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COMMENTARY
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Key Points:

- Integrated, Coordinated, Open science, and Networked (ICON) principles and practices are widely used in geoscience education to improve both research and practice
- Strengthened capacity for ICON practices is needed to advance current educational priorities
- A priority must be placed on full participation by that are systemically non-dominant groups and improving global interactions

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Geoscience Education Perspectives on Integrated, Coordinated, Open, Networked (ICON) Science

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Abstract Practitioners and researchers in geoscience education embrace collaboration applying ICON (Integrated, Coordinated, Open science, and Networked) principles and approaches which have been used to create and share large collections of educational resources, to move forward collective priorities, and to foster peer-learning among educators. These strategies can also support the advancement of coproduction between geoscientists and diverse communities. For this reason, many authors from the geoscience education community have co-created three commentaries on the use and future of ICON in geoscience education. We envision that sharing our expertise with ICON practice will be useful to other geoscience communities seeking to strengthen collaboration. Geoscience education brings substantial expertise in social science research and its application to building individual and collective capacity to address earth sustainability and equity issues at local to global scales The geoscience education community has expanded its own ICON capacity through access to and use of shared resources and research findings, enhancing data sharing and publication, and leadership development. We prioritize continued use of ICON principles to develop effective and inclusive communities that increase equity in geoscience education and beyond, support leadership and full participation of systemically non-dominant groups and enable global discussions and collaborations.

Plain Language Summary The Geoscience Education community describes the value, use, and future of ICON collaboration through three independent, community-produced commentaries focused on the practice of geoscience education; geoscience education research; and diversity, equity, inclusion, and justice.

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Each commentary offers ideas important to building inclusive and effective communities. These ideas apply to science-community collaboration broadly and inform coproduction and network building activities within and across geoscience-public boundaries. The expansion of inclusive and effective networks is needed for equitable outcomes.

1. Introduction

This article is composed of three independent commentaries about the state of Integrated, Coordinated, Open, and Networked (ICON) principles (Goldman et al., 2022) in geoscience education and opportunities and challenges of adopting them. It is part of a larger collection of ICON commentaries across geoscience on the future of ICON Science (Goldman et al., 2022). The word "Geoscience" is used as an inclusive umbrella term that includes science disciplines in which the primary subject of study is the Earth, such as: environmental science, geology, meteorology, and oceanography (American Geological Institute, 2009; Shea, 1995). The geoscience education commentaries were developed as a collaboration between the American Geophysical Union (AGU) Education Section and the National Association of Geoscience Teachers (NAGT) using processes and infrastructure to support open collaboration with draft and community input timelines described on the project website: https://nagt.org/nagt/about/icon.html. Initial ideas for commentary themes reflect existing foci on collaboration to improve geoscience practice and to enhance geoscience education research, and to improve diversity, equity, inclusion, and justice in geoscience education and beyond. The conceptual team proposed these topics and generated preliminary examples and then held a video call with approximately 20 geoscience educators and researchers who expressed interest in discussing the current and future state of collaboration in geoscience education. At that meeting we identified interest in collective writing across these themes, revised some of the examples and descriptive language that would be used to recruit writing teams, and identified writing leads and timelines for community inputs and drafts. Writing leads then led teams to produce drafts informed by teams and community inputs (e.g., web forms, virtual comment sessions). Because the commentaries were produced by three unique teams, they feature overlapping and interconnected topics focusing on how ICON practices can be used to promote: the practice of geoscience education; geoscience education research; diversity, equity, inclusion and justice in geoscience education. Most of the authors are from the United States and this influences the perspectives below.

2. ICON Practice of Geoscience Education

2.1. Introduction

Geoscience educators have developed and curated high-quality, peer-reviewed, *Open-access* resources for learners and practitioners emphasizing meaningful engagement with geoscience topics and analyzing data. We can expand into new audiences using cloud-based digital tools (e.g., visualizations, data analysis platforms and tools, and data repositories) and new professional development opportunities that reach global audiences. To expand our reach, we must create, enhance, and support *Networks* and partnerships. Education for expanded public audiences value *Open-access* and *Integration* of content, including governmental and non-governmental organizations and the private sector.

2.2. Expand Community Science

We challenge ourselves to *Integrate* diverse perspectives by engaging with place-based and locally relevant projects that are co-created through equitable partnerships with communities and non-traditional and/or Indigenous local knowledge holders or producers. Our disciplines position us for networking and building local communities of practice that connect learners to action by promoting environmental justice and improving the quality of life for all.

2.3. Increase Exposure to the Geosciences Through Teaching and Mentoring

There are many pathways into geoscience, so broadening the exposure of learners across all educational settings is a critical component of success. Within the United States, we encourage and support the adoption of the Next

Generation Science Standards, promoting the *Integration* of scientific inquiry and geoscience skills and thinking, and recognizing the importance of an informed society (e.g., Climate, Earth Science, Ocean and Polar Literacy documents). We encourage collaboration among geoscience teachers, social science, humanities, and STEM fields in K-12, higher education, and informal learning contexts as important knowledge *Integration*. Mentoring strengthens our connections, supports career development, and builds our *Networks*; we identify a need for increased networking opportunities and infrastructure.

2.4. Address Workforce Opportunities and Challenges

Geoscience skills and understandings are highly relevant to community workforce needs. We embrace the braided river career development model (Batchelor et al., 2021) and recommend highlighting career opportunities at all levels of geoscience instruction as well as working in partnership with local employers to create relevant flexible experiential opportunities. All resources should be co-developed and/or adapted for local context through *Networks* that support career-connected learning to meet local workforce demands.

2.5. Cross-Cutting Theme: Improve Inclusion and Belonging

The culture within the geosciences must become more welcoming and inclusive. This shift can begin via open discussions of systemic bias (e.g., URGE), the application of universal design principles in curriculum development (Rose et al., 2006), and increased inclusivity and safety protocols during fieldwork (Hill et al., 2021). Inclusivity calls for *Coordination* that places equity-producing practices into education. *Networks* are also important to inclusivity through promoting culturally relevant learning, supporting diverse ways of knowing, doing and sensing the world, developing virtual internships that reduce financial and place-based barriers to participation, helping to bridge silos of language and accessibility, connecting with families, and providing support to incorporate environmental justice into education resources and teaching.

We recognize through our conversations that the most important element to our shared success is the investment of time to build human connections, share resources, and enhance *Networking* especially supports, and collaborative processes that enable us to build education capacity. The marriage between both top-down and grassroots efforts has been the strength of our community, and we call upon one another to be agents of change as we move forward.

3. ICON Geoscience Education Research

3.1. Introduction

Geoscience Education Research (GER) is a form of Discipline-Based Education Research (DBER) that investigates and tests hypotheses about teaching and learning in disciplines that study of the Earth (e.g., geology, environmental science, atmospheric science, and ocean science) "using a range of methods with deep grounding in the discipline's priorities, worldview, knowledge, and practices" (Singer, 2012, p. 769). GER also involves the scholarly development and evaluation of teaching innovations and geoscience curricula (which can relate to the scholarship of teaching and learning (SoTL); How, 2020). GER uses ICON processes and can further utilize these processes to advance this research field in the future.

The GER field has evolved such that many ICON processes are enacted, but not with equal depth. *Integrated* processes are at the core of rigorous GER studies as they are multidisciplinary, interdisciplinary, and/or transdisciplinary in nature (Lukes et al., 2015). That is, the GER community integrates knowledge and practices in geoscience with those from the social sciences, learning sciences, and/or educational psychology. The GER community also benefits from *Coordination* and *Networking* via the GER Division of NAGT and an *Open-access* resource hub via the Science Education Resource Center (SERC). Of the four ICON processes, *Open* and *Networked* processes arguably remain the most aspirational. For example, our research community has not yet established a robust way to openly exchange research software, models, and data (while also adhering to privacy needs of human subject data) throughout the research lifecycle that are findable, accessible, interoperable, and reusable (FAIR). Work remains to coordinate protocols and instruments across systems to generate comparable GER data (although some progress has been made on the design and use of the geoscience concept inventory and other assessment tools). Furthermore, although individual GER scholars often develop collaborations for

research, there is no large-scale formal support for research *Networking* around open access meta-analyses and large-scale comparative research.

Here we address community-informed themes that reflect how ICON processes have contributed to the current state of GER and how ICON processes represent aspirations of the GER community and its conduct of research. These themes are not mutually exclusive.

3.2. Community of Practice

The GER Community of Practice (CoP) (Lukes et al., 2015) uses ICON processes to build our community and GER resources through workshops, webinars, an online toolbox, a survey of GER community needs, and a recent community-developed vision and research-prioritization framework (St John et al., 2020). They help shape our identity as a CoP, establish norms around GER practices, and drive a collective increase in the quality of GER (Arthurs, 2019). In addition, professional organizations (SERC, NAGT, Geological Society of America, AGU) provide nexus points for *Networking* and collaboration (Manduca et al., 2013).

3.3. Capacity Building

The GER community's small size compared to other DBER communities (NAGT-GER membership reported at 387 in 2021 (GER Demographics, 2021)) permits strong coordination and internal communication, but community development initiatives demand much from a few active community members. Evolving leadership must ensure CoP sustainability and represent the wide range of positionalities of GER community members.

As the GER CoP grows, funding and effort should be directed toward capacity building. Training, mentoring, and tenure and promotion of GER scholars are essential components of capacity building, as is the development of a just, equitable, diverse, and inclusive CoP that grows beyond its current United States-centric base. Attention should be given to identification of communities with whom to collaborate and serve (e.g., K-12 schools, two-year colleges, populations that are systemically non-dominant (SND, Jenkins, 2017) in STEM education, and international populations). Developing *Integrated* and *Networked* partnerships for collaborative action on current and future community-defined research priorities is a key component to moving forward. Attention should also be given to strengthening and expanding researcher resources (e.g., instruments, tools, and databases) that enable rigorous GER. In particular, the development of a GER data-and-models repository would enable more systematic reviews and multi-site case studies (St. John & McNeal, 2017).

3.4. Communication

Communication efforts should be strategically expanded to build awareness of GER. Communication about what GER is, the possible pathways to becoming a GER scholar, and ways to engage with the GER CoP should be facilitated and promoted, especially in the international arena. Access to GER findings would be improved by expansion of GER publication venues beyond the Journal of Geoscience Education (Arthurs, 2019). This might include avenues such as AGU's interdisciplinary open-access journal, Earth and Space Science; another option is the development of a new GER-dedicated journal. In conjunction, to bridge GER research and teaching practice, the GER CoP should expand opportunities for *Open* Geoscience Education Research and Practice Forums, which promote sharing, listening, and problem-solving between stakeholder groups.

3.5. Conclusion

The GER field currently utilizes ICON processes and views the ICON framework as aspirational, guiding community-generated recommendations for advancing the field. This commentary identifies several areas of action to expand the GER CoP, build capacity, and improve communication. If realized, these advances ultimately also will benefit the geoscience discipline through GER impacts on teaching and learning.

4. Using the ICON Model to Promote Diversity, Equity, Inclusion, and Justice

4.1. Introduction

The geoscience community is historically one of the least diverse scientific fields (e.g., Bernard & Cooperdock, 2018). For a number of decades geoscience educators and researchers have suggested that management of diverse knowledge and efforts to foster Diversity, Equity, Inclusion, and Justice (DEIJ) have the potential to enhance institutional culture, recruitment, and retention of diverse learners and employers, as well as social justice in geoscience (e.g., Ali et al., 2021; Callahan et al., 2017; Huntoon et al., 2005). While significant effort has been spent on fostering DEIJ within the field (e.g., the recent special issue of the *Journal of Geoscience Education* (Gates et al., 2019)), there are many opportunities for growth and change. Here we discuss how the ICON framework can be used to specifically improve DEIJ within geoscience.

4.2. Integrated

In the context of DEIJ, we consider *Integrated* to mean widely welcoming and incorporating a global community into geoscience, with a particular focus on SND groups (Jenkins, 2017). Geoscience involves topics that are inherently global (e.g., climate change) and thus require global engagement. Nevertheless, to change a community that has lacked DEIJ for decades requires that we first acknowledge the negative historical contexts (e.g., colonization and resource exploitation) present within our science. We should thus teach geoscience topics with a more complete historical and cultural context. By integrating history and culture, new learners can contextualize past social injustices and then motivate reconstructions and reflections within the field (e.g., Apple et al., 2014; Dolphin et al., 2018). The geoscience community should think about people first (e.g., respecting and appreciating tribal sovereignty, history, culture, and local knowledge), before considering scientific advancements, to help integrate a more global community into geoscience.

4.3. Coordinated

Closely related to *Integrated* is *Coordinated* which traditionally is connected to consistent use of protocols and methods across geoscience. We believe *Coordinated* extends to creating environments and opportunities for diverse groups of people to actively work together. Geoscience departments can address these issues by actively engaging in campus communities and recruiting students (Ormand et al., 2021), showing diverse examples of geoscientists in academic environments (Schinske et al., 2016), engaging students in environmental justice and place-based learning (Urgeoscience, 2020), and providing professional development for faculty tackling implicit bias, stereotype threat, and solo status (i.e., being the only member of a group) (CRLT, 2021; Sekaquaptewa & Thompson, 2002; Steele, 2010). Departments must also address historical inequities without solely relying on institutional policies. In some cases institutional practices may not support equitable departmental practices or institutional representation, and accommodations may be different between departments within the same institution.

4.4. Open

An important factor in promoting *Coordinated* efforts is an intentional *Open* access to knowledge and practice for diverse groups of people, particularly by broadly lowering the cost of accessing geoscience content and practices (e.g., conferences, technology, and teaching and learning resources). This includes access to scholarship – less than half of all geoscience articles are open access and many articles of these are in journals that are not fully open access (Severin et al., 2020). Wider adoption of accessible practices and identifying strategies to reduce or remove publication fees could help reduce differences in article access. Opportunities to expand participation could also be supported by open approaches at every stage from conceptualization through manuscript preparation. Examples for successful open development and dissemination of data, model code, and analytic tools already exist (e.g., David et al., 2016; Smith et al., 2020). The geoscience community needs an effective knowledge-sharing system where data and interests and ideas are made accessible to more people through shared resources and centralized sample analysis or archiving. Collaborative use and reuse of data expands opportunities for research that may otherwise not be possible. Additionally, we encourage the geoscience community to

continue making instructional content (e.g., lecture slides and open source codes) freely available on platforms such as HydroLearn and Teach the Earth.

4.5. Networks

We consider *Networked* in the context of DEIJ to mean opportunities and access for SND groups to contribute and be involved in and help shape geoscience community activities. We acknowledge that motivations for SND groups may differ and therefore networking practices need to be modified to be more inclusive. A networked approach can ensure that the interests and perspectives of people from SND groups are adequately represented and included. We recommend promoting altruistic career options that promote societal building and environmental protection in geoscience, particularly in the early career stages. This could attract a more diverse student population to geoscience as compared to emphasizing outdoor opportunities (Carter et al., 2021). Geoscience is often contextualized as a "rural" science (i.e., taking place in deep forests and mountain terrains), which likely keeps people with urban perspectives disinterested (Bellino & Adams, 2017). We suggest that geoscience also be contextualized within an urban framework to support innovations to solve urban problems (e.g., Paul et al., 2018).

While ideas here are not exhaustive, we believe they help to further improve DEIJ efforts within geoscience. We are faced with the opportunity to create a more robust research and teaching community by taking transformative action. DEIJ efforts within the geoscience education community should reflect the global diversity of people, interests, and experiences that contribute to the richness of the field in ways that are equitable and that emphasizes justice.

Data Availability Statement

We are grateful to the National Association of Geoscience Teachers for hosting the public website that allowed us to create an open process and broadly recruit authors, ideas, and feedback and thank Monica Bruckner for her work creating the site.

Conflict of Interest

The authors declare no conflict of interest relevant to this study

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