts. Also suggested was use of a GANTT chart that compares the planned timeframe of specific aspects of the research with the actual timeframe of completed work.

All graduate students should learn ethical research behavior and standards of practice during their master's or doctoral research. Those graduate students substantially supported by NSF (one month or more) are required to take Responsible and Ethical Conduct of Research (RECR) training offered by their institution. Advisors and committees should be intentional to make sure these issues are discussed with respect to the student's research and about research practice in general. A thorough discussion of the concept of co-authorship, of authorship order, and of the recognition of collaborators' contributions should occur early in the research process and be reiterated as timely and appropriate.

The 2022 workshop participants pointed out that in many research projects students develop skills that are applicable across a wide variety of future employment possibilities. Those involved in field research will likely learn about permitting and logistics, including budgeting, lodging, transportation, international regulations and requirements, and buying supplies and backup materials. Many students learn about experimental design, how to develop new techniques, and get experience running and repairing specialized equipment. Some get valuable experience in programming, software development, AI and machine learning. Doctoral students, and even some master's students, need to develop an understanding of how science is funded, about different types of research grants and other funding opportunities, and that to gain funding it is critical to demonstrate why your research is important. All of these prepare students for a successful career.

Another important aspect of conducting research is professional development, as it can foster personal growth, including the development of flexibility and adaptability. In research, students learn how to deal with failure and setbacks, how to normalize disappointment, how to handle delays and like challenges, how to accept feedback, and, importantly, how to persevere to completion. The peer review experience gives them the opportunity to receive and address constructive criticism and how to use such feedback effectively, which helps them build professional resilience. Opportunities to review papers for publications gives them practice and insight into the review process.

COURSEWORK

Graduate courses usually teach students core disciplinary knowledge that they either did not learn as an undergraduate or at a higher level. Such courses can also provide the opportunity to develop specific technical skills and are commonly directly applicable to their research. However, students should also consider (and their faculty should support and even encourage) taking courses that might be useful in a future career. Participants at the 2019 Summit agreed that programs should undertake deliberate planning and coordination of graduate coursework to include key competencies, including data analytics and management, coding, statistics, science communication and project management.

Employers felt that students having completed high-level graduate coursework was at times as important as research. They want to see evidence of students pushing themselves, trying new or different classes to learn new skills, and integrating what they learned in these into their research, using their own data in course-related activities and projects. The intersection of research and course-developed competencies underpins the transition to intentional learning, which generally comes with the completion of a doctoral program; for master's-level students it comes with time and professional experience.

Courses can be an effective way to develop competencies in problem solving. Case studies, either as parts of courses, or through a standalone problem-solving course, can provide additional opportunities at problem solving, and thus support what occurs through the students' research. Students should both identify the problems as well as the questions to be asked and be expected to find solutions and applications for the results. The shorter timeframes of course-related problem solving can be used to direct students toward seeking sufficient solutions rather than a complete solution, helping them recognize this difference which will be valuable in their future employment. They may get experience in analyzing and synthesizing data, characterizing, and communicating the uncertainty of their results, and making decisions. Requiring a short, concise written report and/or oral presentation gives them practice in communicating effectively. If the case study comprises an entire course, they can also be expected to write a proposal, set project boundaries, identify deliverables, define a budget, and manage the project. Commonly, industry partners or retirees will collaborate in such courses, either as advisors and instructors or as "judges" or mock clients to choose winning teams. Alternatively, co-op programs, where students alternate semesters (or months) in the classroom with working in industry, provide similar experiential learning.

Service-learning courses, as suggested by the 2019 Summit participants, require students to identify problems, find sufficient solutions, work as teams in diverse communities and communicate effectively with non-specialists. These courses allow students to practice professional behavior and help demonstrate the importance of broader impacts.

Courses are also a way to integrate teamwork into graduate education and can be especially important for students whose graduate research is not as part of a research team. Group projects that put together students with different backgrounds and skills help teach the importance of diversity. The teams need instruction on the expectations for team interactions. To be successful, teamwork skills require more than just group work or collaborations. Students need to work as a team, not divide the work up with each student only doing what they do best and having a single student merge the results. Using project management approaches, such as Agile methodology, for this process will expose students to a common business practice where a project is broken into phases, with teams following a continuous cycle of planning, executing, evaluation and improvement. This process will require them to manage conflict and use their diversity to achieve a better result. Teamwork-focused activities also help students with both project and time management skills.

Written and oral communication skills can be developed in all courses, as well as in communications-centric courses. To be successful, students need intentional instruction in effective communication, and must be given significant, formative feedback and opportunities for revision. Feedback from both the instructor and from peers is valuable, and peer review of writing often works better than faculty editing. ChatGPT and other AI can also provide feedback on written text instantaneously, which students can use to revise their work and learn writing skills. Many kinds of written documents can be incorporated into courses, including abstracts, literature-intensive term papers and one-pagers. These can explore topics unrelated to their research, or they can support what they need to do for their own research. One-pagers and abstracts require conciseness and careful organization. One-pagers can also allow students to practice writing for different audiences and experiment with different styles.

Coupling oral presentations in classes with required written work helps prepare students for presenting their research. With constructive feedback from their peers and instructors, they can learn how to visually display their data, interpretations, and conclusions, and how to effectively present their work concisely. Another approach is to give students the opportunity to teach, either pieces of a course, or potentially (as permitted by accreditation requirements) a full undergraduate class. Teaching experiences give students a better understanding of how to organize and convey information for a general, non-specialist audience, and how to engage them in discussions about the science, which is important for those going into academics.

Writing a proposal as part of a class project is useful in developing several important skills. Some faculty have students write an NSF-style proposal, while others emphasize shorter proposal templates, like an NSF Graduate Research Fellowship application, or the Geological Society

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of America research grant request. Irrespective of proposal format, the exercise has students identify a problem to solve, integrate data from the literature, and enunciate the broader societal impacts of the proposed work and its likely findings. Students are responsible for generating a budget and a project timeline, which helps develop business skills, and to discuss how they will communicate and disseminate their results. Proposal-writing experiences early in their graduate careers, related to a class or otherwise, greatly facilitates students' writing efforts in a thesis or dissertation, and helps them develop competitive grant proposals for their own research, so also benefits their research experience.

Many entering graduate students do not have a strong quantitative background, so stand-alone courses in geostatistics, geospatial statistics, mathematics for geoscientists (e.g., applied calculus, differential equations, and linear algebra), GIS and geospatial reasoning should be offered, and faculty advisors should encourage students to take these courses even if not directly related to their thesis.

Many programs offer courses on computer programing in a variety of languages (e.g., Python, R, MatLab, etc.), and/or on data analytics and data management. These courses are sometimes taught in other departments and have become very popular within geoscience graduate programs since the Geoscience Employer Workshop in 2018. The use of, and need for, these skills has permeated geoscience research such that many geoscience courses now include working with large databases on a wide variety of topics. For students who do not explicitly need these skills to complete their research, taking such courses gives them both an awareness of, and an opportunity for, basic practice of these skills and the potential to broaden their scope of expertise in valuable ways. The 2019 participants recommended that open and easily usable databases be built for students in all fields.

Business, commercial acumen and leadership competencies can be incorporated in existing courses such as economic geology, petroleum and mining geology, environmental geology, and hydrogeology. Among the institutions represented in our events, alumni, industry, and business school collaborators frequently work with geoscience faculty in teaching such courses.

> "Business courses helped, but real-world experiences — like visiting a mine to see the effects of mine tailings runoff in my economic geology course, or restored wetlands in hydrogeology had a powerful effect."
>
> — Quote from geology master's student employed as a lawyer for the Environmental Protection Agency (EPA)

If professional licensure is a professional expectation for graduates, then coursework that addresses those requirements should be offered (e.g., Practice of Geology Exam - PG, Certified Professional in Erosion and Sediment Control — CPESC, etc.). Some departments also offer industry-specific coursework (e.g., Applied Environmental Policy, 40-Hour HAZWOPER, Sustainability/ Circular Economy/Climate Change, etc.) or courses on reading and understanding local/state/federal regulations, rules, statutes and policies. The latter may also include practice in writing guidance documents to implement rules and scopes of work. Some departments are teaching a course about introduction to professional geoscience — the basics of business, licensing, budgeting etc., co-taught by faculty and local employers.

Participants in the 2022 workshops also recommended that departments require a course or experience for all first-year graduate students that introduces them to research and graduate school. Such courses develop cohorts, build community, and promote cross disciplinary networking. Discussing management skills early in the graduate program, such as communication, time and project management, coping strategies, and prioritization, helps with successful and timely completion of degrees. These first-year courses are also ideal places to discuss ethical responsibilities, authorship, plagiarism, DEI issues, and appropriate professional behavior. Another option is to hold one-hour workshops on non-technical skills; doing so will also help emphasize the importance of these skills. Programs that have such onboarding experiences, or courses, for new graduate students should consider having appropriate, experienced faculty members or external speakers discuss many of these topics, and invite other faculty to attend.

Alternatively, other courses should include direct discussion of professional ethics, standards of practice, and codes of conduct; it is important to ensure that students are exposed to these principles. Discussion of the value of diversity and need for equity, inclusion (DEI) and justice in science and the scientific workforce are also important. Students also should receive training related to problematic interpersonal behaviors, including implicit bias, microaggressions, and other kinds of behaviors that are unacceptable in the workplace.

Graduate programs can differ widely in their course requirements, depending on whether the focus is on master's or doctoral students, the kinds of backgrounds in their incoming student cohorts, and the employment outcomes of their students (i.e., is the program primarily a conduit

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to a specific employment sector). Courses are an important avenue for developing specific competencies, and faculty may find integrating skills development into existing courses to be easier than creating new courses.

CO-CURRICULAR ACTIVITIES

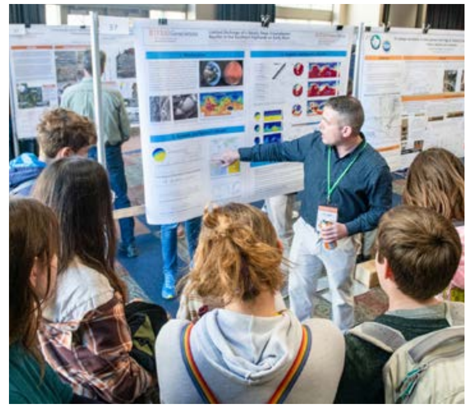
The 2019 academic and 2022 academic and employer participants explored many co-curricular activities that can help graduate students develop non-core research skills and recommended graduate programs encourage student participation. Various departmental activities, including clubs and outreach programs, professional organization activities, including local chapters of national organizations; internships, and other forms of public engagement provide opportunities for practice and growth of non-technical skills, such as leadership, management skills, and potentially entrepreneurship. Outreach efforts to high school or middle school students can provide practice in communicating science to non-specialists in a less stressful environment, and these experiences can encourage younger students to get involved with the geosciences. Optional field experiences, international experiences, and internships can also offer opportunities for personal growth.

These activities help develop interpersonal skills through working in teams with diverse groups. Such teamwork can strengthen students' ability to work with people with different backgrounds and from different cultures and provide them with hands-on experiences with conflict resolution. Volunteering and outreach allow students to give back to the community while building character and developing professional values and ethics. Such experiences can also help students identify broader impacts of their research or field of study. Many of these activities also provide opportunities to do non-technical writing for fliers, news articles or short reports and oral communication in presentations at science cafes, museums, brown bags and even competitions.

True teamwork skills can be developed in partnership with industry, agencies, and professional societies. For example, corporations and government agencies issue challenges or contests where teams of students compete. Scientific societies also have some team-based, cross-disciplinary, longer-term projects for student groups to work on together, also in competition with other student teams (e.g., AAPG's Imperial Barrel Award Program - IBA).

Providing a structure for interchange between graduate students who are developing business, communication, teamwork and leaderships skills, and their peers can broaden their classmates' perspectives. This can be accomplished through students giving presentations about their experiences in informal departmental seminars and for student organizations or in research group meetings. Another professional development mechanism for growth is peer mentoring, both as the mentor and as the mentee, and through informal faculty or staff mentoring.

Other opportunities for co-curricular activities are external to the department graduate programs and/or in conjunction with external individuals or groups. Short courses, online courses and 1-credit courses can be taken to develop a specific skill (e.g., PluralSite, Kahn Academy, LinkedIn Learning, edX, etc.). Usually, these focus on a technical skill that is valuable for future employment, such as HAZMAT training, or that is needed for their research but not offered in their department, such as data analytics. Some of these topics are better delivered in a shorter and more intensive format, and



Courtesy of the Jackson School of Geosciences, University of Texas at Austin

virtual delivery has become easier and readily available (e.g., videos on YouTube). Also available are short courses at professional society meetings (e.g., GSA, AGU, Earth Educators Rendezvous) on specialized software, modeling, teaching, and other technical subjects.

Other non-departmental courses, such as business courses or computer programming offerings, allow students to broaden their skill set in ways that are not possible within their department. Many universities now offer certificate programs or "badging" opportunities that provide students both with experience and with official recognition of their additional skills. Dual degrees are also an option (e.g., Moran, 2021; Moran et al., 2009).

External or institutional professional development workshops, courses, and related web resources (e.g., LinkedIn, Coursera, etc.) offer different types of training for students, faculty, and other professionals. Professional development opportunities include a wide range of topics: diversity, equity, and inclusion training; managing personal behavior; mentorship training for current and future faculty; training on standards of professional practice, conflict management, time management, and entrepreneurship; scientific writing, grant writing, scientific methods, ethics, and pedagogy. Many of these are offered or sponsored by professional scientific societies (e.g., American Geophysical Union — AGU, GSA, AGI, American Institute of Professional Geologists — AIPG, American Association for the Advancement of Science — AAAS, etc.). The National Association of State Boards of Geology (ASBOG) provides materials to help students pass the Fundamentals of Geology exam for those wishing to pursue professional licensure. Some academic programs require students to take this exam to become a Geologist-in-Training.

Many organizations and academic institutions offer communication courses or "presentation boot camps" both in person and online. Toastmasters International has a worldwide network of clubs that teach public speaking and leadership skills.

The National Association of Geoscience Teachers (NAGT) and other geoscience societies offer teacher training and/or teaching assistant training. Many universities have "centers for teaching excellence" that can provide similar training. The NAGT Earth Educators' Rendezvous offers a changing menu of professional development opportunities for geoscience students with interests in an academic career. The Science Education Resource Center (SERC: **https://serc.carleton.edu**) provides free access to a wealth of curricular material, training, and educational opportunities online.

Other websites offer information on the breadth of career tracks available for geoscientists, skills and competencies needed by students for career success, and for students' resources available on campus and through professional societies. AGI has developed a number of Career Compasses (**https://www.americangeosciences.org/workforce/compass**) for different geoscience professions that show paths for undergraduates, master's, and doctorate students.

PREPARING GEOSCIENCE GRADUATE STUDENTS TO BE LEADERS, INNOVATORS AND CREATORS

A concern expressed by geoscience employers across all employment sectors, including academia, was an overall lack of geoscience-focused leaders, innovators and creators compared to many other science and engineering fields. Overall, geoscientists are not developing breakthrough technologies, starting or leading companies, becoming entrepreneurs or becoming leaders in public policy. Lack of leadership has long plagued the geosciences, and this has in part led to it being marginalized as a science capable of addressing societal problems and as a discipline of importance in the education of both scientists and non-scientists. Our graduate students need greater ambitions and aspirations as our field becomes increasingly involved in addressing major societal challenges.

To address this concern, participants discussed the concept of a required first-year class for all incoming graduate students aimed at helping students understand and develop leadership and entrepreneurship competencies early in their academic careers. Lectures and interactive sessions given by external entrepreneurs or faculty with appropriate experience would introduce students to these ideas. Other ways to expose students to some of these competencies are to have non-faculty conduct or take part in classes on careers and applications, or to offer applied science courses that fully integrate all aspects of solving problems in a team environment. If none of these is feasible, other departments such as business and engineering may offer such courses and students should be encouraged to take them. Many such courses are also available online.

The geosciences and its applications, by their very nature, should lead to innovative thinking. Much innovation is the result of collaboration across different disciplines or subdisciplines, and the geosciences is highly interdisciplinary and even transdisciplinary. Dissertations that span more than one field or that involve collaborations with those in different fields can foster innovation. Innovation also occurs when making sense of or interpreting large datasets. Students should be encouraged to take ownership of their research and be willing to take risks and try things outside their comfort zone, where they are in control and taking responsibility. Such behavior leads to innovation and sets the stage for being an entrepreneur. Students should also be directed to write grant proposals where they must "sell their research" to potential funders, giving them practice in demonstrating why what they are proposing is innovative.

Unlike engineering, few geoscience departments maintain dedicated space for innovation and collaboration, such as a makerspace. However, many universities do. Encouraging students to get access and make use of such spaces and resources that are open across all fields helps promote cross-discipline collaborations, which would be beneficial.

Students learn from examples. Faculty should help to foster a culture of empathy and compassion, demonstrate ethical approaches, and exemplify other leadership traits, such as emotional intelligence (EQ skills) — self-awareness, self-management, social awareness, and relationship management. Discussing why these traits are important with their students would be beneficial.

Once students learn what makes a good leader, they can better develop the needed interpersonal skills and can seek out leadership activities. For example, they can mentor undergraduates or less senior graduate students with different levels of support or independence. Participation in departmental activities and organizations provides experience and exposure to leaderships roles and are also good ways to build these skills. Students could have many leadership opportunities (running the seminar series, other informal opportunities) during their graduate career that they can tout those in their resumes. Teaching is also intrinsically an effective leadership opportunity.

Faculty should encourage community involvement or interactions outside their discipline (general public, stakeholders, K–12 students/teachers, their alumni institutions) as a way for students to practice working with others and experience different forms of leadership. Working with social scientists and taking solution-oriented approaches to problems also helps students develop communication skills needed to lead; they must make the science relatable and show how the project or problem and solution has importance locally or to at specific group. They must demonstrate a vision and a plan for execution, especially if they also are seeking funding for the project.

Teamwork also promotes collaboration and provides opportunities for professional growth where students must take charge as a leader and also be a follower. Developing good interpersonal skills is necessary for effective teamwork. Students will learn from experience the importance of valuing diversity and inclusive practices. They also will discover the importance of collective competency of a team - it is not necessarily best to have figured something out all by yourself, but instead to have a team effort that uses the strengths of all involved.

INDIVIDUAL DEVELOPMENT PLANS

Individual Development Plans (IDPs) provide a proven mechanism for developing a customized roadmap for professional training and goals. A 2005 Sigma Xi Postdoc survey of U.S. postdoctoral scholars showed that postdoctoral scholars who created a written career plan or IDP with their mentors were 23% more likely to submit papers, 30% more likely to publish first-authored papers, and 25% less likely to report that their mentor did not meet initial expectations (Davis, 2009). A consensus has emerged that IDPs are also a helpful and important exercise for graduate students.

The 2019 Summit participants embraced the use of IDPs, and by the 2022 workshops, many departments had already implemented them. AAAS offers an IDP model and roadmap (**https://myidp.sciencecareers.org/**) that had largely been used for postdoctoral fellows and many universities have adopted similar roadmaps (see Appendices A & B for an example). As of 2023, NSF is instituting a new requirement for substantially-funded graduate students and postdocs (one person month or more) to develop and annually update individual development plans.

Ideally, students should establish an individual development plan early in their graduate career with the help of their advisor and/or other mentors. To develop their own IDPs, students first need to be able to recognize and assess the suite of skills that they currently have. Suggested skill areas to consider include research, professional time management, and interpersonal, management and leadership skills. Next, they are asked about their career aspirations: specifically, what career pathways are of interest, what do they like to do, and what do they value in their work environment? Students should then investigate and be provided guidance as to the skills, competencies, and knowledge needed for success in different geoscience careers, the likely work environments, and what is involved in the different careers. Students and mentors should use the skills recommended by employers and academics in Section 4: Skills Framework as an overall guide to competencies that should be developed, however, the depth needed will depend on the student's overall career goals and interests.

The IDP exercise encourages reflection on how students' career aspirations match their skills, interests, and professional values, and help them identify those skills they need to gain or improve. Students can then set professional development goals that are specific, sensible, measurable, action-oriented, and time-bounded (i.e., doable in the time available). They should develop a concrete plan for skills development, building a network, and getting the experience they need for their chosen future career. Their mentors can help them identify measures of success. It is important for students to revisit their IDPs throughout their graduate career as their interests may change, and new opportunities or different skills may offer opportunities for different career pathways. Mentoring and guidance all through the development and execution of these IDPs is important, but care is needed to ensure that the student, not the mentor, is making the decisions.

IDPs are useful for more than developing skills for a specific career path. They can also provide students with valuable structure to advising and mentoring conversations with faculty advisors and others, to help keep students on track and to guide their progression through their

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degree programs to completion. Using IDPs also stresses the importance of self-reflection. Effective use of IDPs should ensure a student can express their skills, passion, wants, and needs openly in a safe environment. They are the ones who identify the skills needed, their goals, and where to find necessary resources and connections. Students should diversify their sources of professional information to better prepare themselves for careers. They should learn to develop a diverse network and develop a menu of skills that are transferable to other disciplines (e.g., communication, writing, critical thinking, data analysis, statistics). Mentors should help their students understand why they need to develop specific skills, and what courses and co-curricular activities will help. They should help students decide whether their career goals are better met with a master's or doctoral degree. Mentors also should discuss with them what research careers are like, the breadth and depth of research-related skills that may be needed, and which aspects of conducting research help develop skills that are valuable in other careers. Some departments have active faculty who have non-academic work experience or strong contacts, and these faculty may serve as a resource for students interested in different categories of geoscience careers.

Mentoring should be a mutual activity, not one-way guidance. Faculty mentors need to listen to what the students want to become to effectively discuss workshops, coursework or other options to gain the desired skills or meet the identified needs. Students need to communicate clearly to their mentor(s) what they want to become, and what their goals are. Faculty can work to ensure that opportunities are available to students, such as internships, but likely cannot ascertain the quality of every accomplishment, product, or activity. Emphasis and control need to be in the hands of the students; they need to take ownership of their professional growth, including completion of their degrees and meeting their career goals. This effort will build students' confidence in their accomplishments and can alleviate "imposter syndrome". The result should be a better educated, more focused, and productive graduate student.

Although the 2019 academic participants viewed IDPs as key to providing a pathway to student success, they agreed that their implementation would require a culture change for both faculty and students. IDP strategies work only if the faculty have bought into them, supporting the process, and participating in them with the students. The new requirement by NSF will substantially increase the development of IDPs for graduate students. Faculty need to be educated on the benefits of, and on the process of developing IDPs, and both faculty and graduate programs will need access to resources that can help students with their career choices. Every graduate program will need to develop its own best practices for IDPs, starting from a generic plan that can be modified according to the student interests and needs. The IDP should provide a specific template for a student that is integrated and aligned with their programmatic requirements. Using IDPs needs to become part of the culture of a department, demonstrating to students that faculty are concerned about their professional future, and not only the completion of their research and degrees.

At the 2022 workshops, participants discussed ways to document progress in fulfilling the goals outlined in IDPs. Integrating an IDP with an e-portfolio is one way for students to track their own achievements and demonstrate progress. E-portfolios allow students to compile examples of their research, curricular and co-curricular work products that document their educational experiences and accomplishments. Badges, certificates, and other evidence for successfully completed co-curricular activities help document skill development, along with coursework, published abstracts, posters, professional presentations, and publications. Departments should also ensure that regular assessments of student progress occur. These assessments can be in the form of student annual reports, or semi-annual supervisory committee meetings, as well as through qualifying examinations. Departments may want to develop a template for students to use in reporting progress or request updated graduate student curriculum vitae. At the same time, students can self-assess whether their career goals have changed, and if any course correction is needed.

MENTORS

At the 2019 Summit, academic leaders recognized that graduate students need guidance and experiences during their degree that help them prepare for future careers. Students need to know the skills and knowledge that are needed for a variety of careers, be given opportunities to develop these competencies, and be mentored throughout the program. Participants also realized that faculty, when mentoring, needs to accept the value and importance of non-academic careers and recognize that the same skills are valuable in an academic career.

The 2022 workshops participants discussed the process of mentoring, including the types of mentors, the role of graduate supervisory committees, and advisor-student interactions. Departments need to clarify the roles of mentors, advisors, and dissertation/thesis committees. Students need intentional and periodic mentoring by faculty, peers, and alumni. Advisors and mentors should help students understand themselves, set goals for themselves, and help them build confidence. Individual Development Plans can help facilitate this process. Faculty mentors may need training in mentoring skills and in the scope, oversight, and boundaries of mentoring exchanges. The group recognized that many faculty would likely need incentives to improve their mentoring. Successful mentoring needs structure. On a well-functioning dissertation/thesis committee, more than one member or advisor should provide mentorship. Regular contact and meetings with the student's advisor are nonetheless necessary.

Concerns with student mentoring expressed at the 2022 workshops included the primary advisor generally has some level of a vested interest in seeing the research accomplished, particularly if they are funding the work through grants or contracts. As such, they may not want their graduate students to take non-relevant courses or get involved in co-curricular activities that could provide them valuable professional development experiences, but take time away from research. Additionally, advisors may not be fully aware of non-academic or non-research careers and may not have the knowledge or resources to provide advice for students not interested in following in their footsteps. Early development of an IDP provides a mentoring tool for advisors and promotes discussion of the student's short and long-term goals and interests. In many cases for the student's career goals, the student and advisor may realize that additional mentors or advice from others is warranted. Depending on the situation, a contract between the student and advisor may be needed. It should explicitly state the advisor and program's expectations and what they can offer the student, and how the student's needed or desired skills for their career goal can be met. Explicit expectations should be expressed on both sides, including publications and conference presentations, author and co-authorship, support timeline, time on and off (e.g., working through the summer), skills, coursework, and co-curricular activities.

Graduate students benefit from having multiple mentors who can offer a variety of different perspectives and advice. The student's advisor is generally considered the primary mentor, though other dissertation/thesis committee members, lab managers or other faculty are additional potential mentors. It is important, however, to emphasize that the students' advisor is not their only mentor (formal vs. informal mentors), and that students need someone they can go to in confidence.

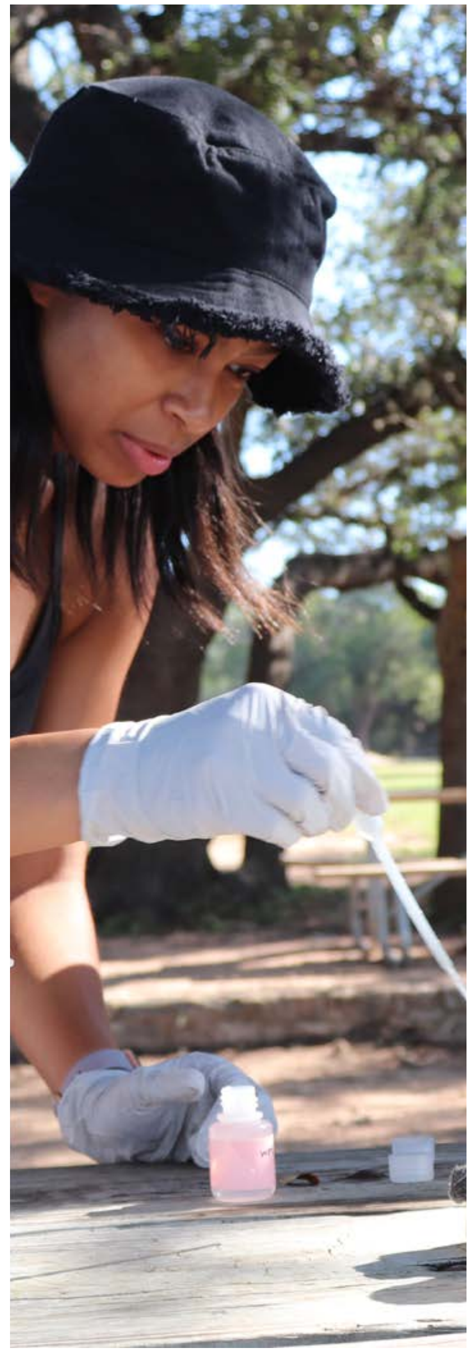
Other possible mentors, depending on the student, research project and graduate program, include external department faculty, external university faculty, and members of professional organizations. Many members of advisory boards or councils and alumni are very interested in mentoring and only need to be asked. Several Earth and Space Science professional organizations participate in Mentoring365 that matches students and early career professionals with experts in Earth and space sciences and/or have individual mentoring programs for specific careers (GSA, AGU, AMS, ASLO, AIPG, GEMS, etc.). In some cases, departments or individual faculty or faculty groups have partnerships with national labs, federal or state agencies, or various industries, and some individuals from those entities may, as appropriate, serve as mentors. Small and medium size businesses from industry can impart knowledge, provide some level of broad mentoring (not necessarily individual mentoring but perhaps 'coaching'). Other mentoring networks may be available through demographic or specialty groups (e.g., women in science, minorities, local professional organizations).

Research groups or cohorts of graduate students (e.g., those entering in the same semester or year) can create shared experiences that build confidence and support that combat the "lonely onlys" syndrome. Lab rotations, where possible, may also help build internal networking. Students also benefit from serving as mentors themselves, either as a peer mentor, a teaching assistant, or a mentor for undergraduate or high school students. Mentoring senior theses is particularly beneficial for those going onto academia. Peer mentoring by fellow students can also be effective.

The 2022 workshop participants also discussed the problems presented by "autocratic" advisors and suggested that departments could offer different options for mentoring to overcome them. One suggestion was having multiple projects for doctoral students, with different mentors for each, and perhaps one mentor from outside the student's area of specialty. Alternatively, requiring two advisors/mentors or more diverse mentoring teams for graduate students is another approach. Collaboration outside the institution can also help in injecting different points of view and/or different perspectives. For example, international opportunities require an understanding of the global workforce, and few faculty are likely to be knowledgeable about this. Those students interested in policy could connect with a present or past Congressional Science Fellow. For students interested in an industry career, learning from the experiences of alumni in industry, and seeking to expand their mentoring to others beyond the small circle of a research group would be helpful.

Section 6. Fostering and Implementing Change

TRANSFORMATIVE CHANGE — WHAT, WHY AND HOW



Courtesy of the Jackson School of Geosciences, University of Texas at Austin

Transformative changes in graduate geoscience education are needed to ensure the long-term health of geoscience graduate programs and to produce geoscientists with the skills and competencies needed to address global societal challenges that require geoscience solutions. Graduate education needs to be student focused, and students should take ownership of their education, developing the skills and competencies they need to be successful in their future careers. Cultural changes as well as structural changes will be necessary in many departments to achieve these changes.

Currently, many advisors focus by default on research productivity and preparing their doctoral students for academic employment, primarily in a research university, with the commonly unspoken goal of replicating themselves. In these situations, graduate education is advisor centric and controlled rather than student focused. This focus and control by the advisor can lead to toxic academic environments where students are not recognized for their contributions and must meet advisor demands regardless of the advisor's behavior. Teamwork and collaboration among students and other faculty is often discouraged. However, only about half of all doctoral students go into academia, including four-year colleges without graduate programs and postdoctoral positions (Figure 3.9b); consequently, even fewer go into permanent research-oriented faculty positions. Many finishing doctoral students report that they do not wish to go into academia, especially research-intensive programs, because of the level of stress and what they experienced in graduate school (National Academies of Science, 2018). Very few master's students (at most ~10%; data from Keane et al., 2021) go into academia, even those who go on for a doctoral degree. This current graduate culture is unsustainable and detrimental to the future health of the geosciences. Academic culture also needs to change its focus from rewarding only individual accomplishments to recognizing the performance and achievement of teams.

Culture change in departments is very difficult, and the first, essential step is to demonstrate it is needed. The perception of many faculty is that the status quo is working, so why change the system? Why is this change a high priority? Many faculty at research universities presume that all or at least most of their students will go into academia, but the data shows that this is not true (Figure 3.9b). Some may feel that only students who go into academia are successes and that only research accomplishments are important in graduate school. Faculty may also argue that they aren't a "trade school" and shouldn't be expected to train students for specific jobs.

The goal of graduate school is to educate students so they can have successful futures, regardless of their choice of career path. The skills and competencies discussed in this document are equally needed for future faculty as well as those in other segments of the workforce.

The primary drivers for change in graduate education are:

- Graduate students are going into a wide variety of careers and employment that are different than in the past and need additional different skills.
- The need for geoscientists to tackle important societal challenges is growing.
- Geoscience has become interdisciplinary and transdisciplinary requiring collaboration and teamwork.
- Industries are changing rapidly, and new employees lack important skills.
- Graduate enrollments are dropping and making positive changes in the academic environment, student preparation for successful careers, and a focus on societally important problems will lead to increased enrollment and retention.
- The geoscience workforce and graduate enrollments are one of the least diverse of the sciences and a focus on addressing societal and local community issues attracts students from underrepresented groups (see Mosher and Keane, 2021).
- Low enrollments impact institutional decisions on whether to replace faculty when they retire or leave the institution, how much financial support a department or program receives — or whether to keep a geoscience program at all.
- Many employers are hiring non-geoscientists to fill positions that require geoscience because there are not enough geoscience applicants.
- An increasing proportion of the private sector are hiring single geoscience employees who must be able to work with non-geoscientists (see Section 3: Graduate Programs and their Interface to Geoscience Work — Culture of Hiring and Employing Geoscientists).
- Some employers rely on individual relationships with departments or specific faculty in departments as conduits for hires, so a lot of talent is excluded, discriminating against those not in that pool. These small conduits don't support the geoscience discipline at large and last only until said faculty retire or move to other institutions.

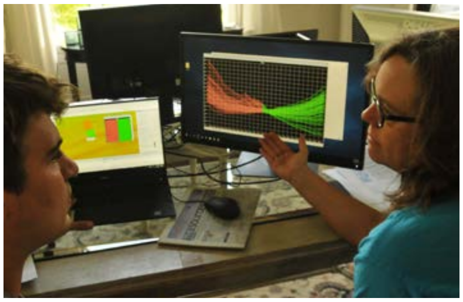
The COVID-19 pandemic forced many changes to departmental practices, and the participants at the 2022 workshops recommended that graduate programs take advantage of any momentum for change created because of the pandemic.

There is abundant literature on change management strategies that can be used to educate heads and chairs, faculty, and deans (e.g., Cameron and Green, 2019; Schabracq, 2007). To make change, you need to identify all the stakeholders and design assessment metrics for managing change. Relationships and the organizational structure also need to be considered. The head or chair's role is critical as they have direct communication with both the faculty and the dean or others in higher administration. When discussing changes to the graduate program, it is beneficial to have a mixture of students, faculty, alumni, and other employers work together with the head/chair and/or graduate program director to identify that which needs changing and possible solutions.

CONVINCING FACULTY AND UPPER ADMINISTRATION OF THE IMPORTANCE OF IMPROVING SKILLS FOR GRADUATE STUDENTS AND IMPROVING GRADUATE MENTORSHIP

One issue that was the topic of lengthy discussions at the 2018 Geoscience Employers workshop, the 2019 Heads/chairs summit and the two combined academic and employer workshops in 2022 was what would convince faculty and upper administration of the importance of improving the broader skills of graduate students, and improving graduate mentoring by faculty? To make effective and lasting change, those undergoing change and those whose approval for change is needed must see a concrete benefit. People are usually busy, so they must see value for change and have incentives to change.

Student legacy is important to faculty and departments. The departmental surveys (see Section 3: Graduate Programs and their Interface to Geoscience Work — The Operational Framework; Figure 3.3) show that the majority (~70%) of departments and graduate programs measure their success based on the employment of their finishing graduate students. The



Courtesy of the Jackson School of Geosciences, University of Texas at Austin

next important measure listed (30–45%) is degree completion. Thus, developing the skills and competencies necessary for future employment success and mentoring students through their degree to completion is the primary motivator for change to graduate geoscience programs. The department's success depends on it.

The participants recommended leveraging external pressures. Improving the rankings of specific degree programs is important to both faculty and administrators. Although numbers of publications and citations and levels of grant support have a large impact on these rankings, the overall quality and size of the graduate program is also part of the calculation. Student legacy and success outside the academic umbrella help advance program and institutional national rankings. The National Research Council assessment uses the number of doctoral students, the percentage of students completing, times to degrees, academic plans of graduating students, graduate student activities and other student related issues. The US News and World Report Best Graduate Schools ranking is largely based on the opinions of graduate advisors and departmental heads/chairs, and the perceived quality of a graduate program can be influenced by reports from undergraduate alumni who attend other graduate schools on what their experiences were like. This Best Graduate Schools ranking methodology is changing and will in the future include surveys of professionals who hire or work with recent graduates and statistical factors such as job placement success and student/faculty ratios. Thus, there will be an increasing need for programs to focus on student success in future careers.

Increasing one's rankings helps in recruiting students, and in convincing the upper administration to support the graduate program. Successful alumni with positive experiences during their education also lead to more philanthropy and more willingness to come back and contribute their time as well as money. One possible incentive for faculty to encourage their students to explore non-academic careers is the potential payback from such alumni, or potentially cooperative research funding from them or their employers.

Another external pressure is the need to improve admissions and retention of graduate students. Higher graduation potential and successful graduate student placements post-degree lead to more graduate student interest in admissions to programs. Professional development opportunities are also an incentive for students to apply. Effective mentoring programs contribute to retention and timely completion of degrees. More graduate students also lead to more publications, which impacts rankings.

Universities need tuition dollars, so if a program doesn't attract students because of a toxic or problematic academic culture, that can lead to a slow-to-fast downwards spiral. The threat of department closures in some geoscience disciplines is real; data supports this happening when enrollments are down significantly. Making faculty aware and cognizant of the American Geoscience Institute (AGI) statistics and trends — such as the plummeting graduate enrollment and number of degrees awarded (see Section 3: Graduate Programs and their Interface to Geoscience Work — Dynamics of the Labor Supply Chain; Figure 3.14a,b) and examples of program closures is important to do. It is essentially a crisis opportunity, with the pandemic and the existing drop-off trend in enrollments. Growth in enrollments lead to more departmental funding and upper administrative support.

Upper administration needs to be convinced of the long-term importance of these changes, i.e., more students and more successful students, higher rankings, increased philanthropy, increased enrollments, attracting high caliber faculty. Administrative resistance is usually financial, so it is important to show that changes will have positive financial impact through more grants, higher enrollments and increased philanthropy.

Departments may also need to help change their administrators' perceptions of the geosciences. Administrators may need a clearer understanding of what the discipline does and its importance, and the underpinning skills and competencies that geoscience graduates need for employment. This document and other reports (e.g., National Academies of Science, 2016a & b) explain the skills that employers are seeking in graduate students and can be used to make the case to upper administration that geoscience graduates need a specific suite of skills. Departments have successfully used the call for action in the *Vision and Change in the Geosciences: The Future of Undergraduate Geoscience Education* document (Mosher and Keane, 2021) to get support from administrators for major change, and this document can be used in the same way.

For programs that have ABET accredited programs, or for others responding to accreditor requirements, as with the *Southern Association of Colleges and Schools* (SACS), the requirements can be a tipping point to move faculty and administrators towards efforts to revise student learning outcomes and more effectively assess student skills and competencies.

CREATING CHANGE

Cultural and structural changes to graduate programs require active participation of heads/chairs and graduate program directors, faculty, students, alumni/employers, professional societies, and funding agencies. Each has an important role to play in making effective change. Heads/chairs and graduate program directors must lead and oversee the change and communicate with upper administration. Department faculty, as a whole, will need to make changes to the overall program, and individually to what and how they teach and mentor students. Students need to advocate for changes and take ownership of their graduate education. Alumni and employers need to be actively involved in graduate programs. Professional societies should work with departments and employers to provide external opportunities for students and disseminate the results of this initiative and the need for transformative change. Funding agencies should make changes to their requirements for graduate student support and provide avenues for funding change and collaboration between academics and employers. Critical to success is collaboration between all these different entities. The sections below summarize the findings of this initiative and discuss the primary roles, responsibilities and advice for each, ways to collaborate and the synergies between the stakeholders and departments and faculty. It is important for everyone to read and consider what the roles are for each other and what the others have to offer that supports them in making successful changes.

HEADS/CHAIRS, GRADUATE PROGRAM DIRECTORS

Heads/chairs and graduate program directors must take a leadership role in creating change. It requires convincing faculty and upper administration leadership that there is a need for change and providing a proposed solution to do so. It is best to use concrete examples to convince them of the need for change, such as student numbers, ABET or other accreditor requirements, negative grant funding reviews because of lack of graduate student support in budget requests, and outcomes from this initiative.

> "Increase open debate and discussion to improve awareness of the need to adapt in the geosciences or be left behind."
>
> (R1 university)

Highlight the impacts of changes on student success by using case study examples (see Section 7 : Fostering Change in Academic Communities: Case Studies). Showing faculty that other programs have good results with these types of changes will make them more likely to buy in.

> "Having the students personally see how helpful the IDPs were for them as a reflection tool, and in aiding communication with their advisors, has in turn allowed the faculty to see that they (the students) actually want this for their own accountability. I suspect that has gone a long way towards the faculty/Graduate Committee seeing the IDPs as something worth requiring."
>
> (R1 university)

Emphasize that employers value research and that the goal is for finishing graduate students additionally to have a solid integration of technical and non-technical skills. Identify the coalition of the willing — those who will engage in the effort, and work around the intransigent ones. In some cases, convincing isn't an issue, but if it is, one should prioritize smaller and relatively painless changes first. Then work to maintain momentum after the early easy wins.

> "There are many relatively easy steps to make that have minimal impact on faculty time, so go for it."
>
> (R1 university)

Change requires champions at all levels, and some of the most persuasive champions are those who were initially against change but were won over by specific cases and examples that demonstrate the value of the changes implemented. One approach is to create a Proof of Concept (POC) "Bungee", a concept proposal that will test whether one of the desired changes will work. Identify a specific problem and propose a solution, then agree to either continue or discontinue it depending on results. Identifying specific ideas to test makes change less nebulous and overwhelming. Often once you get faculty to change something, they don't want to make changes again, even if that is reverting to the prior way of doing things.

Showing how the changes being advocated for students also help faculty, their research groups and programs is a valuable approach. For example, if a graduate program is adopting IDPs, the faculty and students need to be taught how to use them effectively. The department chair/head can set the stage by meeting with each faculty member yearly where they discuss the faculty's goals for next year, what was accomplished the current year, and their most important accomplishment of the year and career. Faculty at all career stages benefit and start to see the value of these planning exercises. Having them do an IDP of their own will let them see how IDPs work and their value. Another method for change is to gradually introduce IDPs to incoming students and their advisors. In doing this over a period of years, all students will have gone through the process. Current students and their faculty advisors will see the benefits, and many may develop them as well.

Heads/chairs should provide vision, create buy-in, develop strategy, follow through with actions, and provide resources and incentives in support. For success one needs a critical mass of faculty and students who support change. It is important to solicit ideas from all faculty and get feedback on strategic planning for ways to make changes to graduate program at all levels.

"Engage the entire faculty within departments in coming up with the final version of the action plan. Have them realize that the success of students is part of the faculty legacy."

(R1 university)

"It is important to get faculty buy-in. If only one or two people are interested in implementing improvements, things cannot be done in a systematic and programmatic way."

(R2 university)

Many departments have done retreats for undergraduate education and would benefit from having such an event focused on graduate education. Faculty retreats provide an excellent venue for faculty to discuss and define student learning outcomes and needed programmatic changes, and for the faculty to work together as a team to improve their graduate program.

"We held a full faculty retreat during August 2019 to discuss improvements to our graduate curriculum, inspired by the NSF Workshop I attended in May 2019. As anticipated, department faculty were enthusiastic about attempting to implement many of the improvements that I was able to propose on the basis of the Workshop experience. A number of such improvements were subsequently implemented or are in progress."

(R1 university)

Faculty need to recognize that the changes discussed will improve and benefit their program, and in the long run make their work easier. Career development will benefit them and their students directly. Remind faculty that the skills we want to teach students also prepare them to be successful in academia, the private sector, and government — which is good for their own group's survival. Pursue grants (i.e., the NSF Innovations in Graduate Education (**IGE**) program, or other funding sources) to support the costs of making change. Success in making change should be celebrated, verbally and in writing, and if possible, with some symbolic or substantive recognition, such as awards or bonuses, pay increases, etc.

External leveraging can also have an impact by paying for time and effort towards design and implementation of change. Cultural changes are often driven by access to funding. Many industries and national labs/agencies are interested in cooperative programs with universities and may provide some funding support for them. Additionally, NSF has programs specifically targeting such cooperative programs (e.g., NSF Industry-University Cooperative Research Centers Program (IUCRC); Grant Opportunities for Academic Liaison with Industry (GOALI)).

Courtesy of the Jackson School of Geosciences, University of Texas at Austin

At NSF, funding levels in core disciplinary programs are not growing. Most of the new money is going to new technologies and synergistic efforts, and NSF's new **Technology, Innovation and Partnerships Directorate (TIP) will increase the level of support for collaborative projects that "**advance use-inspired and translational research in all fields of science and engineering". **These cooperative programs require faculty and even departments to work together as teams.**

Evaluate your department's culture. "Culture eats strategy for breakfast" (attributed to Peter Drucker): no matter how strong your strategic plan for change, if your organization's culture doesn't encourage implementation, it will fail. To change culture, you must move away from how things have always been done (systems), demonstrate through events or decisions what is valued (symbols), and expect and model behavior that matches your goals. Culture is what you allow to happen, so it is important not to tolerate unacceptable behavior. In support of changing behavior, departments can develop expectations for faculty, students, staff, program department, and administration. Make sure to address dispute resolution guidelines, processes for addressing complaints and concerns, and the consequences of negative actions (e.g., **https://www.jsg.utexas.edu/people/jsg-community/for-the-jsg-community/workplace-expectations-guidelines/**). Don't tolerate behaviors that don't meet the guidelines, and where possible, provide positive reinforcement.

Bringing in external input is an effective way of helping faculty understand the need for change. External program reviews every 5 to 10 years can identify systematic changes that may be needed. Alumni Boards or Advisory Councils that meet annually or biannually can provide more immediate outside awareness and help, especially if the members are from diverse backgrounds and professional directions. Another strategy is to broaden the departmental lecture series with talks by speakers from both new and traditional career paths to expose faculty and students to other industries and types of employment. Regular contact with those professional community members makes a variety of career directions more tangible to students and their faculty advisors. Some departments have appointed and support alumni liaisons from among their faculty.

> "Success has occurred across the spectrum, with most coming at the grass roots level by faculty that are responding to the challenges of a changing workforce landscape in the geosciences. This has been supported by the Dean and DGS Chair."
>
> (R1 university)

Another way to create change is through hiring new faculty. Departments can seek to recruit and hire faculty with diverse backgrounds, not just the traditional academia track. Newly retired professionals or younger faculty with some prior industry experience could have a positive impact with different perspectives on the graduate program. Non tenure-track visiting professors from industry or hiring permanent Professors of Practice are another option to showcase careers beyond academia.

Hiring decisions are generally tilted towards faculty members who will publish the most papers or bring in the most grant dollars, but hiring plans and candidate evaluations should include questions about graduate supervision and mentoring. In faculty interviews, ask about mentoring plans and views on graduate student supervision. Also strive to hire faculty who give attention to education as well as to their research. When you interview candidates, ask them about their opinions on the department and what motivates them to choose your department over others. Make sure the candidates hired know what is expected of them in terms of teaching, research, grant support, supervision, and mentoring.

Student-centered initiatives should be developed with the goal of better preparing graduate students and diversifying the student cohort. Make these outcomes measurable and specific. Having students on departmental committees provides easy access to their input and educates them on how the department and university work. To shift graduate education to a more student focused enterprise, empower students to propose changes. Survey current students to find out what they want and do exit surveys and alumni surveys 3–5 years out to find out how they think the graduate program is doing currently, and how it served them as students. This information can be very valuable in guiding changes. Students generally know the careers they want to pursue, and/or classes they want to take, especially if those classes aren't currently offered in the program. Use the student cohort as motivation for making changes to courses and programs, based on student desires and directions for employment. Emphasize that the department intends and expects all graduate students to be successful, and the program is there to allow them to thrive and succeed. Focusing on student centered initiatives will encourage student advocates for change.

To be effective in leading change, heads/chairs and graduate program directors need awareness of and should seek training in change management and leadership studies and courses. Such training is available through self-paced modules, formal short courses, as well as through reading the extensive literature on this subject (Cameron and Green, 2019; Gill, 2002). They need to be guided through key strategies, including how to make small changes that make a big difference: for example, how to roll out and institutionalize Individual Development Plans, or getting faculty to define performance expectations for their research labs, so there are no student surprises (e.g., living documents that outlines meeting times, office hours, authorship practices, turnaround times for manuscript review/revisions, etc.).

Incentivizing Change

Heads, chairs, program directors and deans can incentivize change through a variety of "carrots and sticks". Positive rather than negative reinforcement works best. Carrots should come from the head/chair, and "sticks" through natural consequences (e.g., university will shut down small programs, rankings will decrease, etc.). The conflict between what professors need from graduate students, including meeting deadlines and funding tied to research, and what employers need students to learn is real. However, the students' best interests should be a priority. Tailoring programs to match the

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long-term needs of students by integrating activities or courses that take smaller amounts of time can meet both the faculty and employers' needs. As an example, moving professional development activities online can be very effective at meeting student needs with customized training and practice rather than having a faculty member offer an in-person course.

Rewarding faculty for excellence in teaching, mentoring, and student professional development and/or for having student-led publications provides a strong incentive for them to excel at these aspects of their job. Yearly faculty reviews and promotion and tenure reviews should take these into account along with traditional research-related criteria, essentially changing the requirements for faculty advancement. To change the focus from individual to team-based achievements, heads/chairs also need to reward faculty for performance on teams, and or supporting or leading team-based initiatives. It is important to recognize and support those faculty who are stepping outside of comfort zones.

Rewards could be performance bonuses or achievement awards. Instituting or increasing such rewards can encourage faculty change and help develop a more student focused program. Review of faculty would need to be across all levels, and could be based on graduate student exit surveys, course reviews, student nominations, and other appropriate measures. Similar awards should be offered to graduate students, to pass on the importance of these elements to the next generation of faculty.

Other possible incentives include teaching release, reduced teaching load, extra TA support, full credit for co-teaching a course, funding for development of new courses or equipment, or summer support for new course development or involvement in graduate program management. Depending on the program, another incentive could be extra teaching credit for courses with expanded professional development elements, for larger enrollment classes, or for those that integrate value-added outcomes (e.g., preparation for the IBA, Reynolds Cup or ROV competitions, etc.). Another would be funding or buy-outs for faculty to build teaching modules based on "big data" resources for others to use. Which of these are feasible will depend on the department, the flexibility given to the department head/chair by the upper administration, and available resources. Demonstrating to the upper administration the benefit to students and the program can help in getting support for these incentives. Also, most likely, such incentives would be offered to a small number of faculty in any given year.

> "Convincing the Central Administration that the Dept. was worth some investment — It took some effort, but once you have their ears, and you make a good argument, they can be swayed."
>
> (R2 university)

Two areas, coursework and mentoring, were identified by academic participants as issues that required specific incentives for change.

Coursework

While a reasonable solution to developing skills and competencies needed for future success (and in support of graduate student research) is through coursework (see Section 5 : Organizational Framework for Graduate Programs — Coursework), departments may face a range of issues in using this approach. For example, working with large sensor datasets requires the kind of skillset that generally gets developed through taking specialized coursework. Yet graduate programs and graduate students can face many issues related to new or additional courses. Some doctoral programs have no specific coursework requirements for the degree, and many graduate programs limit the number of credits that students can take. If a student is pursuing a two-year master's degree, then it is hard to fit a lot of coursework in and also complete a research-focused thesis. Doctoral students have more time-to-degree, but the depth of the research they must do, and the need to publish that research, put limits on the number of courses they can take.

Other struggles exist between administrative perspectives (e.g., the need to have threshold enrollments to give faculty credit for teaching a course) versus faculty perspectives regarding students needing a course (or faculty wanting to teach a course). Enrollment limitations mean that it may take a while to build up enough student "demand" to reach acceptable class sizes. Another issue is getting faculty buy-in to teaching new courses and ensuring sufficient student demand so that said courses can be offered regularly. These concerns tend to be less of a problem in large programs, but in smaller programs teaching specialized courses may create faculty teaching overloads, particularly if a minimum number of students are required for faculty to get teaching credit for them. Programs with a cohort structure can help avoid these problems if the needed course is a department's priority, as the students all take the same courses.

Heads/Chairs should find effective ways to foster team teaching, especially by experts in different departments/colleges/schools (e.g., geoscience and business or social science), that could deliver truly transdisciplinary courses. Key in this is finding a way around "bean counting" and workload issues for faculty. Many entering graduate students are missing certain skills or are not up to expected standards, so working for university agreements that allow graduate students to take undergraduate or out-of-college graduate courses will allow them to obtain these missing skillsets. These changes also help take some of the workload off departmental faculty.

In some cases, having students take courses in different departments can help them develop needed skills without adding to the department faculty's workload. Another alternative is to develop a course that is taught by industry employees and/or alumni as guest instructors. Such courses can help broaden graduate student experiences in applied disciplines. Those going into these areas would benefit, and those going into academia would gain insights for their own future students.

If no courses are required in a degree program or the number is limited, students must be incentivized to take them, and faculty to offer them. One way to make faculty and students aware of curricular needs is to have industry guests and/or partners convey the content areas of importance and needed skills they are expecting to see in freshly graduated new employees. Students can be incentivized through demonstrating the benefits of courses, the progression in their skills development, with the outcomes or motivations clearly emphasized (i.e., employers like to see x-y-z, these skills are transferable, etc.), or through the direct relevance of a course to helping their research quality or progress. Skills are empowering and foster interdisciplinary work. Students will gravitate to courses that help them develop such skills, and enrollments in those courses will grow, which should encourage other faculty with lower enrollment classes to change what they are doing and start incorporating or emphasizing skills in their current courses to attract more students. Faculty with connections to the private sector or government agencies/labs will also see increased interest from students for courses and research projects.

A first step in incentivizing faculty to teach such courses is to not disincentivize them by focusing on adding new courses for teaching core skills. Doing so may make faculty feel as if they are abandoning their core academic 'mission' for something new that is not in their wheelhouse. It is more effective to embed key skills-development activities into disciplinary courses that faculty are already teaching. One can build new skills and perspectives into courses through co-teaching, which can be incentivized by increasing support for co-instructors and giving 'full credit' for co-teaching. One can also increase teaching assistant support in such courses, using either graduate students or upper-division undergraduates. In some cases, one can have senior-level graduate students take over the running of a course from the faculty who developed it, and with faculty supervision they can then mentor the next 'generation' of senior graduate students to take over teaching it. For example, lab techniques courses or programming and database management courses can work well being taught this way. This approach relieves the faculty of continually teaching the same skill-based course and gives graduate students peer to peer training, teaching experience, and the opportunity to better master the skill through teaching it to others.

One can incentivize faculty to allow and encourage their students to take courses that develop skills by emphasizing how the courses will help their students do their research, get published, and reduce their time to degree. Faculty can also be relieved of spending time teaching their students needed skills (e.g., statistics, computer languages and programming, GIS, working with instrumentation etc.) one-on-one with each of their students.

> "Bringing faculty together from many different sub-disciplines (e.g., paleontology, petrology, climatology, geophysics, etc.) to discuss the broad area of computational geoscience led to the realization that they were all spending time individually teaching their graduates students the same computational skills. By developing a new course that teaches these skills, the faculty workload was reduced."
>
> (R1 university)

Recognizing that many departments do not have faculty appropriate to teach many of these skill-based courses, participants also discussed ways to share courses across departments and institutions. Recommendations included open-source courses, either delivered by an instructor online, or by sharing the teaching materials (e.g., PowerPoints, labs exercises, etc.) that other instructors could adapt. Another idea is to create sets of curricular modules for key courses or course topics that faculty can adapt for their courses (undergraduate or graduate), with modules that could segue to include spatial visualization and data analyses of statistical data. One example is VHub, a community-managed cyberinfrastructure for volcanology that has a whole suite of modules developed for teaching volcanology and hazard assessment, and more recently sharing and crowd-sourcing modeling codes.

Mentorship

The importance of effective mentoring was identified as crucial to student success. Participants discussed several incentives that could be used to encourage faculty to improve their mentoring practices. It was recognized that without incentives for changing how they advise and mentor students, faculty are not likely to pay attention. Rewards for improving mentoring can be considered in determining merit salary increases, awards, TA support for grad students, bonuses, reduced teaching loads, lower committee service, etc. Departments can make changes in expectations for faculty promotion to include using the faculty efforts towards ensuring their students' success as a measure in tenure decisions, and in decisions on promotion to full professor. Mentoring quality should become an explicit criterion in faculty annual and promotion evaluations, treating it as a separate category for review in addition to teaching, research, and service. If possible, establish funding or decreased teaching loads to support moving to IDPs and related structured mentoring plans. If money or time is available, then faculty will seek it out and use it.

Awards for excellence in mentoring should become common within departments, graduate schools, universities and externally through professional societies. Mentoring, however, is difficult to measure and quantify. Student and faculty annual reports would need to be read by awards committees and/or university graduate offices, not only by the advisor or graduate student committee. Exit interviews with graduating students can be used to reward faculty mentorship, and students could nominate faculty for mentoring awards. If a dean's office or a professional society makes these awards, they will carry more prestige.

Perhaps one of the most effective incentives for NSF funded faculty is the new 2023 requirement for graduate mentoring plans — i.e., developed IDPs updated annually. At the time of the 2022 workshops, NSF proposals did not explicitly consider the nature of mentoring interactions between graduate students and advisor, and participants recommended all federal funding agencies start requiring graduate student mentoring plans, like what are required for postdoctoral funding. Participants also recommended that departments should require faculty to provide mentoring plans for prospective students before admissions and support decisions are approved.

Many faculty will need training in how to be effective mentors and in how to use IDPs. Greater access and exposure to training opportunities offered from professional societies and other organizations (e.g., online) is needed. As part of effective mentoring, faculty need to be made aware of common student mental health issues, differences in generational priorities, and the importance of emotional intelligence. When possible, empower junior faculty, as they are closest in age to the next generation of students and thus more in touch with student culture, needs, and wants. Junior faculty can influence culture by bringing in new ideas from their past experiences and can help break "generational trauma" — just because older faculty had to "suffer" through various challenges, doesn't mean it continues to be necessary for students today. Also, students need training on how to learn to navigate a problem without it becoming traumatic, or it take far longer than it should and setting them back.

> "There's a definite sense that the more junior faculty are more onboard with the need for developing these non-technical skills though specific action items rather than just being picked up via osmosis during the normal course of graduate school."
>
> (R1 university)

When hiring faculty, mentoring experience, philosophy, and potential should be explicitly considered during the interview process.

Collaboration is the new normal in research — we are no longer in a time when one investigator can work alone on a project — so graduate students may end up having several potential project mentors. This collaborative model is followed by most employers, including federal and state governments.

To be effective in implementing changes in their courses or mentoring practices, faculty will need to be provided with information and resources, for their students and for themselves. Heads/chairs should identify and highlight for faculty any department, cross-department, or university resources. For issues where the faculty member cannot provide needed support, students will need aid in getting the help they need (e.g., professional development, mental health issues, etc.).

DEPARTMENTS AND GRADUATE PROGRAMS

Academic and employer participants at the Summit and all workshops associated with this initiative discussed what departments and graduate programs should do to better prepare students for future success. Many actions can be taken by individual faculty. However, department-wide coordination is needed and many actions require full faculty participation. It is important to build a faculty consensus around common goals and objectives for core skills. Departments should decide where in their programs to introduce different skills, and how many and which skills they intend to emphasize in their various degree paths.

The first step in any efforts toward graduate curricular transformation is defining the critical learning outcomes (in terms of skills and competencies) of graduate programs. One can then follow through on this analysis in making any appropriate programmatic changes, and then through a more detailed review and revision of the educational activities and pathways for different graduate students (those specific to subdisciplines; doctorates versus master's, etc.).

Defining Learning Outcomes

Geoscience graduate programs need to define the learning outcomes they expect all master's and all doctoral students to achieve while in their program. Graduate programs may need to take into consideration what type of careers their graduate students generally follow (e.g., weather versus energy); however, most of the skills needed by academia and industry/private sector/government agency/labs are not distinct and are necessary across a wide variety of careers. The skills and competencies recommended by employers in Section 4: Skills Framework can serve as a guide. Individual faculty, research groups or specific sub-disciplines within departments may have additional expected learning outcomes. In defining expected outcomes, it is important to remember that research competencies are critical outcomes for nearly all graduate degrees, and to be realistic as to how much any individual student can accomplish and to what depth. For example, master's degrees are generally two-years, which puts a time constraint on what expected learning outcomes should be.

Some universities and colleges require departments to state what skills graduate students will leave their program with upon graduation. These requirements are generally driven by accrediting requirements or other mandates. Their graduate programs must define clear learning outcomes for graduating students and provide measures of graduating student competency in these outcomes. ABET accredited programs or those with other accreditation (e.g., SACS) will have proscribed methods for evaluating success, and these can be used by other programs as well. Some accrediting agencies do not clearly recognize the ability to conduct research is a student learning outcome, however, and seem to expect similar types of learning outcomes as for undergraduate or K–12 programs. Thus, listing research as a critical skill and competency for graduate students should be part of any statement of expected learning outcomes. Also, some accreditor-mandated assessment requirements can be tailored to other measures of graduate accomplishment (e.g., comprehensive exams, thesis/dissertation defenses, public presentations, etc.).

Some universities require clear learning outcomes for both undergraduate and graduate courses. These outcomes are usually assessed through exams, presentations, written work, or other student products (e.g., computer programs or models, simulations, etc.). How well these are developed and aligned with the course is generally assessed through student evaluations of courses and professors. One suggested recommendation by participants was to put NACE (National Association of Colleges and Employers) competencies on course syllabi (**https://www.naceweb.org/career-readiness/competencies/career-readiness-defined/**) to provide a standard explanation of learning outcomes (see example in Box 6.1).

BOX 6.1 NACE COMPETENCY EXAMPLE

Leadership

Recognize and capitalize on personal and team strengths to achieve organizational goals.

Sample Behaviors

- Inspire, persuade, and motivate self and others under a shared vision.
- Seek out and leverage diverse resources and feedback from others to inform direction.
- Use innovative thinking to go beyond traditional methods.
- Serve as a role model to others by approaching tasks with confidence and a positive attitude.
- Motivate and inspire others by encouraging them and by building mutual trust.
- Plan, initiate, manage, complete and evaluate projects.

Credit: Courtesy of the Jackson School of Geosciences, University of Texas at Austin

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Documenting graduate student achievement of a programs' learning outcomes can be done in many ways. As the primary goal of most graduate programs is competency in research, the common outcomes of research should be recognized as documentation, such as theses, dissertations, publications, presentations at regional, national, and international meetings, and letters of reference (or verbal references). Other kinds of documentation can include other student products, certificates, and in-person or online courses (e.g., Coursera, edX). Additional metrics can include undergraduate mentoring, being active in professional societies, or leadership in local or regional community efforts. Programs can assess these outcomes using surveys of students at degree completion, surveys of faculty (including external committee members) at degree completion, post-graduation surveys of alumni, and feedback from employers of recent alumni.

Graduate students need to know the expected learning outcomes of their programs, and get guidance on how to achieve them, whether it will be from within their program or through external sources. While learning outcomes will vary between programs, the specific learning outcomes that are strongly recommended by both the employers and academics involved in this initiative are presented in Section 4: Skills Framework. Many of these recommended skills and competencies can be developed during research activities (Section 5: Organizational Framework for Graduate Programs — Research). Students can use these expected outcomes to guide their graduate education and for their self-assessments, coupled with developing and using individual development plans (IDPs). It is important for students to find a balance between learning to do (and doing) research and core- and non-core skill development, and graduate programs need to structure their programs to provide a good balance and solid integration of both. As discussed previously, there are subtle differences and commonalities between skills and research.

Evaluation of academic program goals should be an ongoing endeavor, and qualitative and quantitative achievements should be assessed and celebrated. Both traditional disciplinary skills and transdisciplinary skills should be evaluated. Annual graduate student expectation assessments should reflect these goals.

Meeting Learning Outcomes

Graduate programs should deliberately plan and coordinate their graduate coursework to meet their student learning outcomes, include needed skills, and build competencies. A self-assessment matrix of what skills are or are not developed within graduate courses will help identify which courses to revise, and whether new courses are needed (Mogk, 2013; **https://serc.carleton.edu/earthandmind/posts/curriculum_desi.html**). Once done, faculty need to clarify course learning outcomes, so students know which courses provide introductions to specific skills, and which provide practice in those skills. Possible suggested approaches to implementing such curricular changes included having faculty choose which skills they are comfortable teaching and/or could incorporate into their classes, working with on-campus teaching and learning centers programs on revising curricula to incorporate training in professional skills, or hiring an education consultant or specialist who can work directly with faculty to help them adapt their teaching approaches. Many geoscience graduate programs have no "core" curriculum, and their courses are "siloed". When recommended skills are covered in appropriate courses and identified in course learning outcomes and in a skills-course matrix, students can navigate through the available coursework to develop the skills they need.

To be more student focused, departments should endeavor to offer courses that serve student needs (e.g., developing marketable skills) and impact student placement post-graduation. Classes that mirror fields important to industry may also lead to graduate student research funding, which also can drive change. Electives or special topics courses either within geoscience departments or from other departments are one approach, such as stand-alone courses on science communication, data analytics, coding and computer programming, GIS, and/or geospatial statistics and reasoning. For some of these skills (e.g., GIS, data analytics, coding, etc.) to be incorporated into discipline specific classes, prior student familiarity is needed. Other skills, such as written and oral communication, problem solving and critical thinking, teamwork, systems thinking, etc., can readily be embedded into discipline specific classes (see Section 5: Organizational Framework for Graduate Programs — Coursework), though again, it is important for the students to know that they are developing these skills in those courses. Team-taught, case study, and highly engaged "seminar" classes can be very effective, and many employers are willing to provide practical problems to be addressed. Coordination with faculty in different departments can help to expand course offerings. To ensure geoscience content, co-teaching with faculty from other departments (e.g., statistics or computer science) will allow students to work on real world geoscience problems and can be cross-listed for both programs.

Other possibilities for developing key skills are team-based, cross-disciplinary, longer-term projects for student groups to work on together (e.g., the Reynolds Cup, the Imperial Barrel Award, Google's coding or ROV competitions, SEG's Challenge Bowl, etc.), as part of a course or co-curricular activity. Success at these also brings prestige and attention to graduate programs and may increase enrollment interest. Entrepreneurial activities are another way to build useful skills, and some universities allow students the flexibility to engage in such enterprises. In such cases the student's committee should provide oversight in terms of student commitments to ensure continued progress in their graduate work.

Graduate programs can develop certificate programs in conjunction with other departments to support students' needs for additional skill sets. Departments should also provide their graduate students with information on available certificate programs and/or badging opportunities on their campuses and encourage them to take part in those that are appropriate to meet their educational goals. Certificates can cover the gamut, from data analytics, machine learning and AI, computer programming (Python, R, etc.), program or business management, science communication, leadership, and more. When institutions don't offer appropriate certificate opportunities, another option is for graduate programs to identify and encourage Open Badge opportunities that students can accumulate from external sources. Students also need to be made aware of pertinent external training opportunities and certificates (e.g., OSHA 40 hr. HAZWOPER course) needed for specific employment directions.

It is also important for programs to remember that academia is a major employer, especially for their doctoral graduates. Departments should review what they find valuable in faculty colleagues — not just their research productivity — and strive to educate their own students accordingly.

Another programmatic change to consider re-evaluating is qualifying/comprehensive examination requirements within the context of the broader expectations for graduate education. Programs could require students to write press releases, give 3-minute presentations on their research, and/or develop project plans and proposed budgets. Some departments or universities also hold contests (e.g., best 3-minute thesis talk competitions), annual graduate forums, and interdisciplinary poster symposia, similar in form to those at many professional society conferences, where students present their ongoing research, receive feedback and gain practice. In such cases, programs can encourage alumni, employers, or faculty from other departments to participate as reviewers of student work. Giving prizes for best in different categories incentivizes participation and putting their best effort into it.

One disturbing observation made by participating employers was that currently graduating geoscience students have difficulty defining problems and identifying how to apply a solution, although they can readily solve problems that are given to them. As many students end up having their thesis topic and work largely defined by the already funded projects of their faculty mentors, these students need their own independent opportunities to define problems. One approach is to orient students to the overall research project and then have them define problem(s) within that frame that they wish to pursue. Students who develop their own research can also use additional practice. As part of the qualifying exam some departments require students to prepare more than one research proposal, with one or more in areas outside their chosen project or even their primary field. An important additional component to include in qualifying exams is having them discuss the significance of the project and how their results could be used. Project-based classes are another option, where students need to define problems and try to solve them. In this case they also can be required to identify solutions.

Department websites should include a list of the universal skills needed by graduate students presented in Section 4: Skills Framework, with a link to this report and relevant sections. Graduate programs should also provide information, resources and guidance for co-curricular activities that can help build student competencies in important skills (See Section 5: Organizational Framework for Graduate Programs — Co-curricular Activities). It is often unclear to students which skills they are developing in such activities, or what activities are available, or how to access them and/or become involved. Programs should develop checklists of student career development activities beyond their classes (e.g., project management, research ethics, leadership, certificates, etc.), and post it prominently on their departmental webpages, along with information about online courses, professional society activities and short courses, public policy opportunities, externships, co-op programs, and other external co-curricular activities where students can learn or practice each skill. These kinds of resources are also useful if student mentors know their student's career goals (which can get identified and refined through an IDP) so they can help the students identify the specific skills they need to gain, and which co-curricular activities might support that. When possible, make funds available for student professional development resources (short-courses, certificates, drone licenses, etc.).

Programmatic Needs

Participants at the Summit and all workshops associated with this initiative recognized that to shift the focus of graduate education, effective mentoring is needed. One recommendation was for departments to require faculty provide a mentorship plan to admit students into the graduate program, and for all graduate students to have a mentoring plan. Students and advisors would need to identify student interests and potential directions (most effectively via IDP process) early in the students' degree programs. Mentoring plans should be tailored to the student's career path and tied to student learning outcomes. Program websites should include a description of IDPs and how they are developed, with links either to sample IDP forms or their department template (see Appendices A & B). Another suggestion was to consider programmatic mentors who are not advisors (formalized or informal).

Some departments admit students to graduate programs with a mentor or faculty advisory team, not an individual advisor, so students and faculty members can get to know each other and their expectations before committing to a specific project. Other departments are cohort-based programs or may have incorporated group rotations in the first year. Students are assigned to a student cohort, not a faculty advisor. For example, students work with three faculty members as a group for three-month periods or meet with 3–5 faculty, and as a group generate a prioritization and wish list for placement. These kinds of approaches, however, require flexible graduate student funding and won't work in many departments.

Participants also recommended that discussion around mental health be normalized, establishing the "state of things" in the department — e.g., what is the mental health status of our students? If it's not good, then maybe talking about that will help faculty, chairs/heads, and deans recognize the need for changes. Participants noted that we need to grow students, not robots, and recognize their needs for mental health support and work/life balance.

Graduate Student Recruitment and Retention, with Emphasis on Students Underrepresented in the Geosciences

Geoscience departments need to effectively recruit students to their graduate programs and increase the diversity of their student body. As enrollments in graduate programs decrease, all fields of science are competing for a smaller pool of students. Geoscience graduate programs need to retool their programs to recruit from a broader enrollment base. Advice for recruiting and retaining students from underrepresented groups into undergraduate programs (summarized in Mosher and Keane, 2021) is also valid for graduate school. For example, a major attraction to the geosciences for students from underrepresented groups and other sciences is the opportunity to solve problems of societal importance and to address more heavily impacted underserved community issues (e.g., environmental degradation, climate change, water quality and availability, toxic wastes, geohazards, etc.). All students, especially those from underrepresented groups, need strong mentoring to navigate graduate school and develop the skills and competencies they need for future success. By making needed changes to improve the graduate program and making it more student focused, departments will be more successful, both in attracting more, and more diverse students and in student degree completion.

Departments should endeavor to market geoscience graduate degrees as a means of developing the knowledge, skills and competencies needed to solve societal issues. Such marketing can be through active participation at conferences such as Society for Advancement of Chicanos/Hispanics & Native Americans in Science (SACNAS), National Association of Black Geologists and Geophysicists (NABGG), and other professional scientific and/or engineering societies with membership focused on underrepresented populations and/or visiting and collaborating with departments at Historically Black Colleges and Universities (HBCUs) and Minority Serving Institutions (MSIs). Within one's own institution, cross-institution collaboration and partnerships with other STEM departments, such as being part of certificate programs or through collaborative research, gives other science students an insight into what geoscientists do. The increase in transdisciplinary research helps facilitate reaching out to non-STEM students for involvement in geoscience graduate programs. Giving research talks or presentations in other departments helps market the geosciences as well. Many undergraduate students in other STEM and non-STEM fields want to make a difference in the world, but their field doesn't readily lend itself to this desire, whereas the geosciences provide many opportunities.

Additionally, undergraduate students need to know that they can be more effective at addressing problems of interest if they have a graduate degree, that there are well-paying jobs for geoscientists, and that more geoscientists are needed now and in the future. Making these known factors known within your institution and community will make a difference.

As the geosciences takes on a larger role in addressing societal challenges, focusing on real world issues will attract today's students, who overall want to make a difference. This focus requires greater acceptance of different, non-academic career paths, and better alignment between future employment needs and graduate programs. Mobilizing alumni and/or the employers of students, funding agencies, and professional societies will help departments develop this new generation of students.

Faculty

Employers and academic participants in the Summit and workshops recommended further training and support for faculty in effective teaching, mentoring, and supervising their graduate students to provide an education that results in successful students. Faculty need to become aware of the need to change and improve and be provided with the resources to do so. It was noted that the preparation of doctoral students for faculty roles is also limited, as evidenced by NSF early career workshops. Many faculty do not recognize the skills they are (and are not) developing in their current curriculum and courses, which skills are (or can be) developed through doing research, or what kinds of external co-curricular activities and resources are available. Faculty should review Section 4: Skills Framework to become familiar with the recommended skills and Section 5: Organizational Framework for Graduate Programs, which outlines the skills that can be developed in each of these categories, and evaluate what their current courses and research offers now, and how they can incorporate the teaching and practice of more of these skills into their graduate students' education and research.

Most faculty teaching in geoscience programs are strong in terms of content but the pedagogies they use in their graduate classrooms need to evolve. The focus of improved instruction should be on results and enhancing the experiential base for graduate students — critical evaluation and seeking positive and genuine critique. Many external resources for improving pedagogy are available, and although these are generally geared towards undergraduate education, they still provide excellent strategies that are useful in graduate courses (Manduca et al., 2010; McConnell, 2019; Mosher and Keane, 2021). Additionally, by using reformed teaching methods, faculty are setting excellent examples for their graduate students, many of whom will become faculty themselves.

The Science Education Resource Center (SERC) provides numerous online resources and hosts valuable workshops for honing various teaching skills. NAGT has long offered a traveling workshops program in which recognized experts in geoscience education visit academic institutions to address a wide variety of topics from pedagogy to curriculum to strengthening departments and programs. The Earth Educators Rendezvous (EER), held every summer, also offers workshops and short courses on a variety of different topics, and provides the opportunity to network with other educators. Departments should encourage and financially support faculty attendance at these workshops. Two ongoing offerings that are particularly important for junior faculty are the Early Career Geoscience Faculty Workshop, which occurs as a standalone event annually, targeting faculty starting their first academic positions; and the Preparing for an Academic Career workshop, now occurring annually as part of the EER, which targets senior graduate students and postdoctoral scholars.

Many advisors would benefit from additional professional development opportunities in mentoring to provide more effective guidance to their students regarding nontechnical and professional skills. Many universities, professional societies and private firms offer professional development courses on these topics (in-person or online; e.g., edX, LinkedIn, Coursera, etc.), and faculty should be encouraged and supported financially to take them. NSF's new requirement for faculty and other senior personnel to take mentor training and mentorship as part of each institutional RECR training may help address this need. Professional development courses can also help both students and faculty build characteristics such as leadership, time management, and budgeting. Also important is emotional intelligence (EQ skills) — self-awareness, self-management, social awareness, and relationship management and collective competency of a team. Finishing students will need these abilities to be successful, but unless they are exposed to them during their education, they will find it difficult to develop them.

Faculty mentors have significant influence over the opportunities that their graduate students take advantage of. Mentors should encourage graduate students to seek out experiences in professional environments other than academia, and promote awareness of industry and government internship programs, externships, importance of professional society participation, and international opportunities. It is important to encourage students to keep doors open, and to be thoughtfully aware of the skills and competencies they have obtained through these experiences.

To mentor and provide good advice through the IDP process, faculty should know which skills that are needed in different professional settings and how their students can develop them or should direct their students to mentors or resources that can provide that information. Individual

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faculty, particularly research faculty, may tend to offer one-dimensional guidance related to career development and non-technical/professional skills. Having multiple faculty mentors will provide students with a more diverse perspective, though only if the faculty themselves have diverse experiences and/or training.

Employers in our various workshops and events noted that the level of achievement of many skills and competencies among students seems very dependent on the advisor. Many advisors may discourage their students from spending time learning professional skills, thinking students should focus on their research. Department heads/chairs tend to get pushback from faculty advisors on courses that are not directly related to the student's research. Lack of training in how to teach and mentor (and/or conduct other academic responsibilities) perpetuates through the graduate education process under the guise of developing "independent problem-solving skills." Unfortunately, this hurts the students going into academia (and ultimately their student advisees) as much if not more than those taking non-academic positions. Traditional aspects of geoscience graduate education are especially advisor-centric, with less advisory committee (or department) involvement than is desirable. Graduate programs need to find ways to break this mold and have better advising of students at the program level (see Section 5: Organizational Framework for Graduate Programs — Mentors).

The world has changed in a great number of ways, so faculty need to accept that what was acceptable mentoring and support during their graduate education and early career is not sufficient for the current generation of geoscience graduates. Department heads/chairs need to provide leadership in getting faculty to realize that things are not as they were when they were in school.

The elephant in the room, of course, is that faculty are already overloaded with responsibilities and requirements and have limited bandwidth to take on the additional work recommended in this section. Add in the COVID-related recognition of the importance of work/life balance, and departments will need to offer substantial incentives to get faculty to participate. Those who will take on additional duties need to be compensated, either with release time or other incentives. Heads/Chairs also need to make sure that these additional duties are distributed across the faculty and not consistently handled by the same few faculty members, especially new faculty, or those from diverse backgrounds as a form of cultural taxation. One way to share some of this load is to have faculty who attend workshops or professional development courses give seminars for their colleagues, where they communicate what they have learned.

The COVID-19 pandemic impacted faculty as well as students. A problematic fallout from the pandemic is that many faculty struggled (and are still struggling) to find joy in teaching because of the loss of interaction with their students. This isolation is changing, but how fast it recovers depends on geographic location and institution. The lack of motivation to teach, coupled with heavy workloads, stress over university finances, low enrollments, delayed research, a loss of work/life balance, and other factors has led to faculty burnout. Solving this may require structural changes within the department to reengage them (Imad et al., 2022; Pautz and Diede, 2022). Both faculty and students need to find new ways to connect and recapture the advantages of interpersonal educational interactions. Cultivating strong relationships or partnerships with organizations that are addressing societal challenges, community issues, or developing new fields, technologies and research directions may give these faculty new interests to pursue and lead to new ways to connect with students.

> "The second biggest roadblock has simply been faculty apathy. They see the need, but they don't feel they have the time, or they don't think these should be addressed in a systematic manner. I have not been able to overcome this."
>
> (R2 university)

For faculty, the post-COVID culture shift has created a new emphasis on work/life balance, and a resistance to overburdened workloads. Universities and departments may need to adjust tenure expectations to account for this shift or they may find an increasing number of faculty leaving for other types of employment. Providing professional development for faculty to develop new skills and emphasizing that helping students be successful is doing something important — that these actions can make a difference in the world.

Students

Graduate students need to take ownership of their graduate education. Many of the skills that are essential to the students' research and future career success have become very widely recognized, with programs starting to address them in a number of ways, such as the universal need for effective verbal and written communication, quantitative and computational skills, data analytics, collaboration and teamwork skills, project and time management skills, and sophisticated analytical techniques. If a graduate program does not offer the opportunity to develop these skills, students should advocate for changes to the program and should seek out avenues within the institution or externally to acquire them.

The need for emotional intelligence, appropriate behavior, interpersonal skills, and ethics are generally more difficult to address within a graduate curriculum, but students should strive to develop them. Additionally, the growing importance of broader impacts and diversity-equity-inclusion considerations in the geosciences add yet another dimension of needs to graduate student education. Development of an IDP early in the student's career allows students to take control of their education and allows for reflection on the competencies they seek to or have developed. Students should also consider how to sell or market these competencies effectively when looking for employment.

> "Students should have the freedom to try new areas (and even fail sometimes!)"
>
> — 2022 workshop employer participant.

Graduate students face similar issues as faculty. Mental health among students has become increasingly problematic (e.g., Forrester, 2021; Council of Graduate Schools & The Jed Foundation, 2021), and was strongly exacerbated by the COVID-19 pandemic (e.g., Liu et al., 2022). Graduate school has long been a stressful environment and can be overwhelming. Qualifying exams, thesis and dissertation defenses, negative reviews of papers, writers block, etc. put pressure on students who depend on success in these activities to achieve their degree and sought-after career. Many students do not finish their degrees, even if almost completed (STEM: 10–23% masters, Council of Graduate Schools, 2013; doctorate 36–51%, Young et al, 2019). Fear of failure is a large problem. Also, many of the geoscience issues we study (i.e., natural disasters, environmental degradation, etc.) can lead to or reinforce depression. With the long list of skills and competencies outlined in Section 4: Skills Framework, it will be important for faculty to help students develop an IDP that will allow them to gain the skills they need for their own career goals while completing their research.

Students need to develop positive survival instincts and learn resilience to trauma or negative outcomes. Faculty mentors need to find a balance between sheltering their students and exposing them to negative outcomes. Students need to learn to overcome the fear of failure, as without taking risks or moving beyond what has been done before, true creativity doesn't occur. Graduate students need to learn to deal with disappointment or roadblocks and be persistent. Helping them accept criticism of their work and use it to constructively to improve its quality is important. Students also need to be able to offer answers without fear of being wrong, avoiding chastisement or relying only on developing a thick skin. It's important for faculty mentors to have discussions with their students about the need for a healthy, balanced lifestyle, including being able to unplug and be refreshed, how to work optimally with mental breaks, external activities, etc., and learning to say "no".

Students need mentors who they can turn to when they are feeling overwhelmed, and unfortunately this is usually not their advisor. In some cases, they don't want to disappoint their advisor or don't think that they can live up to their advisor's standards, or that their advisor is their harshest critic. Solutions include having multiple mentors, a "care counselor" or access to mental health help without a stigma.

Professional development courses for graduate students usually focus on obtaining employment — everything from applying, interviewing, networking, virtual brands, etc. These skills can be handled by a university career center or by knowledgeable faculty members or external speakers. The types of professional skills discussed for faculty (e.g., leadership, emotional intelligence, collective competency of a team, time management, budgeting) are best learned by example and experience. Having faculty with these skills to learn from is critically important. Some of these less tangible skills, however, can be developed by getting involved in mentoring younger students, volunteering and engaging in organizations or community efforts, and communicating the societal or global relevance of research to the public. Students interviewing for any employment (academia, industry, government agencies/labs, business, NGOs or other private sector positions) will have their skills in these areas assessed, whether directly or indirectly. Having examples of where they have demonstrated these skills through actions, rather than just words, has become increasingly important.

ROLES OF EXTERNAL STAKEHOLDERS AND DEPARTMENT/FACULTY COLLABORATION

Many groups external to the university have a role and responsibility for improving graduate education and benefit from improved the skills, competencies, and success of graduate students. The subsections below discuss what these different stakeholders (e.g., alumni, employers, professional societies, funding agencies) can contribute and how collaboration of departments and faculty with them will advance graduate education. Each group should review these to assess what they are willing and able to do, and department

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heads/chairs and graduate faculty should review these to discover resources that can help them improve their graduate programs. Collaboration and working together as a team are essential for making transformative change.

Developing Collaboration Through Communication

At the 2022 combined academic and employer workshops there was general agreement that more collaboration between employers and academia was needed and could be facilitated with better communication. Many of the employer participants indicate that they and their colleagues would love to become more involved in graduate programs as described below, but simply haven't been asked. Thus, department heads/chairs or a designated faculty liaison should reach out to alumni and employers of their graduate students. Some faculty have private sector or industry experience, and/or work with consortiums involving industry and/or government agencies/labs and can help facilitate interactions. Some younger faculty may also have been exposed to a wider range of experiences than their more established colleagues. Departments should draw on this expertise in their faculty when it is available.

On the flip side, many academic participants say they have no idea how to contact alumni. Unfortunately, development offices at many universities are hesitant to share contact information for their alumni. Sometimes, discipline-specific alumni societies or interest groups gather and maintain such information themselves and are willing to share. Departments should request graduates to provide them with contact information and keep it current so they may be contacted in the future. Also, alumni can themselves be proactive and contact department heads/chairs, faculty, or student organizations to volunteer to come talk to students or be involved in the graduate programs in other ways. Alumni need to recognize that keeping contact information up to date with the department after graduation makes it possible for heads/chairs and faculty to reach out for help and advice.

Academic and employer participants at the Summit and all the workshops associated with this initiative discussed what employers could do to assist graduate programs through formal education, co-curricular opportunities, professional development activities, or other means. Engaging members of the private and government employment sectors in graduate degree programs will foster discussion and advice about what they see as needed in successful geoscientists and can provide additional resources and other valuable contributions. Most faculty are only familiar with academic endeavors and as such find providing advice to graduate students pursuing different careers difficult. There are many ways to broaden the exposure of faculty and graduate students to different professional opportunities, skill sets, and careers.

Stakeholder and Department Interaction

Departments should consider establishing external advisory councils or boards that meet annually or biannually to provide advice on their graduate programs. Employers should help programs by supporting alumni engagement with advisory councils/boards, allowing them time off (covered leave) to participate; or allowing other employees to serve as a company representative. Such interactions can provide departments with more immediate outside awareness and help, especially if the members are from diverse backgrounds and professional areas, and can provide employers insight into potential research collaborations. Doing so has several positive outcomes — it helps keep graduate programs current with what is being done in other academic or non-academic organizations, and it provides fresh-eyes insight into ways to improve the program.

For employers, it gives them the opportunity to provide advice on the skills and competencies they wish future employees to develop and to become acquainted with faculty and graduate students (potential employees). Advisory councils/boards can provide important input to the university administration and regents or trustees, as well as to the department. This help can include marketing the geosciences and geoscience professions to decision makers and the public. Administrators at many universities and colleges are unaware of the important contributions made by the geosciences, or of the wealth of geoscience career opportunities. Advisory council members can also help market graduate programs to their employers and colleagues, which can lead to increased philanthropy, increased institutional investments, higher rankings, and more employment for graduating students.

Departments can broaden their lecture series with talks by speakers from both new and traditional career paths to expose faculty and students to other industries and types of employment. The invited speakers should represent the private sector, government, NGOs, 4YC and if possible 2YC colleges, so graduate students see geoscientists in other careers and faculty will be able to provide better advice when working with their students on IDPs. For invited speakers, regardless of whether they are in academic or non-academic positions, it is worth asking them to record five career-related questions and answers. Departments can also bring in employers to give seminars or presentations in classes and to student groups on career opportunities, or to serve as panelists for presentations about geoscience careers. These activities expose students to what employers think are the most important skills to have walking in the door to a geoscience job, and what they are looking for in a graduate job application. Having speakers talk in classes about what they do and what they found to be required skills or competencies is effective. When permitted, it is good to record these talks for asynchronous teaching and for future review by students.

Alumni are exemplars of the variety of careers available to geoscience students from that institution's graduate program and can communicate the relevance of what they learned in graduate school. They can show how their work impacts others, and what success looks like in these professions. Graduate programs should encourage their alumni to come back and talk to students about their careers, the kinds of things they do, what skills have been (or are) the most important to them professionally, and what they are looking for in new employees. Both faculty and graduate students can be incentivized to broaden their knowledge by listening to past students and those in industries, consulting, government labs/agencies, NGOs and other parts of the private sector. Such presentations can be individual talks or several alumni presenting as part of a panel discussion on geoscience careers or professional practice. Improved capabilities for virtual meetings mean that talk formats can be tailored to the commitments and needs of one's alumni partners, be that in-person, hybrid, or virtual.

Alumni can also serve as mentors to students, help with the development of IDPs in defining goals, skills needed, reviewing plans, etc. Career paths are not a straight line, and advice from the perspectives of alumni who have followed varied career paths can be very valuable. Many graduates from any university typically work within 30 miles of the university, so there is likely to be a large group of professionals ready to help if graduate programs seek them out for this kind of aid. Many departments have developed strong alumni networks, in which alumni help teach courses, give lectures, and run workshops to help with interviewing skills, career searches, and networking. Many graduate programs hold alumni events at professional society conferences, or on campus where students can network with alumni.

Career and recruitment fairs with nonacademic employers can showcase different employment options. Also having any visiting recruiters discuss with students more generally the different types of jobs available in their organizations, and the specific professional and technical skills required for these jobs. Faculty as well as students should attend such events. Changing the culture and expectations of students without doing the same for faculty will exacerbate any current disconnects between student and faculty goals that currently exist.

Departments can ask their alumni and their local employers to help with student professional development, including advice on key skills needed for different careers. Visiting professionals can help students with interviewing skills for in-person and virtual interviews, what belongs in a resume, doing professional presentations, and broader career awareness. In some programs, visiting professionals do mock interviews to help prepare students and give them practice interviewing. They can provide valuable information to students on the dos and don'ts of social media and/or networking events.

Having geoscience professionals, alumni or otherwise, visit departments and spend time with students at department functions is important for building student's networks and honing their informal communication skills. These professionals can also participate further, serving as evaluators for student presentations and reports, which provides an opportunity for more intensive, but still informal interactions. In some programs, geoscience professionals serve as external members on graduate committees, bringing their professional perspective to the students' mentoring and professional development. Our participants recommended that master's and doctoral committee participation should be encouraged, and that programs find ways to facilitate it happening, so that working professionals could become part of the student's cohort of mentors. Having them as an external member of graduate student committees also provides a professional perspective. Graduate programs can also encourage alumni and employers to serve as additional mentors for graduate students, either in person or virtually.

Employers can provide valuable help with graduate courses in several ways. Some employers provide datasets for real-world cost/benefit/risk projects, either for use in graduate research or for classes. Frequently, additional help in the form of specialized training, personal insights, or other employer participation in support of the research is provided along with the datasets. Many of the faculty participants in our different Summit and workshop events expressed interest in these kinds of datasets becoming more widely available and, when possible, accessible online. Some employers work closely with faculty to provide real-problem case studies, for students to work on in classes. Generally, in such cases someone from the company evaluates the results and gives feedback to the students. Classes

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may be built around such projects, and student teams can compete to come up with the best solutions. Poster and/or oral presentations of student results are commonly part of the evaluation. All types of practicum courses, where students apply what they have learned in class to a real environment are valuable.

Other kinds of involvement from employers range from currently employed or retired individuals coming into a department to teach courses, give lectures in courses, or do standalone talks in seminars or as part of student organization meetings. Some employers will sponsor one of their employees to teach a course or short course on a technical subject, or on professional development, or topics such as field and lab safety. Online and blended delivery options help facilitate the offering of these courses so that the participating employee requires less time away from work. Graduate programs should encourage members of the private sector to co-teach courses and seminars as adjunct faculty when appropriate. Experiential learning opportunities are also valuable; some companies will support employees leading or co-leading field trips, or to participate in field camps. Others will sponsor field trips for a department or invite students to attend company-run field trips.

At the 2022 combined workshops, faculty and employers also discussed issues and barriers to some of these interactions and ways to overcome them. One issue that came up repeatedly was the lack of knowledge by many faculty of the types of skills that are needed for various types of geoscience employment. The participants recommended that employers consider providing information pages on their websites for students that describe career paths within their companies or organizations, and a guide to advancement in that field and/or career. Descriptions of specific types of jobs, the skills that are needed and/or required, and job expectations were seen as potentially very beneficial to graduate students and their faculty mentors when developing IDPs. The faculty also noted that help from employers and alumni in developing student mentoring programs was extremely valuable, as it provides students with external and highly credible input during their educational careers.

Employer and Alumni Support

Internships

Internships are the major source for career experience and development for geoscience students. Many employers help students develop the knowledge and skills they need for employment as interns. These opportunities also allow students to find out whether that type of employment (or at least at that company) is something they wish to pursue. These internships often occur in the summer but can also be part of a cooperative program during the school year, where students may also receive course credits.

Overall, there was general agreement among employers and academics that internship opportunities are very beneficial, and more employers should be encouraged to find ways to offer them across a broader spectrum of employment sectors. Currently about 60% of geoscience graduate students have done some kind of internship during their degree and 25% had two or more internships (Keane et al., 2021). Internships can give exposure to careers that match students' goals. Unfortunately, many graduate programs find it difficult to make these kinds of connections with companies and/or across a range of industries. As discussed below, professional societies could fill an important role here by setting up a clearinghouse for internships and connecting industry opportunities to students directly.

Although most faculty were aware of internships with various industries, many other possibilities exist. National labs (e.g., Sandia, Los Alamos, etc.) and Federal agencies (e.g., NOAA, NASA, USGS, etc.) have internship programs. In these, the university typically pays the student's tuition, and the facility pays for their research and/or work-related expenses. The **NSF Graduate Traineeship program** is designed to fund the development of the skills, knowledge and competencies that research-based graduate students need to pursue a range of STEM careers. Graduate programs are strongly encouraged to form partnerships with the private sector, with NGOs, and with government labs and agencies. These types of internships and partnerships allow students to complete an internship as a part of their degree, often with financial support.

Additionally, **NSF's INTERN program** supports graduate students to engage in non-academic internships during the course of their study if they are currently supported by either an NSF Graduate Research Fellowship or a faculty member who is a PI on an NSF grant. In this case, NSF supports the students release time from their research program to build the experience. Internships cannot be directly related to their ongoing research project and are thus ideal opportunities for students to expand their professional development and to explore intellectually adjacent topics.

Participants at the combined employer and academic workshops in 2022 discussed the timing of internships, and their availability across different industries. Research-focused partnerships or internships are best for doctoral students

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and can become part of their research program. Master's students (and undergraduates) generally do applied internships, and may be away from school for a few months. Being able to cross-list the internship as a course for credit can be advantageous for students.

Participants discussed whether internships should be prioritized for undergraduates, so that graduate students could concentrate on research activities and developing those related skills. Doing so would give undergraduate students experience and insight into different careers before embarking on a graduate program. Some geoscience fields, such as meteorology, do offer such internships for undergraduates, and these are actively promoted.

Participants also recommended more mentoring during internships, and some form of assessment at the end. They also recommended more feedback between the departments and employers. The departments need information about what the students accomplished and learned, and the employer needs feedback on the students' experiences and any suggested changes. Having returning interns give a talk to the department about their experiences helps their peers get a better idea of what that type of employment is like and gives them insights into corporate cultures and values.

Several issues related to internships were also discussed. Companies typically want to hire students in the summer, but advisors may often be against this, because it takes time away from the work that needs to be done for the student's research, particularly if there is a need to do fieldwork. Also, master's students are the most likely graduate students to do internship with companies, but because of the short timeframe for master's degrees, it is difficult to embed this external opportunity without extending the length of the program. This extension can disrupt the master's project timeline, which may cause problems with funding. Co-op programs, where students get course credit, or internships that are directly related to the student's thesis topic can help mitigate such issues. Advisors and students will need to balance the value of an internship with the need to graduate on time or before funding ends. Another issue is that international students are often not eligible for many internship opportunities. It was also mentioned that some companies can't afford to train temporary employees (interns) to work in their field; for example, work that requires HAZWOPR training generally can't be done by interns.

Another issue discussed was that the current general business model of how geoscience graduate students are funded is inherently a barrier to enabling release time from research to take an internship. Many programs in other disciplines, such as chemistry, have structured their graduate support with consistent, department-based funding; grant funds are used to help reimburse the departmental costs. With this a lighter coupling between the students' support and the active research, release time can be better managed. How to evolve the fundamental funding strategy for geoscience graduate students is likely far larger than the scope of an individual department chair, but rather a dialogue between employers and institutions. Employers are well placed to help lead this dialogue with benefits of more stable graduate programs and opportunities to engage with graduate students in internships.

Internships are great experiences for students, and those students with internship experiences are often more likely to be hired. In fact, many companies won't hire someone as a permanent employee unless they have done an internship, preferably one with that company. Some internships offered to already-completed graduate students are essentially a very long-format interview. Given the need for such pre-employment experience/training, participants wondered if it could be done in smaller pieces: as an example, instead of a 3- or 6-month internship, do the same kind of work in an evening or weekend short course format. If such experiences were managed by and/or promoted through professional societies, such expertise could be offered to broader audiences.

Externships

Participants discussed other employer/academia interactions that are beneficial to students and encouraged graduate programs to allow and seek them out, and employers to offer them. One example is externships, where students get short-term professional learning experiences ranging from one to several days visiting an employer to learn more about the work environment and get a better understanding of what the employees do. Another similar approach is job shadowing, where a student follows and observes an employee throughout their day.

Financial Support

Employers can also help graduate programs through financial support. Traditionally many companies have offered graduate scholarships or financial aid, but over time these have decreased significantly in number. One reason given is the lack of a clear return on investment, as the students supported by these scholarships commonly did not end up working for that company. Also, mergers have decreased the number of companies (especially those in the petroleum industry), and the overall state of the economy has led to other less expensive types of investments. Many companies now fund short courses or workshops, poster symposia, tailgates, fieldtrips or even field camps, the goal being to get their names known to more of their prospective employees. The benefit here to departments is in the sponsoring of activities that are costly either to programs or to students.

Direct funding of students is usually related to the student's or faculty supervisor's research. If students' internships created opportunities to generate more research funding or better corporate connections for the advisor, it would help overcome faculty resistance to internships. Another avenue for financial support is for industry or government labs/agencies to provide money and expertise for short projects.

Consortiums and Other Types of Partnerships

Consortiums and other types of partnerships between industry or government agencies/laboratories and universities can foster deeper engagement with faculty and students to create more awareness of future careers. NSF's Grant Opportunities for the Academic Liaison with Industry (**GOALI**) program offers supplemental support to existing NSF grants or in conjunction with a regular grant proposal for research university-industry collaborations (also possibly with National laboratories or NGOs). These collaborations involve a continuum of employer activities, from giving seminars, having sit-down chats with students, participating in career days, externships (with or without academic credit) and internships (paid or unpaid). Students may be able to shadow an employee, be directly funded or have their research funded, be provided with data needed to conduct their research, or be able to do the research using the organization's facilities or labs. Another option is to support faculty/employee exchanges, where faculty take sabbaticals and an employee takes their place, or for corporations to offer sabbaticals to faculty individually. Participants discussed the pros and cons to these various nurturing relationships: it helps prepare students for employment with a specific employer or type of employer, but at the same time it is critical that they don't become less broadly employable. Participants also pointed out that contractors for federal agencies may legally or contractually have to spend a certain amount of their budget on engaging with academic institutions. Participants recommended universities develop processes to take better advantage of such opportunities.

Additional Support

Participants recommended more employer-facilitated modular training and certificate opportunities. One example mentioned hosting skills workshops or short courses at conferences or via webinars that teach student niche software and similar skills. These kinds of offerings would open participation up to a broader cohort of students. If connected to meetings students are attending related to their research, travel costs are minimized. Making resources easily available online will provide access to a broader group of students and faculty. A key challenge to overcome will be making students and faculty aware of these resources. Additionally, interacting with programs in more "remote" areas, either virtually or in person, will broaden the opportunities for more and more diverse students.

Many private-sector geoscience careers in 32 states require professional geoscientist licensure, requiring it for non-petroleum geoscientists tasked with preparing plans, reports, or documents of a geological nature. ASBOG (the Association of State Boards of Geology) administers the Fundamentals of Geology exam, which is the first test required for a person to become a licensed Professional Geologist (PG). Students and faculty need to be aware of this requirement, and if the students express an interest in a career that requires a PG license, it is important for them to know the requirements early in their education and to take courses that will prepare them for the exam. Additionally, those departments should have a list of courses that cover the topics on the exam and should also highlight any available alumni/university networks for professional geoscientists.

Many industries or professional societies host and/or sponsor competitions to create opportunities for students. Some sponsor research symposia, with either posters or oral presentations with alumni judges. Other technology and research competitions have broad participation, such as the Reynolds Cup, the Imperial Barrel Award, Google's coding or ROV competitions, SEG's Challenge Bowl, etc.

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These activities engage a lot of students and help build important skills and confidence outside of faculty labs or courses and may lead to collaborative investments. Expos are also important for showcasing different types of professions.

Participants at the Summit and all the workshops strongly encouraged more collaborative connections between industry, funding agencies, and departments to help graduate students develop key skills. Doing so will require better and expanded linkages among the employers, funding agencies and academic programs, as well as buy-in from existing faculty and academic institutions. They agreed that more discussion was needed on how these opportunities work together to develop the future workforce.

Responsibilities of the Employer Post-graduation

In discussions about the skills and competencies needed for graduate students to be successful in the workforce, academic participants noted the push back they hear from many faculty that graduate education is not training for employment and that graduate programs are not "trade schools". This prompted the question - what is the responsibility or role of the employer after graduate students are hired, starting from when they are first hired and throughout their early career?

Employers stressed that they expected graduate students to have developed a menu of broad core skills during their education that could be applied in multiple directions. So, the necessary post-graduate school government or corporate training was less about core science knowledge and skills and more about organizational specifics and culture. Employers agreed that they were responsible for any higher-level, job specific training. Because industry-specific technical and business skills, ethics, compliance and regulations, time accounting and interacting with stakeholders or clients vary between employers, new employees will require training specific to their position. This need is particularly true for those skills that wouldn't be widely used in other employment, proprietary training, company licensure requirements and baseline training.

It was agreed that when hiring, employers need to do proper onboarding for recently finished graduate students. These new or prospective employees need clear communication by employers about their corporate culture and expectations. This onboarding is most effective when the student has done an internship with the company or there is already a strong university-industry connection. If employment is international or the prospective employee is from a different country, collaboration on managing any cultural or language differences is a must.

Both academics and employers recognized that few finishing graduate students come in fully prepared for the workforce, even including positions in academia or research labs. Finishing graduate students have learned how to do research at a university and have strong technical skills and knowledge related to their research area. However, they need professional training in other aspects of their work. The biggest issue for new graduates to learn is how corporate, consulting, industry, national labs and agencies, and universities and colleges work financially, in terms of research and development, time commitments, policies, standards, etc. Learning some of these things during doctoral degree programs would be helpful, such as occurs within industry consortia or partnerships, but is not common.

All companies, organizations and institutions need to provide continuing education for new and early career employees, both internal training and one-on-one mentoring. Continuing education is also needed throughout careers, as essentially all employment takes on new directions over time. Recent examples include the major emphasis on data analytics and machine learning, and on Earth observation for environmental and climate purposes. The needs of employers vary with projects, financial incentives, and changing interests.

Professional Societies

Professional societies reach a wide audience of academics, students, and employers. They should be proactive in disseminating the results of this initiative and make their members aware of this report. They should also have information on recommended necessary skills on their websites for students, faculty, and graduate programs to use, along with a list (with links) of the resources the society offers to support preparation of graduate students.

Professional societies should partner with universities and industry to offer a variety of external opportunities for graduate students. Many geoscientific societies currently offer short courses on a variety of subjects, including the use of new technologies and analytical or computational methods. Making use of the list of needed skills discussed in Section 4: Skills Framework, professional societies can work with academics and employers to develop curricula for a series of short courses and/or workshops focused on the desired skills, either online or as summer offerings. They can also set up certification, badging and/or accreditation programs for these skills so that students can demonstrate to others that they have attained these competencies. Pricing for graduate students at such courses or workshops should be free or minimal to make the opportunities as

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equitable as possible. Departments can offer credits and/or funding to support students attending these courses. The societies will benefit from increased attendance and will develop a growing student membership who will be more likely to retain their memberships and give back to the society after finishing graduate school.

Many professional societies hold student research forums in different disciplinary or sub-disciplinary areas, either as standalone events or as part of their larger conferences. These events allow students practice at presenting their science as well as a chance to see what other students are doing and develop professional networks. Some societies include graduate student members on their committees, which provides those student members the ability to develop important future skills in areas like how to run a meeting, set an agenda, or depending on committee, how publishing, convention planning, or managing organizations, etc., is done.

Professional societies from all fields in the geosciences offer online resources and videos that include interviews with geoscientists about their careers. More such content, with a greater diversity of possible careers and pathways, is needed. Some societies also run sessions at meetings on career related information, including poster sessions with companies and other networking opportunities. For example, the American Meteorological Society (AMS) holds a one-day student conference session just before their annual meeting, so that students can meet with different industries and graduate schools. The Association of Environmental and Engineering Geologists (AEG) hosts webinars with practicing professionals answering questions about careers, preparing for the ASBOG Fundamentals of Geology Exam, and addressing a wide variety of applications. The National Association of Geoscience Teachers (NAGT), in conjunction with SERC, offers a variety of workshops, conferences and online resources for graduate students interested in an academic career. Several GSA sectional meetings offer free lunches to meet with professionals.

Closer collaborations between graduate students, industry, and professional societies could create more opportunities for student career development and facilitate closer engagement between industries and academia. One possibility would be the promotion of internship opportunities, where professional societies can act as a clearinghouse collecting information on internship opportunities and providing contact information and links for applying.

Professional societies should continue to expand their mentoring programs, including virtual mentoring. The American Geophysical Union (AGU) is partnering with other societies in the successful Mentoring365 program to provide mentors from outside of academia. GSA's "On to the Future" program provides mentoring and other support to diverse communities at their annual conference (GSA Connects).

As noted previously in Section 4: Skills Framework, participation in professional scientific societies is important for graduate students in providing networking opportunities, experience in communicating science, and keeping them up to date on their science, as well as in career advancement. Societies should keep the cost of membership and meeting registrations low so all students can afford to attend and access these resources. Faculty influence whether a student becomes a member of a professional society and which ones they join. It is important for faculty to stress the importance of professional society membership, participation, and attendance. Students should also interact with professional nonacademic societies (e.g., American Water Resources Association — AWRA, American Institute of Professional Geologists — *AIPG*).

Funding Agencies

Funding agencies can influence the direction of graduate training by providing explicit requirements for the granting of graduate student support, such as requiring that plans for mentorship and career development using IDPs be reported as part of the proposal, or as a condition of award (as recently instituted by NSF). They should encourage and support modifying graduate curriculum for our changing field. For example, agencies can provide grant support for departments implementing changes to graduate programs, including "proof of concept" or pilot studies, and for faculty developing shared large databases for data analytics.

NSF and federal government agencies provide opportunities for supplemental funding which can be used to fund internships through currently funded awards. These opportunities are undersubscribed, partly because PIs and faculty are unaware of them but also because there is no obvious incentive for a faculty member PI to do so. These programs should be well advertised; notifying new PIs of this opportunity (e.g., Non-academic Research Internships for Graduate Students (INTERN) Supplemental Funding Opportunity) and others like it, when a grant is awarded may increase the number of applications. The broader impacts part of proposals should also include developing links to the private sector for training students and fostering interactions.

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Section 7. Fostering Change in Academic Communities: Case Studies

At the May 2019 three-day Summit for Heads, Chairs and Graduate Program Directors, 53 individual institutional action plans were developed and submitted. Of these fifteen reported on their progress in the fall of 2020 or 2021, two indicated that no one else on their faculty had any interest in making changes, and many of the others indicated that responding to the COVID-19 pandemic had consumed all their workplace bandwidth and no progress had occurred. In 2021 and 2022 a second progress report was provided by ten of those who had previously documented their progress.

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Clearly the onset of the COVID-19 pandemic in the spring of 2020 had a significant impact on implementing action plans, and later reports (2021, 2022) from heads/chairs discussed related factors that impacted their efforts, such as low faculty morale, budget issues, lower enrollments, loss of faculty, new personnel in upper administration, and other changes. Also, many plans became outdated during the pandemic, and/or new heads/chairs with different priorities took over.

At the 2022 workshops, many additional departments reported on changes they had made. They had learned about the 2018 Geoscience Employers' Workshop and 2019 Heads/Chairs Summit results, either through the AGI/AGU webinars, the Jackson School of Geosciences Summit webpages, or from the graduate programs section in the 2021 *Vision and Change* undergraduate report. Despite the smaller number of progress reports, these case studies show the types of successes and implementation strategies that worked, and the kinds of issues that different programs faced.

Overall, the participants at the 2019 Heads/Chairs Summit reported that they had presented the results of the Geoscience Employers Workshop and the Summit to their faculty, which was followed by faculty discussion on the best ways to promote graduate student academic and professional development. Some also had their faculty participate in the AGI/AGU webinars summarizing the results of these events.

Many heads/chairs found broad support among their faculty, with everyone on board regarding the need to improve graduate education, even in departments that had much less success in making changes to their undergraduate programs. In some cases, all the faculty were very supportive, while in others either the senior or junior faculty were less resistant to change. Approaches like those taken related to their undergraduate transformation efforts, such as mini-retreats, full day faculty retreats, and NAGT workshops, were found to be very helpful. Also, taking time to get collective buy-in, and efforts by individual faculty or graduate advisors, were instrumental in making department-wide changes.

"We held a full faculty retreat during August 2019 to discuss improvements to our graduate curriculum, inspired by the NSF Workshop I attended in May 2019. As anticipated, department faculty were enthusiastic about attempting to implement many of the improvements that I was able to propose on the basis of the workshop experience. A number of such improvements were subsequently implemented, or are in progress."

"We've had both quick success and incredibly good luck. Our department culture is the foundation for the quick successes, as our faculty enthusiastically embraced the ideas presented to them based on the workshop presentations. I thought we would, but I'm gratified to say that turned out to be true. We did not have to contend with any negative attitudes toward the idea of students interested in careers beyond academia."

"Success has occurred across the spectrum, with most coming at the grass roots level by faculty that are responding to the challenges of a changing workforce landscape in the geosciences. This has been supported by the Dean and Chair."

"I summarized the main points gleaned from the workshop at a faculty meeting in fall 2019. There's a definite sense that the more junior faculty are more onboard with the need for developing these non-technical skills though specific action items rather than just being picked up via osmosis during the normal course of graduate school."

"I have thought it was revolutionary from the start and it has been terrific in every way! Do it!"

(R1 universities)

As mentioned above, only two described no interest from their colleagues. For example,

"There was little (no) enthusiasm to hear much about the summit or explore any of the findings or suggestions. It is increasingly clear that everyone is mostly interested in their own research and students and their development rather than a coherent strategy that would require change. I have grown increasingly frustrated and disillusioned and have basically given up trying to fight windmills and pursue any changes."

(R2 university)

"Although I honestly still can't quite believe it, there was absolutely no positive response and no interest from others. I think that it is the usual mix of resistance to change, fear of new things, and unwillingness to put effort into something new and extremely worthwhile. My experience was actually the opposite … I anticipated strong positive response and a willingness to try, none of which actually happened."

(R1 university)

Others found that the easy things or those that did not require additional resources were most successful. Also, if the head/chair or graduate advisor could accomplish the changes on their own, it was easier than those requiring a larger group of their faculty to agree to or take on the effort to make the changes.

"The easy things were successful. Things that required more faculty effort (like establishing new courses, etc.) are taking more time, and have been somewhat side-tracked by reacting to the impact of the COVID pandemic and having to do deal with modifying instruction and research activities."

(R1 university)

"Anything that I could do by myself as Grad Advisor was successful. Anything that required a group effort was not. Altering grad courses, educating grad students as to desired skills and giving those students those skills in the Intro Course was successful because I was in control. Having other faculty embed these core skills has been less successful."

(R2 university)

INDIVIDUAL DEVELOPMENT PLANS AND MENTORING

The most widespread and successful change was in implementing Individual Development Plans (IDPs) and in changing approaches to the mentoring of students. Over half of the progress reports indicated at least a partial implementation of IDPs, and many of the participants in the 2022 workshops who had not participated in the Summit had also instituted IDPs. Programs with a required introductory course for all incoming graduate students incorporated the development of IDPs into that course, as this allowed all students to complete an IDP over time. These programs also found that positive responses by students to this process

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resulted in widespread implementation for students at more senior levels. Other programs implemented a pilot program and had faculty test its success with their own students before wider adoption. One department chair is working to increase the number of faculty participating after a core group of them started the process with their own students. Several mentioned using another department's website, which posted a description of their process and the forms they used or said that more non-postdoc examples, particularly for master's students, would be of great help. [see Appendices A & B for examples] In most cases students developed their IDP's through discussions with their advisor or graduate committee.

> "Having the students personally see how helpful the IDPs were for them as a reflection tool, and in aiding communication with their advisors, has in turn allowed the faculty to see that they (the students) actually want this for their own accountability. I suspect that has gone a long way towards the faculty/Graduate Committee seeing the IDPs as something worth requiring."
>
> (R1 university)

> "By implementing an IDP myself and working with one of my closer friends (also a full professor), I now hope to produce some sample/examples others can launch from and also will identify any challenges as I review my own students' plans."
>
> "I now think adding the IDP process into a Grad Seminar class I am teaching this fall will allow me to be the primary pilot test."
>
> (D/PU university)

One program started a new annual student reporting process that emphasized the use of IDPs, while another department modified its doctoral time-to-degree timeline to include aspects of professional development and self-assessment. A more in-depth approach taken by some was having students complete an IDP and then write a required reflective statement about their strengths and what areas they wished to focus on in the coming year.

Some universities are beginning to introduce individual development plans across the board in their graduate degree programs, and this helped department chairs to increase the use of IDPs.

> "We have been able to implement the IDP and committee mentoring for our graduate students. The Graduate School was just becoming interested in implementing IDPs, so we were able to be the beta-testers. This has worked well, but it was slow going to prod the reluctant faculty into complying. Fortunately, by the end of the semester we had nearly 100% compliance."
>
> (R1 university)

Even where it was not part of the formal structure, one department indicated that many students completed them regularly, and the faculty were working to integrate them into their program in a more systematic way.

> "It was very helpful to be able to initiate a trial run of the IDPs at scale across the department so that students could see the benefit of them. I believe having IDPs become a formal requirement for our graduate programs will help clear some other roadblocks, e.g., communication breakdowns between advisors and advisees based on goals and subsequent progress."
>
> "The Summit approaches have given students and postdocs even further ease and confidence in discussing their progression planning and futures."
>
> (R1 universities)

At the 2022 combined academic and employer workshops, much discussion centered around problems associated with mentoring and recommended possible changes. Several progress reports indicated they had made efforts to address such problems. One department made sure that each graduate student meets with their committee twice a year. Other departments concentrated on mentoring new students. One developed a new "Pod" mentoring program for first-year students that surrounds the new students with several mentors including faculty, research staff, and more senior students. Another revamped their onboarding to build cohorts.

> "We have ensured that each graduate student meets with the committee twice a year. This gives broader mentoring and a better sense of empowerment to graduate students."
>
> "Effectively on-boarding of new students eases inequalities in mentoring across the department and helps students develop a cohort."
>
> (R1 universities)

Two departments augmented their mentoring activities by reaching out to their alumni and developing alumni mentoring programs. Another is offering graduate students the ability to mentor undergraduates in their REU program. It was also noted by several departments that introducing IDPs has served as a helpful tool for increasing communication between advisors and advisees.

In one case, the graduate students successfully petitioned for a change. Although they were required to annually submit a progress report signed by their advisor, they found that many committee members were not aware of the direction the research had progressed and this often resulted in problems at defense time. This program now requires a formal meeting of the entire committee with the student to discuss their research after their comprehensive exam and at least one semester prior to their dissertation defense.

One department has specific written guidelines for advisors and co-advisors that, among other recommendations, includes setting clear expectations and goals for students regarding their academic performance and research progress, and meeting regularly and often to provide feedback on progress. Their guidelines also state that advisors should acknowledge that some students will pursue careers outside of academia and/or outside their research discipline, that their advisors and committees should assist them in achieving their chosen career goals, and recommends scheduling meetings to discuss topics other than research, such as professional development, career objectives and opportunities, climate, laboratory personnel relations, etc. Guidelines for graduate students are also provided. Another department developed "TA agreements that allow for clarity of expectations between TAs and supervisors."

To increase student input, one department now has two student-selected student representatives participate in faculty meetings. Another has implemented an "Ask A Graduate Student" webpage, with five current students working in representative fields in Earth Sciences who can answer questions by perspective students. "Each time the students are approached by the public, they brief the Graduate Coordinator on the interaction, and further contacts are then programmed, if warranted. The Grad Coordinator also offers feedback on the students' performance." The goal is predominately to help with student recruitment, however, another goal of this exercise is to "provide these students with some informal — yet important — experience in navigating the recruitment process from the position of recruiter, a novel experience."

NEW COURSES AND CONTENT CHANGES

Developing new courses and embedding more skills development into existing courses was the next most successful change.

The main new courses added were in machine learning and data analytics. One department started an experimental course on machine learning, called "Machine Learning for Atmospheric Science"; another developed both a machine learning and a data analytics class, and another instituted a cross-disciplinary machine learning tutorial/workshop. Taking this further, one program developed a diverse curriculum and certificate program of graduate and mixed undergrad/graduate classes in machine learning and data analytics in conjunction with faculty from non-geoscience departments.

Working in collaboration with other units on campus to foster skills development was a successful approach for several departments, including statistical applications, computer programming and training on instrumentation. One program has written three intra-University funding proposals involving collaborative efforts across broad groups within the University with the goal that graduate students will benefit from training in working with broadly diverse groups in a team setting.

At the 2022 workshops, the participating faculty clearly recognized the importance of students learning data analytics, and one progress report from the 2019 Summit noted that by 2022 their faculty had also recognized this need. In contrast, one report indicated that the need for such new courses was not embraced because they had no course requirements.

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Other new courses added included remote sensing and social responsibility in atmospheric sciences. Another department was able to transition a periodic 1- to 2-week short course in Economic Geology, run in conjunction with members of their Alumni Board who work in economic geology industries, to a full class by hiring a lecturer to work with them:

> "The course is specifically designed to introduce graduate students to career possibilities beyond academic paths, and thus fulfills a major goal of our curriculum improvement, to better prepare our students for careers in industry." The "first cohort of graduate students has already benefited from the class and from the networking opportunities it provided."
>
> (R1 university)

Another chair noted that he started teaching a class entitled "Environmental Rules and Regulations".

> "Many of the programs geoscience majors choose involve some need to understand science supporting rules, regulation, and legislation… It is essential to understand the role of science in rule development. That includes both the social sciences — especially economics — and the physical, chemical, and biological sciences…. Many of the students who participated in the class reported that the exposure was beneficial to them in both consulting careers and as regulators. So, incorporating some familiarity with rules is of value."
>
> (R1 university)

One department added an Introduction to Professional Geoscience course through hiring a recently retired alumnus as an adjunct instructor who collaborated with other local alumni to provide broader coverage of potential careers. They hope to use Zoom to be able to tap into a national pool of alumni as well. Another has an "Introduction to Professional Geology" course that focuses on work practices and expectations in the environmental and regulatory fields and discusses preparation for the national Practice of Geology exam.

Courtesy of the Jackson School of Geosciences, University of Texas at Austin

Of the several departments that offer an introductory course for new graduate students, most have embedded lectures on universal skills required by employers (see Section 4: Skills Framework), and one is developing a follow-on course that will cover time management, ethics, individual development plans and industry input. Others note that they have expanded and improved non-technical skills training in many courses, including for one department in a course on research conduct. Another has expanded their ethics and research integrity course to include other non-technical skills such as proposal writing, grant management, etc.

One department strongly encourages their students to take a semester-long course in a closely allied department that offers training in developing activities suitable for inclusion as "Broader Impacts" as defined by NSF.

One chair reported that "individual faculty have either expanded and improved 'non-technical skills' training or have added exercises and instruction — with detailed feedback — in existing courses." Several other reports noted that faculty were discussing ways to incorporate some of these skills into their courses, although at the time of the progress report nothing specific had occurred. Other course changes reported included developing and adding more field-oriented learning, and adding courses that are relevant to natural hazards and climate.

OTHER SUCCESSFUL CHANGES

Programmatic changes occurred in a couple cases. One department is updating their program goals and student learning outcomes to make it explicit that training in formal graduate coursework should provide students with many of the career skills needed beyond academia and research-oriented careers. They are waiting for upper administration approval. Another also defined new learning objectives and outcomes for their graduate program. One department did curricular revision using backwards design in an effort to align with employer priorities.

Professional development enhancements included a lunchtime professional development series in one department, while several other departments mentioned covering the need for developing non-traditional skills in their graduate student orientations. One program conducts a regular series of professional development talks by alumni and recruiters. Other departments identified and publicized workshops and courses to their students, from around campus and online, including professional societies, and/or assembled a list of on-campus resources for graduate students. In one case faculty PIs were given contract verbiage to include professional development as a requirement for RA's.

Alumni engagement was sought in many ways. In one department, their alumni board was reinvigorated and now provides career advice, mentoring, and is a source for internships; another reached out to their alumni to try to create a professional advisory board. Others invited alumni to speak about career experiences and opportunities, which has helped students become more aware of professional opportunities outside of academia. One department surveyed recent graduates on the skills where they felt their graduate experiences provided them with training and support, and what skills they found they needed in their professions but didn't get help in developing as graduate students. They used emails, alumni visits to campus and professional society meetings to get input.

In terms of communication, several departments sought to provide more opportunities for their students to present their science at conferences, developing an internal travel award competition that was touted at workshops and within the department seminar series. One program had a proposal pending to offer a Science Communication course.

> "Our student-led seminar program was expanded, and its organizers were briefed in detail to provide them with inspiration to facilitate improvements in graduate student communication training. Subsequently, faculty were allowed to participate in the seminar series, and both organizers and presenters exhibited a marked increase in the seriousness with which both presenters and audience brought to the effort."
>
> (R1 university)

Many heads/chairs indicated that they were making or exploring DEI efforts within the department and/or with other STEM fields, including holistic admissions, creating diversity and recruitment committees, dropping the GRE requirement, and joining or applying to join AGU's Bridge program.

> "We now have holistic admissions with required supplement prompts that map to the traits for success in our program. We use a rubric system to evaluate applicants."
>
> (R1 university)

ROADBLOCKS AND OTHER ISSUES

Unquestionably the main roadblock mentioned by respondents was COVID. As with the rest of the world, it upended universities and colleges, provoking a complete overhaul of instruction, disruption of research, loss of contact with students, increased workloads, major impacts on budgets, faculty burnout, student and faculty mental health issues, decreasing enrollments, and loss of faculty, to name a few of the issues listed. One chair reported in 2020 that he had discussed the concept of IDPs with about 25% of the faculty and was "sowing seeds" to gain acceptance but had made little headway a year later because he was still trying to get the faculty and students "past COVID." Generally, those that already had started to implement changes were able to put these on hold and restart them once things began to open again, and some who had not made any progress have been able to get traction since then. Because of the need to change their instructional modalities and approaches during the pandemic, many faculty became more receptive to changing their undergraduate pedagogies, courses, and curriculum. At the graduate level, discussions at the 2022 workshops showed that during the interim, faculty had become much more aware of the need for change, particularly the importance of computer programing, data analytics, and science communication.

The other roadblocks included resistant faculty, faculty apathy, poor faculty morale, workloads that were too high, lack of department bandwidth to reach out to alumni, and lack of resources and funds.

"Faculty are reluctant to change the ways that they have done things until the problem impacts them. So, showing data that the problem is impacting our department helped garner some buy in to change elements of the graduate program."

(R1 university)

"The second biggest road block has simply been faculty apathy. They see the need, but they don't feel they have the time, or they don't think these should be addressed in a systematic manner. I have not been able to overcome this. I do what I can — but if I don't have faculty buy in, many of the proposed changes to our program will not happen."

"Faculty reluctance to change. I find faculty to be rather risk-averse. There is little willingness to take on new initiatives. Change management is not easy. While transparency and democratic decision making are fine, incentives must be created to drive change."

(R2 universities)

Several progress reports mentioned issues with the upper administration. In some cases, the appointment of new deans impacted the ability of the departments to make change, for example, through new directives that took precedence, or by requiring substantial work of faculty that took time away from implementing changes to the graduate program. Also, some deans did not allow faculty hiring to replace those that left or retired or had such strapped budgets that they could not support any of the proposed new courses, etc. Two departments mentioned a lack of upper administration support for their Master's program, which is an important degree for geoscientists.

"There is an increasing sentiment that our administration does not appreciate master's degrees and there is a push to offer and support Ph.D. programs rather than master's programs unless the latter provide a revenue stream."

(R2 university)

A misconception expressed by the director of a doctoral-only graduate program at the 2019 Heads/Chairs Summit, was that all of their graduates went into academia, so the skills recommended by geoscience employers were unnecessary. Clearly faculty with this attitude cause roadblocks to change. A similar problem was expressed in a progress report:

"The Dean and several vocal faculty members successfully pushed for what I can only describe as a free-for-all curriculum — no course requirements of any kind for students."

"The Dean said that it was "arrogant" to suggest anyone but a student's faculty advisor would know what training was best for their student."

"We have a surprisingly large number of faculty who believe we shouldn't have graduate class requirements at all and think students will learn everything they need to know in the lab."

"The proposed curriculum will result in students not taking any classes at all outside of their narrow discipline, nor will most faculty promote non-technical skills unless they apply to their specific research."

"Unfortunately, I have no advice for others. For substantial graduate training change to occur one either needs substantial buy-in at the faculty-level, or an administration that is passionate and willing to support change. Both are ideal, but at least one is critical. Having neither means going nowhere."

(R1 universities)

One issue with IDPs was noted and points out the need for good mentoring.

"Some students were not good at self-assessment and goal setting, so their initial IDPs were not useful. We were not aware of this problem, but we mentored students to think more in-depth about their strengths, weaknesses, and goals."

(R1 university)

The department that required each graduate student to meet with their committee twice a year, received pushback from faculty but was able to demonstrate it was worthwhile.

"Some faculty felt that organizing committee meetings took too much time, especially if they advise more than 4 students or serve on a larger number of committees." However, "meeting with committees has worked, as it has exposed faculty who have issues with particular students and sheds light on the process for all."

"Eventually, the argument that this investment of time would pay off in the long run as it minimizes future issues won the day."

(R1 universities)

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Courtesy of the Jackson School of Geosciences, University of Texas at Austin

ADVICE

Heads/chairs found various ways of convincing their faculty to implement changes, from emphasizing that the geosciences have changed to appealing to their sense of pride.

> "Increase open debate and discussion to improve awareness of the need to adapt in the geosciences or be left behind."
>
> "Engage the entire faculty within departments in coming up with the final version of the action plan. Have them realize that the success of students is part of the faculty legacy."
>
> (R1 universities)

Others stressed the need to have all the examples and samples of what you are proposing collected as early as possible and have them ready to hand out to other faculty before you try to get buy-in, or being proactive and pushing ahead even though such changes may take you out of your comfort zone. Some felt that it was important to get all the faculty to buy-in whereas others took a more stepwise approach.

> "It is important to get faculty buy in. If only one or two people are interested in implementing improvements, things cannot be done in a systematic and programmatic way."
>
> (R2 university)
>
> "There are many relatively easy steps to make that have minimal impact on faculty time, so go for it."
>
> (R1 university)

> "Pick one battle at a time. This past year I ended up working on holistic applicant assessment because it was easier to get everyone on board for that one."
>
> "I will pick up other issues that need consensus building now that that one is done."
>
> (R1 university)

Others noted that heads/chairs should not be discouraged if not everyone buys-in.

> "There will always be faculty who do not see the importance or have dissenting views on the need to make major changes."
>
> "While we need to listen and acknowledge these viewpoints, as long as there is a critical mass of energetic faculty who have buy-in to make positive change, it makes it substantially easier to make forward progress."
>
> "Don't be surprised if people do not want to, or are not willing to, understand."
>
> (R1 universities)

Several reports noted that there is a lot of graduate education reform going on across STEM and that comparing notes with others in the same institution should be helpful, especially as other science departments will know how to work within the constraints of your institution.

While most mentions of funding and resources were in terms of roadblocks — i.e., needed but not available, a couple departments found support from their university.

> "The good luck stems very, very clearly from the unexpected — and unreliable! — injections of funding both into our department, in the form of new faculty, and into the university as a whole to pursue machine learning/AI based research. I doubt this is easily reproduced elsewhere in the absence of serious funding support. History is replete with examples of this phenomenon: when funds are available, rapid and positive development follows."
>
> (R1 university)
>
> "Convincing the central administration that the dept. was worth some investment — It took some effort, but once you have their ears, and you make a good argument, they can be swayed."
>
> (R2 university)

One report stressed the need to talk to graduate students to identify their "pain points". They recommended acknowledging that you won't be able to address them all, but being clear about how you will (or plan to) make changes to the program accordingly — or how you will advocate on their behalf. Another chair said that it was important to remind faculty of the value of IDPs for students so that they continued to use them in advising.

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Appendix A. Individual Development Plan for Graduate Students

An **Individual Development Plan** (IDP) is a 'living' document (one that is continually edited and updated) that helps a student identify areas of strength as well as areas that need improvement in order for the student to achieve their professional development and career goals. An IDP is an important tool for facilitating clear communication between a student and their supervisor(s).[1] It can be an important component of a broader mentoring program.

The goals are straightforward. The IDP helps to identify:

- Long-term career options/goals a student may wish to pursue (subject to change as the student progresses through the degree)
- The necessary tools to meet a given career goal
- Short-term needs for improving current performance

The IDP provides a structured pathway for developing and working towards long-term goals. Identification of short-term goals helps a student and supervisor to establish milestones during the course of study for the degree, and helps foster a sense of continued accomplishment as specific objectives are met. In addition, the IDP is a convenient tool to foster clear communication between the student and the supervisor(s).

Development, implementation, and revision are important steps in the production of an IDP. Both the student and the mentor are **necessarily** involved in the process, and the effort should be interactive.

BASIC STEPS

Steps	…for the student	…for the mentor
Step 1:	Conduct a self-assessment	Become familiar with available opportunities
Step 2:	Survey opportunities with mentor	Discuss opportunities with student
Step 3:	Write an IDP, share it with mentor and revise	Review IDP and help revise
Step 4:	Implement the plan, review regularly, and revise as needed	Establish regular review of progress and help revise the IDP as needed

1 The example given in Appendices A & B combines and modifies wording from numerous academic institutions.

EXECUTION OF THE IDP PROCESS FOR GRADUATE STUDENTS

Step 1. Conduct a Self-assessment

- Assess your skills and strengths; identify areas that need further development. Formal assessment tools may be helpful.
- Take a realistic look at your current abilities. This is a critical part of career planning. As part of this process, ask peers, mentors, family members, and friends what they see as your strengths and your development needs.
- Outline long-term career objectives. Ask yourself:
  - What type of work would I like to be doing?
  - Where would I like to be in an organization?
  - What is important to me in a career?

Step 2. Survey Opportunities with Mentor(s)

- Identify career opportunities and select from those that interest you.
- Identify developmental needs by comparing current skills and strengths with those needed for your preferred career choice.
- Prioritize your developmental areas and discuss with your mentor(s) how these should be addressed.

Step 3. Write an IDP

The IDP will help you to map out the general path you want to take and helps to match skills and strengths to your career choices. It is a challenging document to produce because it requires honest self-appraisal, acceptance of constructive input from others, and because **needs and goals will almost certainly change** over your time as a graduate student. The goal is to build upon current strengths and skills by identifying areas for development and providing a way to address those needs. The specific objectives of a typical IDP include:

- Establishment of effective dates for the duration of your time in program (usually externally imposed to some extent)
- Identification of specific skills and strengths you need to develop (based upon self-assessment and discussion with your mentor(s) and others)
- Definition of approaches to obtain specific skills and strengths (for example, courses, technical skills and training, teaching experience, supervisory experience)
- Discussion of draft IDP with your mentor(s)
- Revision of the IDP as appropriate

Step 4. Implement the Plan, Review Regularly, and Revise as Needed

The plan is the beginning of a career development process, and serves as a map you can easily revise as needed.

- Put your plan into action.
- Revise and modify as needed. The first draft of your IDP is not the final one! It needs to be modified as circumstances and your goals change. The challenge with implementation is to remain flexible, recognize when your goals are changing, and be open to change.
- Review the plan with your mentor(s) regularly. Revise the plan on the basis of those discussions.

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EXECUTION OF THE IDP PROCESS FOR MENTORS

Step 1. Become Familiar with Available Opportunities

Because of your experience, you should already have knowledge of some career opportunities. Always bear in mind that your student may have career goals that are different from your initial assumptions or expectations, and that those goals may change through time. Familiarizing yourself with other career opportunities and with trends in job opportunities helps you be a more effective mentor to students whose career paths may well differ from your own.

Step 2. Discuss Opportunities with Your Student

This needs to be a private, scheduled meeting distinct from regular research-specific meetings with a lab-group or the individual student. Set aside adequate time for an open and honest discussion.

Step 3. Review the IDP and Help to Revise It

Provide honest feedback — both positive and negative — to help your student set realistic goals. Agree on a development plan that will allow the student to be productive in the laboratory/field/research arena **and** will help prepare them for their chosen career.

Step 4. Establish Regular Review of Progress and Help to Revise the Plan as Needed

The mentor(s) should meet at regular intervals with the student to assess progress on the IDP, expectations, and changing goals. This is distinct from research progress, or progress on the thesis or dissertation. On at least an annual basis, the mentor(s) should conduct a performance review designed to analyze what has been accomplished and what remains to be done. A written review is helpful in objectively documenting accomplishments.

Appendix B. Individual Development Plan Outline

STUDENT PORTION

1. SKILLS ASSESSMENT — what skills do I currently have?

2. CAREER ASPIRATIONS — what career pathways interest me? What do I like to do and what do I value about my work environment?

3. DESIRED SKILLS — setting goals for the skills I want.

4. PROFESSIONAL DEVELOPMENT — what support can I take advantage of?

DESIRED SKILLS

Desired skills should be:

- **Specific & Sensible** — Are goals focused and unambiguous? Considering difficulty and timeframe, are goals attainable?
- **Measurable** — Could someone identify whether or not you achieved this goal?
- **Action-oriented** — What action(s) do you need to take to achieve the goal?
- **Help** — What support will you need? Where can you get it?
- **Time-bound** — What time frame are you accountable to?

Use the spaces provided (expand as needed) to reflect on your self-assessment and career aspirations/professional values while considering the following questions:

1. How do your strengths align with your current role? Can you identify gaps in skills or strengths?
2. If you are unsure of a career path that is of interest to you, how can you apply your strengths towards career exploration?
3. How can the information in boxes 1 and 2 be used to prioritize the goals that you set in box 3?

STUDENT-MENTOR RELATIONSHIP DISCUSSION—THOUGHT QUESTIONS

1. What are potential barriers to successful student-mentor conversations? What strategies can you use to work around those barriers?
2. What do you think 'productive conflict' means? How can you establish goals when you and your mentor disagree?
3. What should the next steps be after your initial meetings(s) with your mentor? How can you follow up with your mentor?

MENTOR PORTION

1. SKILLS ASSESSMENT—what skills does my student currently have?
2. CAREER ASPIRATIONS—how can I support my student's career goals? What does my student like to do?
3. DESIRED SKILLS—helping my student set goals for the skills they need to be successful.
4. PROFESSIONAL DEVELOPMENT—what support can my student take advantage of? How can I advocate for my student?

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Appendix C. Participating Employers and Universities

EMPLOYERS

AGU Bridge

AIR-Worldwide

American Geophysical Union; Higher Education

American Geophysical Union; Affiliation, Engagement and Membership

American Geosciences Institute; Geoscience Workforce

American Geosciences Institute; Policy and Critical Issues

American Geosciences Institute; Technology and Communications

American Meteorological Society

ARCADIS U.S., Inc.

ASBOG

Bureau of Safety and Environmental Enforcement

Chevron Energy Technology Company

Consortium for Ocean Leadership

EL-SURGE GEOSCIENCES ltd

ExxonMobil Corporation

Florida State Fire Marshal

Freeport McMoRan

GeoCorps

Geological Society of America, Diversity Office

Global Weather Corporation

Google

IBM and the Weather Company

Integral Consulting

Jupiter Intelligence

Langan Engineering and Environmental Services

Leigh Freeman Consultancy

Liberty Mutual

Mining Matters

Mortenson

NASA Johnson Space Center; Astromaterials Research and Exploration Science (ARES) Division

NASA Goddard Flight Center; Carbon-Climate Feedback

NASA Goddard Space Flight Center; Aerospace Technology and Research Meteorology

NASA Headquarters

NASA Jet Propulsion Laboratory; Science Division

NASA Jet Propulsion Laboratory; Geophysics and Planetary Geosciences; Mars

National Academies of Sciences, Engineering, and Medicine; Ocean Studies Board

National Technical Association

Nebraska Oil and Gas Conservation Commission

New World Associates

NOAA — National Oceanic & Atmospheric Administration; Research Fishery

NOAA — National Weather Service, National Centers for Environmental Prediction

NorthWest Research Associates

National Science Foundation; Einstein Fellow

National Science Foundation; AAAS Science & Technology Policy Fellow

National Science Foundation; Antarctic Science Section

National Science Foundation; Division of Atmospheric and Geospace Sciences

National Science Foundation; Division of Graduate Education

National Science Foundation; Earth Sciences

National Science Foundation; Education and Cross Disciplinary Activities Program (GEO/AGS)

National Science Foundation; Education & Diversity (GEO/OAD)

National Science Foundation; Geoscience Directorate

National Science Foundation; Geospace Science Section

National Science Foundation; Management and Program Analysis

National Science Foundation; RISE

Pacific Northwest National Laboratory

S&ME

Scripps Institution of Oceanography

Shell USA

Smithsonian Museum of Natural History; science communication

Smithsonian Museum of Natural History; Rocks and Ores

Spire Global

Swiss Re

Tahoe Expedition Academy

TCEQ — Texas Commission on Environmental Quality

The Institute of Marine Engineering, Science and Technology

Timberline Resources

USGS — US Geological Survey; Florence Bascom Geoscience Center

USGS — US Geological Survey; Water and Science

Utah Department of Environmental Quality

vbh2o

WeatherCall Services

Weathernews Inc.

Woods Hole Oceanographic Institution

Woodside Energy

World Bank

ACADEMIC INSTITUTIONS

Boise State University

Bowling Green State University

Buena Vista University

California State University — Chico

California State University — Long Beach

Carleton College

Central Michigan University

Clemson University

Colby College

Colorado School of Mines

Colorado State University (Atmospheric Science)

Colorado State University (Geoscience)

Columbia University in the City of New York

Coppin State University

Cornell University

Cuesta College

Dartmouth College

Daytona College

Delta College

Delta State University

East Carolina University

Edinboro University of Pennsylvania

Elon University

Fitchburg State University

Flagler College

Florida Agricultural & Mechanical University

Florida Atlantic University

Florida Gulf Coast University

Florida State University (Earth Science)

Florida State University (Atmospheric Sciences)

George Mason University

Georgia Southern University

Graduate Center of City University of New York

Grand Valley State University

Hardin-Simmons University

Honolulu Community College

Idaho State University

Illinois State University

Indiana University — Bloomington

Indiana University of Pennsylvania — Main Campus

Indiana University Purdue University Indianapolis (IUPUI)

Johns Hopkins University

Lawrence University

Long Island University — CW Post Campus

Miami University — Oxford

Michigan State University

Michigan Technological University

Middle Tennessee State University

Missouri State University

Nevada State College at Henderson

New Mexico State University

North Carolina State University

Northeastern University

Northern Illinois University

Oklahoma State University

Old Dominion University

Oregon State University

Pennsylvania State University — Main Campus (Meteorology)

Pennsylvania Western University — California

Purdue University (Atmospheric Science)

Rensselaer Polytechnic Institute

Sam Houston State University

Savannah State University

South Dakota School of Mines and Technology

St. Petersburg College

Stanford University

Stony Brook University (Marine Science)

SUNY Buffalo State

SUNY College at Fredonia

SUNY College at Oneonta

Syracuse University

TCU – Texas Christian University

Tennessee State University

Texas A & M University (Atmospheric Sciences)

Texas A & M University (Geology/ Geophysics)

Texas A & M University (Oceanography)

Texas Tech University

University of Alaska Fairbanks (Fisheries and Ocean Sciences)

University of Albany — SUNY

University of Arizona

University of Arkansas at Little Rock

University of Arkansas at Pine Bluff

University of Arkansas — Main Campus

University of Calgary

University of California — Berkeley

University of Colorado at Boulder

University of Connecticut (Earth Science)

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University of Connecticut (Marine Sciences)

University of Delaware (Marine Science and Policy)

University of Delaware (Geological Sciences)

University of Denver

University of Florida

University of Georgia — Athens

University of Georgia (Sea Grant College Program)

University of Hawaii at Manoa

University of Houston

University of Illinois — Urbana-Champaign

University of Iowa

University of Kentucky

University of Louisiana at Lafayette

University of Massachusetts — Amherst

University of Minnesota

University of Missouri

University of Montana — Missoula

University of Nebraska at Lincoln

University of New Mexico

University of North Carolina at Chapel Hill

University of North Carolina at Charlotte

University of Oklahoma — Norman Campus (Meteorology)

University of Oklahoma (Geology/Geophysics)

University of Oregon

University of Puerto Rico — Mayaguez Campus

University of Rhode Island (Oceanography)

University of Saskatchewan

University of South Carolina

University of South Florida (Geosciences)

University of South Florida (Marine Sciences)

University of Southern California

University of Tennessee — Chattanooga

University of Texas at Austin (Geosciences)

University of Texas at Austin (Marine Sciences)

University of Texas at Dallas

University of Texas at El Paso

University of Texas — San Antonio

University of the Virgin Islands

University of Toledo (Environmental Sciences)

University of Toronto

University of Utah (Atmospheric Sciences)

University of Wyoming (Atmospheric Sciences)

University of Wyoming (Geology/Geophysics)

Vanderbilt University

Virginia Tech

Washington University in St. Louis

Western Kentucky University

Westminster College (UT)

Winthrop University

Woods Hole Oceanographic Institution (Marine Science)

York College (City University of New York)

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