Framework Development

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Summary

Fourteen years ago the Wingspread Report (Manduca, Mogk, & Stillings, 2003) helped establish geoscience education research (GER) as an important research field and highlighted major research questions for GER at the time. More recently, the growth and interest in GER is evident from the increase in geoscience education research articles in a peer-reviewed journals, the establishment of the NAGT GER Division, the creation of the GER Toolbox, an increase in GER graduate programs, and the growth of tenure-eligible GER faculty positions. As an emerging DBER field (NRC, 2012), the GER community is examining the current state of their research and considering the best course forward so that it can have the greatest collective impact on advancing undergraduate teaching and learning in the geosciences.

	Research on:
1	Students' Conceptual Understanding of Geology/Solid Earth Science Content
2	Students' Conceptual Understanding of Environmental, Oceanic, Atmospheric, and Climate Science Content
3	Elementary, Middle, and Secondary Earth and Space Sciences Teacher Education
4	Teaching about Earth in the Context of Societal Problems
5	Access and Success of Under-represented Groups in the Geosciences
6	Cognitive Domain in Geoscience Learning: Spatial and Temporal Reasoning
7	Cognitive Domain in Geoscience Learning: Quantitative Reasoning, Problem Solving, and Use of Models
8	Instructional Strategies to Improve Geoscience Learning in Different Settings and with Different Technologies
9	Geoscience Students' Self-Regulated Learning, Metacognition, and Affect
10	Institutional Change and Professional Development

Table 1. Themes that span the spectrum in which GER operates and have the potential to impact **undergraduate geoscience teaching and learning.**

Building on a prior NSF-funded workshop, this NSF-funded GER Framework project engaged ~200 geoscience educators and researchers through a sequenced series of virtual and face-to-face events to share ideas, gain feedback, and create and revise priority research questions, or "Grand Challenges", that span 10 geoscience education research themes (Table 1). For each theme, several Grand Challenges and recommended strategies have been proposed by the community.

Goal and Objectives

The project goal is to improve teaching and learning about the Earth, by focusing the power of Geoscience Education Research (GER) on a set of ambitious, high-priority, community-endorsed grand challenges.

To achieve this goal, we sought to:

- Engage the community, where "community" involves discipline-based education researchers, scholars on geoscience teaching and learning, geoscience educators from a range of institution types and career levels, and cognition scientists.
- Focus on challenges that can be achieved within 10 years.

- Focus on strategies that impact undergraduate teaching and learning.
- Produce, and widely disseminate, a report on the Community Framework for GER.

Vision

It is our vision that the final outcome of this community-grounded process is a published **guiding framework** to:

- Focus future GER on questions of high interest to the geoscience education researcher and practitioner community,
- Provide funding agencies with a strong rationale for including GER in future funding priorities,
- Increase the strength of evidence of GER community claims, and
- Elevate the visibility, stature, and collaborative potential of GER in the geosciences and in STEM education research.

Process Used to Develop the GER Framework

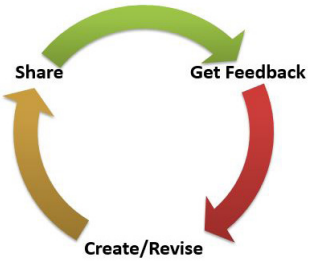

Figure 1. A community-engaged iterative process was used to develop the GER Framework.

Figure 2. Major steps in the process toward defining GER grand challenges and strategies.

The project was a community-engaged iterative process that involved multiple steps of creating, sharing, getting feedback, and revising (Figures 1 and 2).

Themes Defined by Literature Review and Community Input

An initial step in the process was to identify themes that have the potential to impact *undergraduate* teaching and learning.

The GER themes were informed by a range of reports, discussions, and surveys including: focus group discussions at the 2015 GER workshop, results from the 2017 GER Survey, the DBER Report (NRC, 2012), the Wingspread workshop Report (Manduca, Mogk, & Stillings, 2003), the Earth and Mind II Synthesis report (Kastens & Manduca, 2012), and Lewis & Baker (2010). The Wingspread and Earth and Mind II reports emphasized

Alignment of GER Framework Themes with Topical Areas Addressed in Relevant Prior Discussions, Surveys, Reports

GER Framework Themes	Wingspread Report (Manduca et al., 2003)	Editorial (Lewis and Baker, 2010)	Earth in Mind II synthesis Report (Kastens and Manduca, 2012)	DBER Report (Singer et al., 2012)	2015 GER workshop	2017 GER Community Survey
WG1: Students' Conceptual Understanding of Geology/Solid Earth Science Content	√		√	√	√	√
WG2: Students' Conceptual Understanding of Environmental, Ocean, Atmosphere, and Climate Science Content	√		√	√	√	√
WG3: Elementary, Middle, and Secondary Earth and Space Sciences Teacher Education		√				√
WG4: Teaching about the Earth in the Context of Societal Problems						√
WG5: Access and Success of Under-represented Groups in the Geosciences		√			√	√
WG6: Cognitive Domain in Geoscience Learning: Temporal and Spatial Reasoning	√		√	√	√	√
WG7: Cognitive Domain in Geoscience Learning: Quantitative Reasoning, Problem Solving, and Use of Models	√		√	√	√	√
WG8: Instructional Strategies to Improve Geoscience Learning in Different Settings with Different Technologies	√		√	√	√	√
WG9: Self-Regulated Learning, Metacognition, and Affect		√		√	√	√
WG10: Institutional Change and Professional Development		√		√	√	√

Table 2. Alignment of GER Framework Themes with topical areas addressed in relevant prior discussions, surveys, and reports. Note that distinctions between students conceptual understanding in different sub-areas of geoscience (e.g., WG1 and WG2) and the full range of geocognition sub-themes (WG6 and WG7) did not emerge until the 2017 GER Survey.

themes of research on conceptual learning, geocognition, and instructional design, all largely under the umbrella of research on the development of geoscience expertise. In contrast, Lewis and Baker's "Call for a New Geoscience Education Research Agenda" emphasized research on K-12 teacher preparation, pipeline issues of attraction of under-represented groups to the geosciences, and on motivation and institutional support factors that affect these populations (Table 2). The DBER Report was more broad in scope, identifying several education research themes that cross STEM disciplinary fields, but not addressing either of these special populations. The 2015 GER workshop was a preliminary exploration of the comprehensive set of themes that emerged out of the earlier resources. Outcomes from the 2015 GER workshop highlighted the potential value of an additional theme on geoscience teaching in the context of societal problems, which was included along with K-12 teacher education as a themes for the community to give feedback on in the 2017 online GER survey.

Iterative Process of Community-Engaged Project Activities

Initial Community Survey and Webinar

The 2017 online GER survey was the first of a series of community-engaged activities in this project. The purpose of the survey was to share tentatively defined themes, and develop an initial database of important developments, recommended resources, and important research questions for each of the themes. Survey respondents (n=66, Figure 3) recommended ~100 resources related to the themes. Their comments highlighted the varying scale and scope of prior work done in different theme areas, the need for greater awareness and collaboration between GER and other STEM Education research fields, the need for better grounding of research in theories, and the need for stronger research design and assessment. Results demonstrated interest in all themes, with the greatest interest in cognition topics, instructional strategies, conceptual understanding, and teaching the Earth in the context of societal problems (confirming the decision to create this new research theme area). While prior reports (Table 2) emphasized research on conceptual understanding and on cognition research, the 2017 GER survey results suggest it would be valuable to make thematic distinctions between different sub-areas of conceptual understanding (Table 2, WG1 and WG2) and different sub-areas of cognition (Table 2, WG6 and WG7). In particular, although there is widespread interest in teaching with an Earth system science perspective, much of the published research in students' conceptual understanding lies in geology/solid Earth concepts. Creating a theme for the other Earth system "spheres" highlights their importance as areas of future geoscience education research. Survey results were reported to the community in a webinar and informed the program development of the 2017 GER workshop.

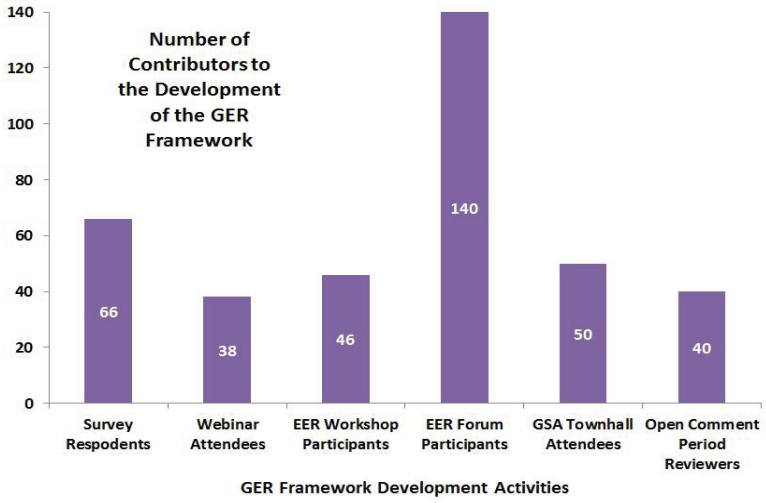

Figure 3. Community participation in the activities towards developing the GER Framework.

EER Grand Challenges and Strategies Workshop

A critical step to facilitate action towards the project goal was a multi-day workshop of 46 geoscience education researchers at the 2017 Earth Educators Rendezvous. Prior to the face-to-face workshop, 10 working groups were defined, one for each GER themes (Table 1). Applicants were matched

Figure 4. Draft grand challenges and strategies were presented and critiqued by the other workshop participants and feedback was used to revise their work. Sharing and feedback also occurred in a preliminary community online survey, in a webinar, at the EER Geoscience Educator and Researcher Forum, at the GSA Townhall, in posters at the GSA, AGU, and AMS meetings, and during the online Open Comment Period.

to the thematic working groups, and working group leaders were nominated and selected based on experience and expertise for that theme. Working groups had 3 to 5 members. Participants included geoscience education researchers at different stages in their career and different types of institutions.

The expectations of the workshop were high, and working groups were tasked with defining an initial set of 3-5 grand challenges for their theme, a rationale for those challenges, and preliminary strategies to address those challenges. The grand challenges were to be in the form of well-justified, large-scale research questions that could, and should, guide future research for the GER community, and the recommended strategies were to be ideas on how the GER community could make significant progress on those important research questions, given their knowledge of the GER landscape.

To support this effort, the workshop was structured to include focused working group time, opportunities for working groups to share and get feedback from other participants, and two whole-group cross theme sessions, the topics of which emerged out of the earlier survey (Table 3 and Figure 4). Working groups had access to recommended resources submitted from survey respondents, as well as resources recommended by project leaders and submitted pre-workshop by working group members.

Workshop Overview				
	Sunday	**Monday**	**Tuesday**	**Wednesday**
Working Group Time	Grand Challenges Part 1: Discuss	Grand Challenges Part 2: Add & Refine	Grand Challenges Part 3: Finalize & Present. Strategies Part 1: Discuss	Strategies Parts 2 and 3: Finalize & Present
	→ Record in Online Workspace → → Share and Get Feedback →			
Whole Group Sessions	Lessons Learned from the Wingspread Workshop/Report	Role of Models and Theories in Research Design		Thinking Strategically about Assessment
Special Connected Session		*Geoscience Education Research and Practice Forum*		

Table 3. Workshop structure to support thematic working groups in defining GER grand challenges, their rationale, and preliminary strategies to address the challenges.

Engaging with the Broader Community: Opportunities to Share and Get Feedback

In order to ensure broad community input, there were opportunities for sharing with and getting

feedback from outside the working groups at different stages in the GER Framework development process. The largest of these was the EER Geoscience Education Research and Practice Forum, which attracted ~140 geoscience educators and researchers. The purpose of the Forum was for researchers to listen to educators' ideas on what questions they would most like geoscience education researchers to address on their behalf. Educators divided into small discussion groups organized around the GER theme areas, with one or more working group researchers present in each small group. Discussions were rich; this provided an opportunity to identify promising practices and puzzling questions that are important and suitable for research, as well as a means of gauging

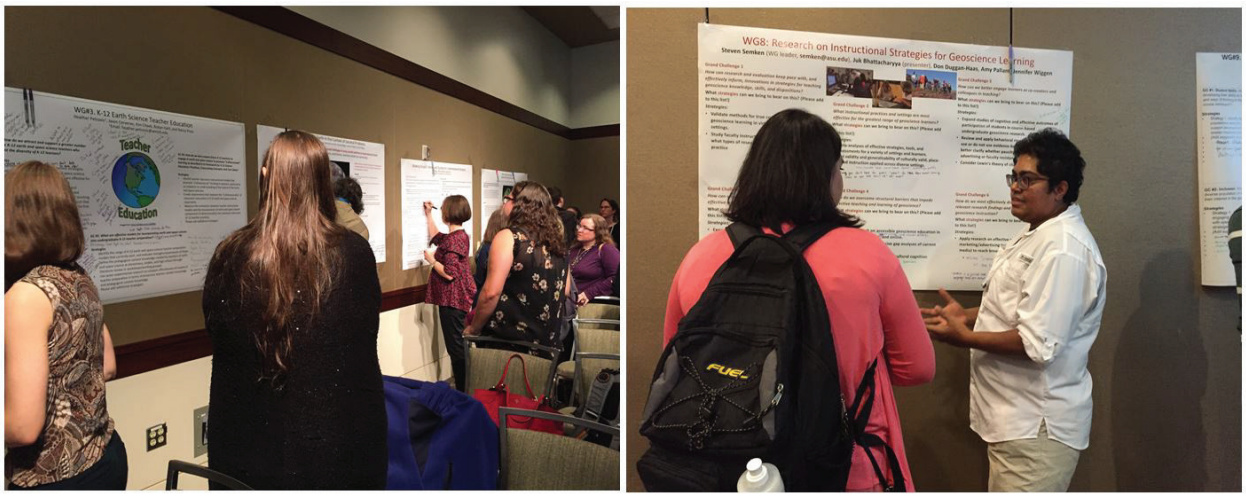

Figure 5. Working group representatives shared their theme's draft Grand Challenges and preliminary strategies at a GSA Townhall for review and discussion. Attendees could write comments and suggestions on the posters, which later working groups would use to revise their work.

alignment of ideas on what educators think is important to address with ideas that GER working group members were already generating on grand challenges. Feedback from the Forum influenced the evolution of the draft grand challenges and raised the awareness among GER working group members of educators' interests, concerns, and priorities.

By the close of the EER GER workshop, a preliminary set of theme-based GER grand challenges and supporting strategies was produced. A GSA Townhall meeting was organized as the first opportunity to publicly share and vet these draft Framework materials. It was attended by ~50 people. Representatives from each working group gave a "lightning" 1-2 slide presentation on their GER theme, and then attendees had the opportunity to visit and write notes on theme posters (Figure 5) which listed all of their grand challenges and had space for adding critiques, ideas on prioritization, and suggested strategies. In addition, more traditional outlets of conference presentations were also used as ways to share ideas and get feedback; these included posters at GSA (poster accessible online) and AGU meetings, and an oral presentation at the AMS meeting (recorded presentation accessible online).

Following the GSA Townhall, working group leaders and contributors from their teams revised the grand challenges, and expanded upon the rationales and strategies so that by the start of the AGU meeting each theme had a full draft ready for critical review by the broader community. This was facilitated through a 2-month Open Comment Period. Draft GER Framework materials (at this point referred to as theme "chapters") were hosted on a SERC website; comments could be entered in 'Discussion' boxes directly on the webpages for each of the 10 theme chapters. Efforts to alert and encourage community members to contribute their comments included distribution

of flier (with a QR code to the webpage) at the AGU NAGT booth and at the project poster, notices in the NAGT newsletter, the NAGT GER Division newsletter, the GSA Geoscience education listserv, direct emails to attendees of the 2015-2017 EER GER workshop attendees, authors that published articles in the JGE theme issue on *Synthesizing Results and Defining Future Directions of GER*, and other members of the GER and geoscience education community. In sum, comments from 40 people were submitted; 67% of these were from geoscience educators and researchers external to the project, and the remaining comments were from those internal to the project but from other working groups than the themes they critiqued. Each theme chapter received comments from 3 to 5 reviewers. Reviewers provided substantial feedback, on par with the thoughtful constructive comments expected on manuscripts submitted for peer-review. These comments helped chapter authors recognize and address gaps, refine the ideas communicated, and better situate the grand challenges and recommended strategies in a meaningful context.

Framework Scope and Audience

Intended Scope of the GER Framework

This project embraces a broad definition of GER that reflects the geoscience education community's values and the evolution of STEM education research. The geosciences have a long and rich history on the scholarship of teaching and learning (SoTL), which involves the development, application, and evaluation of new geoscience teaching innovations and curricula. More recently, in the geosciences and in other STEM fields, there has been rapid growth in interest and activity in discipline-based education research (DBER), which develops and tests discipline-specific (i.e., geoscience) education research questions and hypotheses. Both SoTL and DBER are important for improving teaching and learning in the geosciences, and therefore both are included in the scope of GER for this project (Figure 6). Contributors to this project were asked to situate their thinking about GER to include both SoTL and DBER as they considered GER themes, grand challenges, and strategies to meet those challenges.

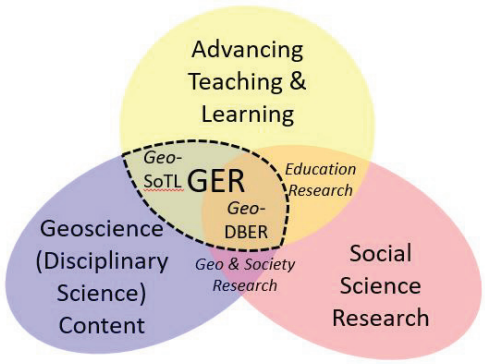

Figure 6. Geoscience education research Venn diagram. Figure by Kristen St. John, modified from one by Lukes et al., (2015).

In addition, this project focuses on GER that informs future teaching and learning at the undergraduate level. We recognize that GER itself is broader than this; there are researchers that focus on pre-college, graduate level, and informal geoscience education, as well as those whose work is purely for the advancement of knowledge (non-applied) research. The project emphasis on undergraduate-related GER was made for two reasons: (1) the majority of GER activities as reflected in meeting abstracts, publications, and geoscience education workshops are largely undergraduate-focused, and (2) the NSF-IUSE program, which funded this project, targets improvement in undergraduate STEM education.

Organization of the GER Framework Chapters: Communicating to Multiple Audiences

In organizing the GER Framework chapters, we recognized the need to effectively reach multiple

audiences: geoscience education researchers, geoscience educators, colleagues, administrators, program officers in funding agencies, as well as education researchers in other STEM disciplines. Therefore, theme chapters have two tiers of information: (1) an introductory page and (2) expanded pages for each grand challenge (Table 4). The aim of the introductory page is to help those outside of GER understand what we do, what we want to do, and why it is important. It includes a brief overview of that theme, and lists the grand challenges with brief descriptions; citations are kept at a bare minimum on that page and jargon is avoided. In contrast, the expanded pages on each grand challenge are for those who want to dive deeper. Each of these grand challenge pages can be accessed from the theme introductory page, and contain a more thorough rationale for why research to address that grand challenge is needed, and makes recommendations for immediate strategies to be used to address it. It includes a set of key references to support the rationale and strategies, however it is not intended to be a full literature review of all the work done thus far that inform that theme. Both the introductory page and the expanded grand challenge pages include one or more diagrams, tables or photos that help illustrate that challenge and/or strategies to address it.

GER Framework Organization	
Want just a short overview of the Theme and its Grand Challenges?	Go to the Introductory page for each Theme Chapter
Want to dive deeper and get a more detailed perspective along with recommended strategies and key citations?	Go to the expanded pages on each Grand Challenge
Want to see how it all connects together?	Go to the Synthesis Chapter

Table 4. The GER Framework is designed for multiple audiences. It includes introductory, detailed, and synthesis levels of information.

In addition to the theme chapters, the GER Framework includes a synthesis chapter, which highlights strands that connect multiple themes (in some cases, all themes), which may serve as high impact pathways to achieve transformative research. It also describes the potential for using the GER Toolbox as a means to support a range of recommended strategies. The synthesis chapter compares the outcomes of this effort to that of earlier community efforts (e.g., Wingspread report) to give a longitudinal perspective on the evolution of GER. It looks outside of GER as well, to describe potential synergies between the outcomes of this project and that of other relevant and timely large-scale efforts, including the Summit on the Future of Undergraduate Geoscience Education and cross-DBER efforts; and it situates the outcomes of this project within the recent NSF report on big ideas for the future funding investment.

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Figures and Tables

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