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

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Abstract

Practitioners and researchers in geoscience education embrace ICON (Integrated, Coordinated, Open science, and Networked) principles and have a history of using them to create and share educational resources, to move forward collective priorities, and to learn from one another. Geoscience education brings substantial expertise in social science research and its application to building individual and collective capacity. This can be used to support ICON processes and improve the coproduction of knowledge between geoscientists and diverse communities. Geoscience is an important part of the knowledge needed to advance equity 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, that support leadership and full participation of systemically non-dominant groups, and that enable global discussions and collaborations.

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Key Points:

- 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 groups that are systemically non-dominant groups and improving global interactions.

Abstract

Practitioners and researchers in geoscience education embrace ICON (Integrated, Coordinated, Open science, and Networked) principles and have a history of using them to create and share educational resources, to move forward collective priorities, and to learn from one another. Geoscience education brings substantial expertise in social science research and its application to building individual and collective capacity. This can be used to support ICON processes and improve the coproduction of knowledge between geoscientists and diverse communities. Geoscience is an important part of the knowledge needed to advance equity 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, that support leadership and full participation of systemically non-dominant groups, and that 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. 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. 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 commentaries were developed using processes and infrastructure to support open collaboration described on the project website hosted by the National Association of Geoscience Teachers: https://nagt.org/nagt/about/icon.html. The commentaries are on three different but 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. A majority of the authors are from the United States and this perspective influences the perspectives below.

2 ICON Practice of Geoscience Education

2.1 Introduction

Geoscience education encompasses learning about the systems of the oceans, Earth, and atmosphere and is uniquely positioned to embrace ICON principles. Geoscience education is relevant to society, communities, and individuals especially concerning issues such as climate change, air quality, water security, resources, and natural disasters. Geoscience educators and learners employ creative and practical habits of mind (e.g., transdisciplinary thinking, big data analysis, exploration of deep time and space). We also have a focus on advancing equitable outcomes (e.g., learning and attitudes). These attributes prepare geoscience educators for innovation in collaboration and developing new ways to apply ICON. We engage learners across disciplines, at all education levels, from the local to global community through both formal and informal education.

Geoscience educator communities already use aspects of the ICON model. **Open** and freely accessible peer-reviewed K-16 teaching resources are available through online repositories and are paired with robust professional development opportunities grounded in research-based pedagogy. **Coordinated** efforts between geoscience education researchers and practitioners have resulted in a strong representation of geoscience content and its **Integration** with knowledge, skills, and attitudes from other disciplines in the recommendations of the Next Generation Science Standards (NGSS). Most recently the COVID-19 pandemic sparked further growth in the development and sharing of **Open** resources for online education (e.g., lab-based courses, field camps, and undergraduate research). We also observe an expansion in the development of simulation- and computation-based opportunities that **Integrate** diverse learning domains, including virtual reality and immersive online experiences. There has been significant progress in offering **Open** resources and training, **Integrating** content and practices, and providing **Coordinated** contributions to strategic guiding documents. An important challenge is increasing cross-level interaction between established networks of K-12, undergraduate, and informal educators.

The call for ICON commentaries provides an opportunity to imagine a more equitable future with greater transdisciplinarity, community engagement, and a more inclusive culture. Here we outline five key areas for practitioner community growth and shared identity that follow the ICON principles.

2.1 Improve the Range and Accessibility of Online Resources

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 have the opportunity to 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 US, we encourage and support the adoption of the NGSS, promoting the **Integration** of scientific inquiry and geoscience skills and thinking, and recognizing the importance of an informed society. 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 National Association of Geoscience Teachers (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 [GSA], American Geophysical Union [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 towards capacity building. Training, mentoring, 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 US-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 and 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; King et al., 2018; Vila-Concejo et al., 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., 2015; 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 (Shinske 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, 2016; Steele, 2010; Thompson & Sekaquaptewa, 2002). 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. Particular examples for successful open development and dissemination of data, model code, and analytic tools already exist (e.g., David et al., 2020; WHONDRS, 2020). The geoscience community needs an effective knowledge-sharing system where data and interests and ideas are made accessible to more people through 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 in-

clusive. 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 and 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.

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