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# Reimagining Geoscience Education for Sustainability

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Geoscience is crucial for addressing sustainability challenges related to climate change, the energy transition, water resources management, and natural hazards. However, the capacity of the geosciences to enable sustainable societies is limited by several weaknesses in geoscience education. This paper supplies a concise review of Earth science education around the world and highlights resources and strategies for reshaping it to better support sustainability initiatives and attract more students to geoscience degree programmes and careers. The poor quality of Earth science education in schools around the world reverberates throughout society to perpetuate low levels of awareness of geoscience and misperceptions about its relevance and problem-solving potential. University geoscience programmes, which typically focus on geoscientific content and technical skills, must broaden to encompass the social and ethical dimensions of sustainability and to foster communication skills that enable interdisciplinary, cross-sector collaboration. Efforts to recruit future geoscientists must diversify to highlight a wide range of sustainability-related career paths and to attract people who bring perspectives from different backgrounds, cultures, gender identities, and life experiences. Many of these challenges have persisted for decades, but connecting geoscience education to wider conversations around sustainability, social justice, diversity and inclusion, and ethics is providing a new narrative for Earth science education that better aligns with evolving societal needs and the interests of today's young people. This piece aims to provide a point of entry into the multifaceted literature around geoscience education and its importance to sustainability. It also reflects on how critical examination of the history, culture, and ethical responsibilities of the geosciences underscores the urgent need to reinvent Earth science education as an essential tool for addressing obstacles to sustainability arising from human-Earth interactions.

**Keywords: sustainability, sustainable development, geoscience, earth science, education, geoethics**

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## INTRODUCTION

In this time of multiple, converging, and accelerating socio-environmental crises, the need for geoscientific expertise has never been greater (Mora, 2013; Gill, 2017; Gill and Smith, 2021; Capello et al., 2023). Yet, geoscience's ability to contribute to more sustainable societies is hindered by several weaknesses in current Earth science education. These limitations include: 1) the low-quality of school-level Earth science education (King et al., 2021; Orion and Libarkin, 2023); 2) a public perception of geoscience as boring, irrelevant, and complicit in environmental

degradation through its association with the oil and mining industries (Whitchurch, 2019; Wadsworth et al., 2020; Boone et al., 2021; Stewart et al., 2023); 3) inattention to the human dimensions of sustainability in the preparation and professional development of geoscientists (Gill, 2017; Stewart and Gill, 2017; Gill, 2021; Metzger et al., 2021; Capello et al., 2023); and 4) a lack of racial, ethic, gender, and cultural diversity in the geosciences that restricts creativity, narrows perspectives, and diminishes problem-solving capacity (Geological Society of London/University Geoscience UK, 2019; Mogk, 2021; Carrera et al., 2024; Rogers et al., 2024).

Geoscience education at all levels and in different settings is a powerful tool for addressing obstacles to sustainability arising from human-Earth interactions. However, "geoscience education as usual" will not suffice. As the relationship of geoscience to society changes in response to global crises linked to resource extraction and management, environmental damage, and climate change (e.g., Stewart et al., 2023), so too must geoscience education evolve.

This paper provides an overview of the current state of Earth science education around the world, explores its connections to education for sustainability and geoethics, and surveys strategies for reshaping geoscience education to better align with sustainability initiatives and the values of today's young people. It also highlights a fundamental shift in decades-long efforts to reshape and strengthen Earth science education, moving from "preaching to the choir" mostly within the geoscience education community, to a more outward-facing perspective that links Earth science education to wider, intertwined, social and educational concerns. These include sustainability, social justice, diversity and inclusion, and ethics. This re-orientation, combined with critical examination of geoscience's roots in colonialism and extractivism, provides a fresh framework for reimagining Earth science education to better support sustainability agendas.

## THE CURRENT STATE OF GEOSCIENCE EDUCATION

It is important to note that, although efforts have been made to include examples from around the globe, the summary below is biased towards accounts of geoscience education in the United States and Europe. This is especially true for discussions about university-level geoscience education and workforce preparation. The relative scarcity of papers about geoscience education in non-Western nations is consistent with the more general problem of under-representation of authors from the developing world in the academic research literature of the English-speaking world (e.g., North et al., 2020; Lund, 2022).

Geoscience's roots in colonialism and resource exploitation is another factor to consider regarding the status of geoscience and geoscience education in the non-Western world. Paul (2020) connected the development of modern geoscience during the period of Europe's colonial expansion to a diminished capacity for geoscience in India and other economically developing countries. He suggested that native contributions to Earth science and development of local geoscientific expertise in these countries were overshadowed by colonial influence, limiting opportunities for geoscience to flourish. Relatedly, Scarlett (2022) noted that colonialism "continues to block local geoscientists from researching natural hazard phenomena that they live with. This is done by removing agency in their own knowledge and understanding of natural hazard phenomena, the lack of resources to train homegrown geoscientists and to support the research of local geoscientists, who in some cases, must rely on the collaboration of overseas partners to access the funding" (p. 2).

Several authors stress the need to build geoscience capacity in developing countries, where economic and political factors may contribute to a lack of investment in Earth science education and research (Gill et al., 2018; Jones and McCormick, 2020; Geology for Global Development, 2022). For example, many nations in Africa lack the geoscience expertise, facilities, and financial resources needed to sustainably develop their natural resources and mitigate against natural hazards and the effects of climate change (Martinez-Frias and Mogessie, 2012; Jessell et al., 2018).

Geoscience education, broadly interpreted, encompasses two modes of communicating geoscience to society: the formal education system, and out-of-classroom channels including television, museums, and parks (Orion, 2019). A brief summary of geoscience education at different levels and in diverse settings around the world is provided below. For a recent, comprehensive review of four decades of geoscience education and geoscience education research, see Orion and Libarkin (2023).

### School-Level Earth Science Education

A number of studies (King, 2008; King, 2013; Orion, 2019; King et al., 2021; Orion and Libarkin, 2023) have revealed a disturbing gap between the importance of Earth science education and its position at "the bottom of the school science food chain" (Orion and Libarkin, 2023, p. 693). This disconnect is reflected in the fourth and most recent international survey of school-level Earth science education, conducted in 2017/2018 by UNESCO and the International Geoscience Education Organization (IUGS/COGE, 2019). Data were collected from 51 countries. King et al. (2021) reported the key findings listed below.

- Most countries have national standards covering Earth science, but the Earth science curriculum is either absent or not followed closely in more than half of them.
- Earth science instruction is most common at the lower secondary (elementary) level.
- Geoscience content is distributed across the curriculum, and Earth science is rarely taught as a "stand-alone" subject.

- Most Earth science teachers are not specialists in the field, support for these teachers through courses and professional development is generally low, and very little financial support is provided.
- The relatively low status of school-level Earth science is reflected by the often-poor quality of the written materials available to support it.
- In three-quarters of the surveyed countries, students are provided with little or no information about Earth science career paths.

Additional issues include the widely-held misperception that Earth science is inherently less rigorous than physics, chemistry, and biology (Orion and Libarkin, 2023; Rogers et al., 2024) and the lack of a coherent narrative for what Earth science is and what Earth scientists do (Geological Society of London/University Geoscience UK, 2019; Rogers et al., 2024). The latter is exacerbated by the often-piecemeal distribution of Earth science content across different school subjects including geography, other science classes, and environmental science (Boatright et al., 2019; Geological Society of London/University Geoscience UK, 2019; Orion and Libarkin, 2023).

In the United States, the Next-Generation Science Standards (NGSS Lead States, 2013) feature an expanded focus on Earth science topics as compared to previous science standards, and include attention to sustainability-related topics such as climate change, human impacts on the Earth system, and resource use and distribution (LaDue and Manning, 2015; Egger et al., 2017). The Next-Generation Science Standards were welcomed as an unprecedented opportunity to raise awareness of the relevance of Earth science and increase its presence in American high schools (e.g., Wysession, 2014; LaDue and Manning, 2015; Egger et al., 2017). However, resistance to change and a shortage of certified Earth science teachers have proven to be barriers (Wysession, 2022).

## Informal Earth Science Education

King et al. (2021) observed that although formal Earth science education is weak in many countries, informal geoscience education enjoys wide support around the globe, with many dedicated educators working to counter the poor quality of Earth science instruction in schools. Out-of-classroom activities that inform young students and the general public are provided by museums, interactive science centres, parks, and numerous other organizations and agencies (King et al., 2021).

UNESCO Global Geoparks, which UNESCO describes as "single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development" (UNESCO, 2024a), are notable providers of informal Earth science learning. Geoparks offer out-of-classroom programmes and activities for both students and their teachers and the general public (UNESCO, 2024a; Catana and Brilha, 2020). There are currently 213 Geoparks in 48 countries around the world (UNESCO, 2024a).

## University-Level Geoscience Education

Enrolments in university geoscience programmes in several industrialized countries have shown alarming declines in the past decade (Boatright et al., 2019; Whitchurch, 2019; Wadsworth et al., 2020; Boone et al., 2021; Geoscience on the Chopping Block, 2021). Decreases ranging from 30% to 43% have been reported from the United Kingdom, Australia, Canada, and the United States (Stewart et al., 2023). The status of enrolments in university-level geoscience programmes in developing countries is less well-documented, although Anderson (2023) reported that universities in Latin America are not experiencing a similar decline in geoscience students.

No single explanation can account for the diminishing numbers of students pursuing geoscience degrees and careers (Bird et al., 2020; Wadsworth et al., 2020; Anderson, 2023; Stewart et al., 2023), but one widely-cited factor is the perception among students, teachers, parents, and the public at large that geoscience is linked exclusively to "dirty" extractive industries that harm the environment (Geological Society of London/University Geoscience UK, 2019; Boone et al., 2021; Stewart et al., 2023).

The lack of diversity in the geosciences, a problem that has persisted for decades in both the United States and the United Kingdom (e.g., Bernard and Cooperdock, 2018; Carter et al., 2021; Dowey et al., 2021; Marín-Spiotta et al., 2020), is another factor. Accessibility and inclusion issues are additional obstacles to student recruitment and retention (Dowey et al., 2021; Mogk, 2021; Rogers et al., 2024).

# A CYCLE OF UNAWARENESS AND MISPERCEPTIONS

The geosciences are caught up in what Orion (2017) called a "vicious cycle" of unawareness that starts with the low quality of Earth science education in most of the world's schools. Greco and Almberg (2018) explained that as a result of this cycle "many students leave the school system with misconceptions and apprehensions about the relevance of Earth Science to their lives and the importance of Earth science education. These attitudes help perpetuate the narrow perspectives of reductionist education policymakers including politicians, scientists, and educators. Consequently, we see no appreciable change in the Earth Science status in schools and how it is taught" (p. 9).

Where there *is* societal awareness of the geosciences, the impression is often negative. The geosciences are facing "a crisis of confidence" as a result of their traditional association with the exploitation of Earth resources, legacy of colonialism, and low ethnic, racial, gender, and cultural diversity (Capello et al., 2023; Stewart et al., 2023). Whitchurch (2019) observed that "Many people do not fully comprehend the essential role the geosciences must play in addressing the grand challenges and several geoscientific professions are not viewed as noble in the way they once were. The association of geoscience with the oil and gas and extractive industries has (not unfairly) led to

the subject being labelled as 'dirty'. . .and few youngsters are interested in studying a subject that played a central role in damaging our planet" (p. 9).

A 2021 survey of nearly 600 people in the United Kingdom sought to understand public perceptions of geology and factors that present barriers to pursuing degrees and careers in the geosciences (Rogers et al., 2024). The most common perceptions among those not involved in geology were that it is boring, dull, outdated, and dominated by white males. The comments below capture some common negative impressions of geology and geologists (Rogers et al., 2024, p. 11):

- "You just look at rocks and have beards"
- "Studying rocks feels old fashioned, and maybe a little like stamp collecting. Is there anything new to discover with rocks?"
- "Oil and gas, old fashioned, white able-bodied bearded men in the field with hammers and boots"
- "I think its often thought of as an antiquated science associated with fossil fuels and mining etc."

How can we reimagine geoscience education to break the cycle of unawareness and better position geoscience as an essential player in the sustainability transition? The first step is to make more explicit connections between geoscience and sustainability and highlight the potential for geoscience education to support local and global sustainability goals.

The synergy between geoscience and sustainability may be obvious to geoscientists and has been well-documented (e.g., Gill, 2017; Stewart and Gill, 2017; Gill and Smith, 2021; Capello et al., 2023). Examples include water resource and land use management, natural hazard mitigation, and fostering the clean energy transition through exploration for critical minerals, evaluating the potential for geothermal energy, and carbon sequestration and storage (Jansson et al., 2020; Gardiner et al., 2023; Sorkhabi, 2024). However, geoscience is not well-represented in international sustainability agendas (Gill and Bullough, 2017; Stewart and Gill, 2017) and the connection is often overlooked in the geoscience curriculum (Rogers et al., 2018).

## GEOSCIENCE EDUCATION FOR SUSTAINABILITY

The Sustainable Development Goals (SDGs) were adopted by 193 nations in 2015 as a blueprint for a more just and sustainable future (United Nations, 2015). Comprised of 17 goals and 69 targets to be achieved by the year 2030, the SDGs have been described as an action plan for "people and planet" and stress the need to balance human wellbeing with protection of the Earth systems that support all life on Earth (United Nations, 2015).

Although the SDGs have been widely criticised for their non-binding nature, inconsistencies, inadequate financing for low- and middle-income nations, focus on continuing economic growth, and grounding in Western ideologies (e.g., Swain, 2018; Arora-Jonsson, 2023; Nerini et al., 2024), they remain the world's current roadmap for a more just and sustainable future (Nature, 2023; Nerini et al., 2024). The SDGs are widely used around the world in government, business, policy, and education as a framework for addressing challenges to sustainability (Nature, 2023; Ordonez-Ponce, 2023).

According to Rieckmann (2017), "Embarking on the path of sustainable development will require a profound change in how we think and act" (p. 7). This change can only be achieved through the transformative power of education that provides people with the knowledge, skills, and mindsets that enable action for sustainability (UNESCO, 2020; Parry and Metzger, 2023). Education is said to be at the heart of the SDGs and plays an essential role both as a standalone goal (SDG 4: Quality Education) and as a powerful catalyst for achieving the other Goals (United Nations, 2015; Metzger et al., 2021).

Several authors (Gill, 2017; Stewart and Gill, 2017; Gill and Smith, 2021; Capello et al., 2023) have aligned geoscience concepts and skills to the SDGs, demonstrating the relevance of the geosciences in solving society's grand challenges. However, Earth Science education often fails to make explicit connections with sustainability and is barely mentioned in the international discourse about education for sustainability (Gerbaudo et al., 2022).

Education for Sustainable Development (ESD) forms part of Target 4.7 of SDG 4 and, according to UNESCO (2024b), "gives learners of all ages the knowledge, skills, values and agency to address interconnected global challenges including climate change, loss of biodiversity, unsustainable use of resources, and inequality. It empowers learners of all ages to make informed decisions and take individual and collective action to change society and care for the planet." ESD is a holistic, lifelong process that addresses learning content, teaching strategies, and the learning environment. It integrates three interrelated domains of learning that work together to nurture a holistic understanding of sustainability (Orion and Libarkin, 2023; UNESCO, 2024b). As specified by UNESCO (2021), p. 22, the learning domains are:

- "Cognitive learning covers knowledge, understanding, and critical thinking";
- "Social and emotional learning builds the emotional awareness and social skills needed to relate to others in positive and respectful ways"; and
- "Behavioural learning concerns the ability to act effectively and responsibly at local, national and global levels for a peaceful and sustainable world."

Vasconcelos and Orion (2021) and Gerbaudo et al. (2022) underscored the potential for Earth science education to make valuable contributions to global sustainability education initiatives. Earth science aligns with the thematic content of ESD. Earth science instruction also fosters sustainability-relevant skills that

are commonly missing in the other sciences. These include systems thinking, interdisciplinary problem-solving, and the ability to think across diverse spatial and temporal scales (Gill et al., 2018; Vasconcellos and Orion, 2021). However, the role of Earth science in sustainability-themed education is ambiguous, as geoscience may be perceived as incompatible with ESD due to its association with the extractive industries that have contributed to our unsustainable trajectory (Chalkley et al., 2010; Gerbaudo et al., 2022). There is little understanding that geoscience expertise is essential to developing solutions to the world's most pressing problems (Whitchurch, 2019; Wadsworth et al., 2020; Jermyn et al., 2023).

Preparing citizens and geoscientists to take effective action for achieving the SDGs will require moving beyond a primary focus on content knowledge by providing opportunities for students to apply their learning in real-world settings. To become agents of change, students need to be engaged in action-oriented, experiential learning and problem solving around the intertwined environmental, social, economic, and ethical dimensions of sustainability (Vasconcellos and Orion, 2021; Parry and Metzger, 2023).

## GEOETHICS, SUSTAINABILITY, AND EDUCATION

Geoscience education and communication play a key role in geoethics, an emerging and expanding field of study that pertains to the multifaceted relationship of geoscientists to planet Earth and to society (Bobrowsky et al., 2017; Mogk and Bruckner, 2017; Peppoloni, and Di Capua, 2022). According to the International Association for Promoting Geoethics (2024), geoethics "consists of research and reflection on the values which underpin appropriate behaviours and practices, wherever human activities interact with the Earth system." Geoethics encompasses not only standards for geoscientists to work responsibility in their profession, but also addresses their responsibilities to society and to Earth stewardship (Mogk and Bruckner, 2017).

Geoscience education plays a prominent role in geoethics. According to the Cape Town Statement on Geoethics (Di Capua et al., 2017), "Promoting geo-education and outreach for all, to further sustainable economic development, geohazard prevention and mitigation, environmental protection, and increased societal resilience and wellbeing" is a key value of geoethics (p. 6).

Earth science education is both a key component of education for sustainability and part of the geoscience community's ethical responsibility to society. What strategies are needed to enhance its value as a catalyst for enabling more sustainable societies?

## STRATEGIES FOR RESHAPING GEOSCIENCE EDUCATION

Fortunately, a number of efforts are underway to tackle the Earth science education-related challenges that limit geoscience's contributions to sustainability agendas. The examples below furnish a snapshot of representative tactics and resources.

### Strengthening School-Level Earth Science Education

Consistent with research suggesting that geoscience education is most effective when connected to everyday life and to the learner's community and culture (e.g., Semken et al., 2017; Carter et al., 2021; Orion and Libarkin, 2023), many efforts to improve pre-university Earth science education occur within individual countries, provinces/states, or local communities. However, some initiatives are taking place on the international scale, providing opportunities for cross-national collaboration and learning. For example, the goals of the International Geoscience Education Organisation (IGEO) are to "promote geoscience education internationally at all levels, to work for enhancement of the quality of geoscience education internationally and to encourage developments raising public awareness of geoscience, particularly amongst younger people" (International Geoscience Education Organization, 2024). Several IGEO activities support these goals, including the Quadrennial International Conference on Geoscience Education, associated teacher training workshops, and publication of an international geoscience syllabus for 16-year-old students and their teachers. The syllabus is accompanied by free, downloadable textbooks (Orion et al., 2020; King et al., 2021). The IGEO's flagship initiative, an annual International Earth Science Olympiad for secondary students, was established in 2000 (Orion et al., 2020).

Earth Science Week (ESW) is a national and international event held each October since 1998 by the American Geosciences Institute in partnership with other organizations (American Geosciences Institute, 2024a). It fosters the active involvement of schools and other stakeholders within local communities and "brings together scientists, educators, students, and the general public to promote awareness and understanding of earth science concepts... and highlight the importance of earth science education and research in addressing global challenges and improving the quality of life for all" (American Geosciences Institute, 2024a). ESW features webinars, contests, events, and educational materials organized around an annual theme (American Geosciences Institute, 2024b). Some past Earth Science Week themes include, Earth Science for a Sustainable World, Water Today and for the Future, Earth Materials in our Lives, Geoscience is for Everyone, Earth as Inspiration, and Our Shared Geoheritage (United States Geological Survey, 2024).

### Supporting Earth Science Teachers

Teachers are widely recognized as crucial agents of social change and the importance of their role in the pursuit of a more sustainable future cannot be overestimated (Potter Nelson and O'Neil, 2019; Parry and Metzger, 2023). Supporting Earth science teachers, many of whom have no formal

background in geoscience, is pivotal to improving the quality of school-level Earth science education. Many organizations provide teachers with resources and training opportunities, including university geoscience programmes, geological surveys at the state/province and national levels, geoscience-related government agencies, geoscientific societies, and teacher associations. These organizations and agencies can also enhance Earth science teaching by broadcasting and supporting participation in international events such as the International Earth Science Olympiad and Earth Science Week.

Earth science teachers' associations are often key players in promoting high-quality teaching of Earth science. For example, the Earth Science Teachers' Association, a charity that depends heavily on the efforts of volunteers, has supported teachers in the United Kingdom for more than 50 years (Boatright et al., 2019). In the United States, the National Association of Geoscience Teachers (NAGT, 2023) and National Earth Science Teachers Association (NESTA, 2024) play similar roles.

The European Geoscience Union (EGU) provides professional development for teachers via two key initiatives: 1) International Geoscience Information for Teachers (GIFT) workshops, which have been held each year since 2003 in Vienna and other locations, and 2) the EGU Geoscience Education Field Officers Programme (Realdon et al., 2020; European Geoscience Union, 2024). The two-and-a-half-day GIFT workshops, which are presented in conjunction with EGU's annual General Assembly, aim to "spread first-hand scientific information to science teachers of secondary (and primary) schools, significantly shortening the time between discovery and textbook, and to provide the teachers with material that can be directly transported to the classroom" (European Geoscience Union, 2024). Since 2019, the EGU has appointed Geoscience Education Field Officers (GEFO) in eleven European countries. Each GEFO is trained in presenting hands-on teacher workshops featuring activities available from Earth Learning Idea (see below) that use inexpensive, readily-available materials. GEFOs work closely with other providers of teacher training in their respective countries to develop a network for promoting geoscience education (Realdon et al., 2020; European Geoscience Union, 2024).

Earth Learning Idea (ELI), which was launched in 2007, is an online source of inquiry-based learning activities. The ELI website (Earth Learning Idea, 2024) provides professional development workshops and free, high-quality teaching materials to teachers across the world (King et al., 2021; Loader et al., 2023). There are over 400 ELI activities, many of which are accompanied by videos; a new activity is published every 2 weeks (Loader et al., 2023). A number of the activities have been translated into 11 different languages, and there have been more than 6.1 million downloads since December of 2008 (Loader et al., 2023).

Additional free, online repositories of materials and strategies for teaching Earth science in the United States and United Kingdom, respectively, include Teach the Earth (Teach the Earth, 2007), which is jointly managed by the National Association of Geoscience Teachers and the Science Education Resource Center at Carleton College, and Teach Earth (University Geoscience UK, 2024).

## Looking Beyond Traditional Geoscience Career Pathways

As previously noted, few students are aware of career opportunities in the geosciences beyond the traditional employment in petroleum or mining (Geological Society of London/University Geoscience UK, 2019; Whitchurch, 2019; Boone et al., 2021). Geoscience jobs are often perceived as low-prestige and relatively low-paying (Hoisch and Bowie, 2010; Lyon et al., 2020; Carter et al., 2021).

Surveys in the United States, United Kingdom, and Indonesia revealed that, broadly speaking, young people belonging to Gen Z (those born ~1995–2015) seek to apply their learning in the real world through flexible, reliable, and enjoyable employment that has value to society (Jermyn et al., 2023). Similar results were reported by Ayoobzadeh et al. (2024) based on an online survey of several thousand post-secondary students in Canada. As noted by Jermyn et al. (2023) there are geoscience career opportunities that align with these aspirations, but few teachers, students, and parents are aware of them. This connects back to the fact that in most cases school-level Earth science education provides little or no exposure to geoscience career information during a formative period in young people's lives during which they are exploring options for their futures (King et al., 2021; Jermyn et al., 2023).

Connecting geoscience expertise to the Sustainable Development Goals shows students how geoscientists can contribute to a more sustainable future. For example, the Geological Society of London's Geoscience for the Future poster (Geological Society of London, 2020), which has been translated into several languages and is available for free download, shows how the various geoscience subdisciplines and sectors link to the SDGs.

*Geoscience in Action: Advancing Sustainable Development*, a recent report copublished by UNESCO and the American Geophysical Union (Capello et al., 2023) describes how geoscience knowledge and skills apply to the "people," "planet," and "prosperity" pillars of the Sustainable Development Goals. According to Lunn (2023) this publication is "designed to inspire current and aspiring geoscience students by demonstrating how a geoscience degree can open up many career options in a range of fields all of which can make an impact and advance the sustainability agenda." A set of case studies from across the globe "capture the diversity of initiatives in which geoscientists are engaged across the sustainability spectrum, from water resource management, reducing natural hazard risk, and accelerating decarbonization to confronting gender inequities and discrimination" (Capello et al., 2023, p. xvii). These case studies highlight the value of cross-disciplinary and cross-sector communication in tackling such issues (Capello et al., 2023).

Research shows that under-represented minority (URM) students place a higher value on affecting social change and working to serve their communities than do their non-URM Peers (Carter et al., 2021; Mogk, 2021). Better informing students about the altruistic potential of geoscience careers may be an effective strategy for attracting more under-represented students to the geosciences (Carter et al., 2021; Mogk, 2021), suggesting that establishing links between Earth science and sustainability may also help to broaden participation in the geosciences.

## MODERNISING THE GEOSCIENCE CURRICULUM IN HIGHER EDUCATION

### Broadening the Education and Training of Geoscientists

Geoscientists will need new knowledge and skills to help achieve global sustainability goals in a world grappling with poverty and inequality, environmental degradation, climate change, and the urgent need to transition away from fossil fuels (Stewart and Gill, 2017; Gill et al., 2018; Gill, 2021). A sound scientific and technical grounding in the geosciences is a necessary, but insufficient requirement for tackling complex socioecological issues. To prepare the geoscientists of the future, university-level geoscience programmes must expand to include (Stewart and Gill, 2017; Gill et al., 2018; Gill, 2021):

- sustainability themes and concepts;
- interdisciplinary connections that go beyond engineering and the other natural sciences to include social sciences, the humanities, and other fields of study;
- development of "soft skills" such as "cross-cultural and cross-disciplinary communication, diplomacy, and community engagement" (Gill, 2017, p. 75); and
- early exposure to the full-spectrum of sustainability-related Earth science careers.

Applying geoscience to issues such as resource extraction, water resource management, and natural disaster reduction raises complex ethical issues, and there is a growing call to incorporate geoethics into geoscience degree programmes and professional training for practicing geoscientists (Mogk et al., 2017; Keane and Asher, 2021; Vasconcelos et al., 2020). For example, Villacorta et al. (2024) highlighted a critical need to incorporate geoethics into tertiary education in Latin America and the Caribbean as a critical tool for achieving sustainable development in those regions.

The UNESCO-American Geophysical Union report *Geoscience in Action: Advancing Sustainable Development* (Capello et al., 2023) emphasizes the need to more fully develop the social skillsets of future geoscientists. Geoscientists will also need postgraduate training opportunities designed to enhance their ability to collaborate with others in respectful and ethical ways to jointly address pressing societal challenges (Gill, 2021).

The pivotal role of geoscience in rapidly transitioning away from fossil fuels provides an important and timely example of the need to integrate social skills and geoethics into geoscience education (Katz, 2022; Gardiner et al., 2023). The increasing demand for critical energy transition minerals such as lithium, nickel, cobalt, and rare earth elements will require mining, which has a legacy of extensive environmental damage and social disruption (Gardiner et al., 2023; Matanzima and Loginova, 2024). Geoscientists are involved in the scientific and technical phases of mining including discovering and developing new mineral deposits, efficiently mining them, and taking steps to protect the environment (Price, 2019). They must also be prepared to engage responsibly with key stakeholders, including mining companies, regulators, and the communities impacted by mining (Price, 2019). As noted by Katz (2022), social issues related to mining are becoming increasingly important, yet are not typically addressed in undergraduate geoscience curricula.

At the launch of a new United Nations-convened Panel on Critical Energy Transition Minerals, UN Secretary-General António Guterres remarked: "For developing countries, critical minerals are a critical opportunity -- to create jobs, diversify economies, and dramatically boost revenues. But only if they are managed properly. The race to net zero cannot trample over the poor. The renewables revolution is happening – but we must guide it towards justice" (UNEP, 2024). Owen et al. (2023) estimated that more than half of the minerals and metals needed for the energy transition are found on or near the lands of Indigenous peoples, often in developing countries. The urgent need to take action against climate change must not perpetuate patterns of the past, in which wealthy nations profited at the expense of vulnerable populations in distant parts of the world (Matanzima and Loginova, 2024; Owen et al., 2023).

Geoscientists are often the first on the ground at a new mineral exploration site and the first to interact with local communities (Capello et al., 2023). To help foster a just and inclusive energy transition, geoscience instruction needs to address the cultural and ethical implications of mining and prepare geoscientists to communicate effectively and transparently with and listen to the concerns of affected communities (Katz, 2022; Knipe et al., 2022; Gardiner et al., 2023).

Broadening formal geoscience education to encompass the socioeconomic dimensions of sustainability and nurture skills that go beyond the geoscientific and technical presents a number of challenges. These include instructors who lack training in these elements, limited time, and concerns about "diluting" the core geoscience curriculum (Jones et al., 2008; Metzger et al., 2017; Gill et al., 2018). However, as illustrated by the examples below, a number of resources are available to help address these obstacles.

With a focus on "leaving no one behind," Geology for Global Development (GfGD) is a non-profit organisation that directs its resources, expertise, networks, and influence to help build a sustainable future for all by transforming understanding of,

access to, and capacity to use the geoscience required to implement the Sustainable Development Goals. Alongside research and policy engagement, one of their core areas of work is empowering the global geoscience community to contribute to sustainable development (Geology for Global Development, 2022). GfGD has developed a downloadable, open access "Geoscience and Sustainable Development" module (Geology for Global Development, 2020). A case study by Natasha Dowey (Geology for Global Development, 2021) describes how GfGD resources for higher education were used at the University of Hull during the 2020/2021 academic year.

The book *Geosciences and the Sustainable Development Goals* (Gill and Smith, 2021) aims to enhance the teaching of geoscience in a societal context by exploring how geoscience concepts, skills, and practices link to the 17 Sustainable Development Goals. Each chapter is accompanied by educational resources to help students contextualize and apply their learning.

In the United States, the National Science Foundation-funded Interdisciplinary Teaching about Earth for a Sustainable Future (InTeGrate) Project (2012–2019) provided examples of how geoscience can be taught in a social context. Gilbert et al. (2020) described InTeGrate as "a major nationwide effort by academic institutions and employers to meet evolving needs for the geoscience workforce and to increase societal capacity to use geoscience knowledge to live successfully, sustainably, and justly on Earth." The InTeGrate Project united geoscience faculty with colleagues from other disciplines to "promote the integration of the geosciences and an interdisciplinary mindset into the development of high-quality, classroom-tested educational materials, using a rigorous rubric and peer-review process" (Gosselin et al., 2019 p. 10). The InTeGrate web site (InTeGrate, 2011) features an array of downloadable materials, including peer-reviewed teaching activities and modules, to assist geoscience educators with bringing sustainability to their instruction.

For Earth science educators who may not feel comfortable with including the ethical dimensions of sustainability in their geoscience classrooms, Metzger and Curren (2017) provide some practical suggestions for getting started. The GOAL (Geoethics Outcomes and Awareness Learning) project, a European Union-sponsored partnership to teach and promote geoethics, supplies educational resources that can be used in higher education, including a free, downloadable e-book (Vasconcelos et al., 2020).

Accreditation requirements represent a high-leverage approach to incorporating sustainability into university-level geoscience education. The Geological Society of London accredits degrees in Earth science and related subjects across the United Kingdom. In recognition of significant changes in the geosciences over the past two decades, a major review of the Society's undergraduate accreditation scheme was undertaken between 2018 and 2022 (Geological Society of London, 2022a). This review was paralleled and informed by an updated Subject Benchmark Statement for Earth Science, Environmental Science, and Environmental Studies from the Quality Assurance Agency, which oversees academic standards for graduates in specific disciplines (QAA, 2022). Human Interactions with the Earth System is now a key category of Essential Subject-Specific Knowledge for Earth Science Graduates in the UK (Geological Society of London, 2022b; see Appendix 3, Theme 4). This theme includes natural resource management, climate change, mitigation of natural hazards, the Sustainable Development Goals, geoethics, environmental justice, and perspectives on the history of Earth science and its influence on the discipline today (Geological Society of London, 2022b; Appendix 3, Theme 4).

## Making Geoscience More Diverse, Equitable, and Welcoming

The STEM (Science, Technology, Engineering and Mathematics) disciplines as a whole are notably less diverse than the general population (Ormand et al., 2022). However, geoscience has the dubious distinction of being one of the least diverse (e.g., Bernard and Cooperdock, 2018; Dowey et al., 2021), leading Dutt (2020) to identify the lack of diversity and inclusion as "the single largest cultural problem facing the geosciences today" (p. 3). In the United States, there has been little progress in remedying the situation during the past 40 years despite considerable effort and significant investment by the National Science Foundation (Bernard and Cooperdock, 2018; Karsten, 2019; Ormand et al., 2022; Castro and Atchison, 2024). Dowey et al. (2021) painted a similarly bleak picture of diversity in the geosciences in the United Kingdom.

In their discussion of the diversity crisis in UK geoscience, Dowey et al. (2021) wrote: "Geoscience is vital in developing a more sustainable society, and a critical aspect of sustainable development is the reduction of inequalities" (p. 258). The severe and persistent lack of racial, ethnic, and other diversity in Earth science education and the geoscience workforce impedes the ability of the geoscience community to address complex socioenvironmental issues related to sustainability (McDaris et al., 2019; Mogk, 2021). Growing research shows that creativity, innovation, and problem-solving are enhanced in diverse groups, although diversity may also bring some challenges (Page, 2007; Galinsky et al., 2015), and the low diversity of the geosciences means we are missing out on valuable talent (Mogk, 2021). As noted by Mosher and Keane (2021) the societal impacts of climate change, natural hazards, and resource extraction are growing, with disproportionate effects on marginalized communities. Broadening participation in the geosciences will foster greater engagement with these communities and lead to more effective solutions (Mosher and Keane, 2021).

A comprehensive review of efforts to address the complex, multi-dimensional, multilevel, and solution-resistant problem of the diversity deficit in geoscience is beyond the scope of this paper. The discussion below offers an overview of some issues relevant to geoscience education and recommends

resources for further exploration. See Mogk (2021) for a more in-depth review of diversity-related challenges within the geosciences and their geoethical implications.

Over the past two decades, issues of accessibility, diversity, and inclusion in the geoscience have been the subject of intense investigation by the geoscience education research community in the United States (Bernard and Cooperdock, 2018; Gates et al., 2019; Karsten, 2019; McDaris et al., 2019; Orion and Libarkin, 2023; Castro and Atchison, 2024). A common approach to the problem focuses on fixing the "leaky pipeline" through outreach programmes that actively recruit students from underrepresented groups (Marín-Spiotta et al., 2020; Cisneros and Guhlincozzi, 2022). As mentioned above, obstacles to recruitment include lack of awareness of the geosciences, negative perceptions of the field, and lack of information about careers (Orion and Libarkin, 2023; Rogers et al., 2024). Attracting more diverse students is important. However, attempting to "patch" the leaky pipeline detracts attention from addressing institutional and structural barriers to retaining and supporting them (Dutt, 2020; Berhe et al., 2020; Monarrez et al., 2022). Once recruited, students from marginalized groups often experience hostile academic and work environments marked by racism, bias, and harassment (Marín-Spiotta et al., 2020).

Efforts to broaden participation in the geosciences have often focused on a singular identity such as gender, race/ethnicity, or disability. There is growing recognition that to improve recruitment of under-represented students to the geosciences and to retain them, exploration of identity must expand to include research around how multiple identities intersect to shape the lived experiences of students from marginalized groups (Núñez et al., 2020; Castro and Atchison, 2024). As observed by Núñez et al. (2020) "Understanding more about the experiences of students with distinctive identities will inform the development of inclusive practices to serve these students and enhance equitable conditions in the discipline" (p. 109).

Another issue is the lack of institutional support and recognition for diversity, equity and inclusion (DEI) work (Jones, 2021; Cisneros and Guhlincozzi, 2022; Rogers et al., 2024). Jones (2021) emphasised the need to recognize and reward this work: "If we expect our departments to promote research excellence, we measure it and reward it through fellowships, tenure and promotion, and awards. If we expect excellence in DEI efforts, similar rewards (and consequences) should be present" (Jones, 2021, p. 3). When there are few faculty members from marginalized groups within a discipline, the burden of this extra work may fall disproportionally on them at the expense of their research and grant-seeking efforts (Gewin, 2020; Cisneros and Guhlincozzi, 2022).

Although much work remains to be done, progress *is* being made, albeit slowly (e.g., Gates et al., 2019; Beane et al., 2021; Rogers et al., 2024), and a number of research based strategies and related resources are available to assist with recruiting, supporting, and retaining diverse students and fostering a sense of belonging in the geosciences (Ormand et al., 2022). For example, Karsten (2019), McDaris et al. (2019), Hall et al. (2022) and Dowey et al. (2021) outlined several strategies for broadening participation in the geosciences.

Additional articles and resources for getting started can be found on the Geoscience for the Future web site (Geoscience for the Future, 2024). The National Association of Geoscience Teachers (United States) also provides an extensive collection of resources (National Association of Geoscience Teachers, 2022). The International Association for Geoscience Diversity (2024) supplies resources for "improving access and inclusion for people with disabilities in the geosciences."

Any action to increase diversity, equity, and inclusion must start with acknowledgement of how the colonial roots of the geosciences continue to influence their structure and culture (Marín-Spiotta et al., 2020; Monarrez et al., 2022; Rogers et al., 2022). Monarrez et al. (2022) observed that "Western geosciences were founded on systematic practices of exclusion, oppression, and erasure. These practices have been ingrained in the structure and culture of these disciplines ... and continue to permeate modern academic settings" (p. 179).

Geoscience's legacy of colonialism and resource exploitation, often to the detriment of native populations, continues to influence the discipline today and helps to explain the ongoing exclusion of students from under-represented groups (Hall et al., 2022). Rogers et al. (2022) suggested that this may also be one explanation for why geoscience is underrepresented in international sustainability agendas.

Calls to decolonize the university curriculum have been gaining momentum in the past few years, especially in the United Kingdom (Charles, 2019; Rogers et al., 2022). The Keele Manifesto for Decolonizing the Curriculum (2018) explains how the legacy of colonialism is maintained in university curricula "through the presentation of a White, Western intellectual tradition not only as superior to other forms of knowledge but also as universal. The curriculum remains largely Eurocentric and continues to reinforce White and Western dominance and privilege, while at the same time, being full of stereotypes, prejudices, and patronizing views about non-White people and culture" (p. 97).

Rogers et al. (2022) provided a comprehensive overview of what it means to decolonize the curriculum, particularly in the geosciences, with concrete steps for getting started. An online collection of open-source educational resources is available from the Decolonizing Earth Science Project (Decolonizing Earth Science, 2024).

## DISCUSSION

Geoscience is fundamental to addressing challenges arising from interactions between humans and our planet, and high-quality Earth science education is a key component of the geoscience community's toolkit for contributing to a more sustainable future. The sections above furnish an overview of Earth science education around the world, examine ways it can be reimagined to better contribute to sustainability

agendas, and highlight examples and resources that can guide that work. Among the recommendations for enhancing geoscience education are strengthening school-level Earth science instruction, connecting geoscience to international sustainability goals, enhancing diversity in the geosciences, and expanding the preparation of geoscientists to include sustainability concepts, interdisciplinary connections, and development of "soft skills" that enable cross-cultural and cross-disciplinary communication.

As mentioned previously, this paper focuses mostly on geoscience education in the United States and Europe. This reflects the relative lack of information about geoscience programmes in developing nations, reflecting a bias in the Western academic literature, and the fact that these programmes are often under-resourced for historical, economic and/or political reasons. Gill et al. (2018) identified resourcing university-level Earth science education in developing nations as an important strategy for building geoscience's capacity to support sustainability initiatives, and a key priority for the nonprofit Geology for Global Development is empowering the global geoscience community and overcoming the isolation of geoscientists in the Global South though effective and respectful partnerships (Geology for Global Development, 2022). The International Geoscience Programme also promotes projects that build capacity and facilitate knowledge sharing between scientists through North-South and South-South cooperation to benefit society (UNESCO, 2023).

A decades-long, self-reinforcing loop in which inadequate school-age Earth science education leads to a continued disrespect for the geosciences and fewer young people choosing geoscience-related careers presents a fundamental barrier to high-quality Earth science education (Orion, 2017; Orion, 2019; Orion and Libarkin, 2023). In his call to raise the status of Earth science education, Schaffer (2012) lamented that we can write repeated commentaries about the problem, attend numerous meetings to discuss it, create literacy guides for Earth systems science, and write new science education standards, but nothing will change until we find a way to break the vicious cycle of societal unawareness of and misperceptions about the geosciences.

The world has changed in many ways relevant to geoscience education since Schaffer made his plea:

- In 2015, the international community committed to the Sustainable Development Goals (United Nations, 2015). Geoscience is relevant, either directly or indirectly, to most of these goals.
- The COVD-19 pandemic and the Black Lives Matter movement that arose from the police killings of George Floyd in 2020 exposed and exacerbated existing inequalities and put a spotlight on issues of diversity, equity, and inclusion in the sciences, including the geosciences (Mogk, 2021; Tooth and Viles, 2021; Williams-Stroud, 2021).
- Geoethics has gained visibility as a discipline, reshaping views about how geoscientists interact with the planet and society. This has important implications for Earth science education and how we prepare future geoscientists (Mogk et al., 2017; Vasconcelos et al., 2023).
- Geoscience education research has expanded as a discipline in the United States and is contributing new, evidence-based strategies for teaching about Earth in a social context and for supporting the success of students from under-represented groups (St. John et al., 2020; Orion and Libarkin, 2023; Ryker et al., 2024).
- Challenges related to human interactions with the Earth system have continued to grow, and the effects of climate change have become more tangible (e.g., Richardson et al., 2023; United Nations, 2023; Fletcher et al., 2024). The need for geoscience in addressing these challenges has never been greater.

The events and trends above, in combination with growing initiatives to confront the colonial and extractive roots of the geosciences (e.g., Rogers et al., 2022; Stewart et al., 2023), are driving new conversations about how Earth science education can be broadened and strengthened to better contribute to sustainable societies. Although the "vicious cycle" has not yet been broken, progress *is* being made as illustrated by the examples above.

## CONCLUDING REMARKS

This is far from the first paper to highlight current weaknesses within geoscience education that limit its effectiveness as a catalyst for a more sustainable future and it certainly will not be the last. However, the ongoing conversation about obstacles to high-quality Earth science education has shifted as a result of both looking inward to confront the colonial foundations of modern geoscience and looking outward to connect to broader societal and educational issues. This shift has the potential to help overcome persistent obstacles to high-quality Earth science education, and it could be argued that we are at a juncture where we can either leverage and build on the momentum of new narratives about geoscience and society, or continue to lament the poor quality of school-level Earth science and our discipline's image problem.

As previously discussed, advancing high-quality geo-education and outreach for all is part of geoscientists' ethical responsibly to society and Earth stewardship (Di Capua et al., 2017). Ultimately, the systemic changes needed to tap the full potential of Earth Science education to help achieve sustainability will not happen without a holistic, coordinated, and collaborative commitment from multiple stakeholders in the geoscience community. This is not a new idea. Several authors (e.g., Karsten, 2019; Orion, 2019; Mogk, 2021; Orion and Libarkin, 2023) have cited the need for the geoscience community to take more responsibility for overcoming the lack of diversity in the geosciences and advocating for high-quality school-level Earth science education.

Hopefully, the ideas, strategies, and resources presented here can serve as a springboard for further conversation and collaboration and an opportunity for readers to reflect on how

they can support high-quality geoscience education, both as individuals and as advocates for collective action.

For those who may understandably respond with a sign of frustration to yet another call to improve Earth science education, think of what is at stake, both for the future health of the geosciences and for their capacity to help make a better world, now and in the future. We have an urgent need for Earth-literate citizens and policymakers and for geoscientists equipped with the scientific, technical, social, and ethical competencies needed to help achieve global sustainability goals. If this is not enough to inspire action, what will be?

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The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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