Research on Teaching about Earth in the Context of Societal Problems

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Introduction

The use of societal problems as an effective context for teaching about the Earth was suggested in projects (e.g., InTeGrate) and conversations leading up to the 2017 workshops on the future of Geoscience Educational Research. Around the same time, the Summit on the Future of Undergraduate Geoscience Education (Mosher et al., 2014) indicated that among the content and competencies of graduating geoscientists, students "must understand the societal relevance of geoscience topics as well as their ethical dimensions." (Summit Summary Report, p. 3) Similarly, at a societal level, as our population likely exceeds 9 billion by 2050, there will be increasing pressures on Earth systems (e.g., water, energy, soils, biochemical cycles) so efforts to understand how to live sustainably on our planet will require interdisciplinary, applied skills and experiences for the next generation of geoscientists.

AGI: Geoscience for America's Critical Needs:

1. Ensuring sufficient supplies of clean water
2. Developing energy to power the nation
3. Building resiliency to natural hazards
4. Managing healthy soils
5. Providing raw materials for modern society
6. Expanding opportunities and mitigating threats in the ocean and at coasts
7. Confronting climate variability
8. Managing waste to maintain a healthy environment
9. Meeting the future demand for geoscientists

Modified from AGI, 2016

Figure 1. Geoscientists have scientific expertise and valuable perspectives needed to address a range of economic, environmental, health, and safety challenges as identified by AGI (2016) in their report Geoscience for America's Critical Needs. Research is needed on how societal problems can serve as effective context for teaching and learning in the geosciences.

Knowledge and consideration of societal issues are critical for students majoring in the geosciences, as well as for non-science students (Figure 1) and the general public who vote and make decisions that should be based on sound science. Thus, the importance of integrating geoscience with other disciplines such as urban planning, social justice, politics, communications and more has become a critical call to action for geoscience researchers and educators merits examination.

Improving undergraduate STEM education with the use of relevant issues such as societal problems is a useful mechanism to help students find science to be personally relevant and to develop their interest based on societal contexts. Increased use of student-centered pedagogies in STEM teaching is consistent with research examining student learning and persistence.

The Grand Challenges in this chapter examine the use of societal issues to teach about the Earth, which include consideration of the impact on student learning, the design principles of curricula that best integrate geoscience content within the context of societal issues, and the assessment needed to measure the efficacy of these methods (Figure 2).

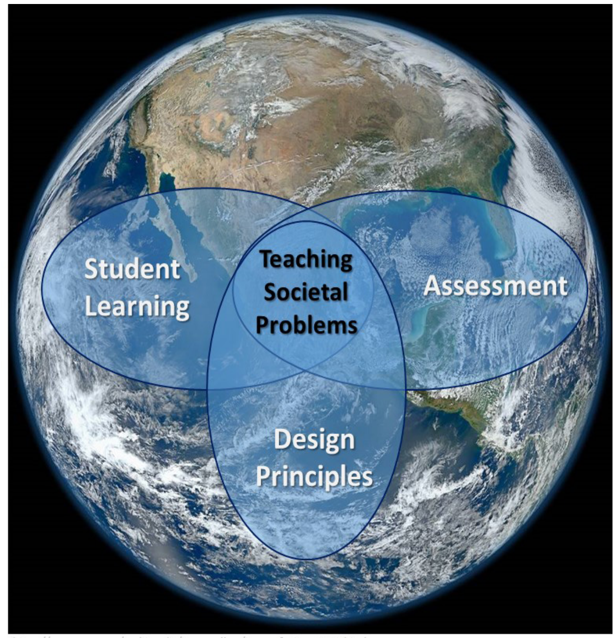

Figure 2. Components considered in the Teaching about Earth in the Context of Societal Problems Grand Challenges included here. Graphic modified from NASA, 2012.

Grand Challenges

Grand Challenge 1: How does teaching with societal problems affect student learning about the Earth?

Societal issues are of high interest to students, which provides an opportunity to increase student exposure to, and interest in, the geosciences. The efficacy of teaching with societal issues merits further research to characterize curriculum that exists and the extent to which it increases student learning and motivation as they develop their geoscience literacy.

Grand Challenge 2: What are the design principles for curriculum needed to teach with societal problems?

As curriculum is designed to incorporate the use of societal problems, there must be a clear set of design principles that clarify best practices that promote student learning. There are a variety of research-based teaching strategies available but characteristics of effective curriculum must also be considered in the context of teaching with societal issues. An important strategy is to assess the use of research-based design principles that operate at different scales of issues (e.g. local vs. global scale) and at different scales of course activities (e.g. within a class period or across a course or program).

Grand Challenge 3: How do we assess the influence of teaching with societal problems in terms of student motivation and learning about the Earth?

Teaching about the Earth through the use of societal issues or problems can theoretically increase student motivation, engagement, and learning. New research should measure changes in both cognitive (e.g. problem solving and learning) and affective domains (e.g. motivation, engagement, self-efficacy) at short term (course) scales as well as in multi-institutional longitudinal studies.

Grand Challenge 1:
How does teaching with societal problems affect student learning about the Earth?

Rationale

Geoscience plays a critical role in building sustainable societies and managing environmental issues, both in the types of research that address societal needs as well as creating scientifically literate citizens (Lewis & Baker 2010). Geoscientists have long been involved with research that intersects with societal issues, including resource issues (food, water quantity, mineral/aggregate resources, energy), environmental stability (environmental degradation, environmental justice) and health and safety issues (natural hazards, climate change, water quality; InTeGrate, 2017). However, there is a need to increase the number of undergraduate students choosing geoscience subjects to prepare them with skills and content required in the workplace (Wilson, 2016), and this requires us to examine novel approaches to teach geoscience.

Increasing undergraduate student engagement and motivation are key. Societal issues are of high interest to students (e.g. Pelch & McConnell, 2017). Science education research has shown that the disconnect between school science and students' day-to-day lived experiences contributes to lack of interest in science (Basu & Barton 2007, DeFelice et al., 2014; Lemke 2001, Roth & Tobin, 2007). As a result, this disconnect has created a false impression among students that science has little relevancy. Furthermore, students need to recognize the usefulness of the knowledge or skill in their lives and future goals for learning experiences to lead to usable knowledge (Edelson et al., 2006). Underrepresented and urban students (often with great diversity) are often at greater risk of losing interest in science as there is the added cultural and linguistic disconnects between school, school science, and their life-worlds (Basu & Barton, 2007; Rahm, 2007; InTeGrate, 2017). The world is becoming increasingly urbanized and it expected that the proportion of the world's population to live in urban areas will rise from 55% to 68% by 2050 (United Nations, 2018).

Teaching geoscience in societal contexts opens avenues to increase student exposure to and interest in geosciences (InTeGrate, 2017). Students tackle open-ended, real world, and often complex problems that are relevant, especially if using placed-based pedagogy and high impact teaching approaches (e.g., learning communities; service learning or other courses with a community-based project component; study abroad experiences; internships capstone courses or culminating senior experiences, and research with a faculty member) (NSSE, 2016). Students today, especially millennials, want to make a difference in their communities and the world at large. By providing societal contexts, they become interested, empowered, and motivated to become agents of change (Kang et al., 2016).

Whether or not students choose geoscience as a career, exposure to societal issues increases the role of science in building sustainability and can directly or indirectly affect attitudes and behaviors toward sustainable consumption (Kang et al., 2016) According to the United States National Center for Education Statistics, "scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (NASEM, 2016, p. 139). Lack of geoscience literacy makes society less informed and more vulnerable to resource use, disasters, and impacts of climate change.

The Summary Report for Summit on Future of Undergraduate Geoscience Education contributed toward building a collective community vision for the undergraduate geoscience instruction focusing on three areas: (1) curriculum, content, competencies, and skills, (2) pedagogy and use of technology, and (3) broadening participation and retention of underrepresented groups and preparation of K-12 science teachers (Mosher et al., 2014, p.1). This provides a framework in which to research how the inclusion of societal issues contributes to student learning about the Earth.

To examine the efficacy of using societal problems to teach about the Earth, we need to determine the theoretical frameworks that connect the use of societal problems with student motivation to learn about the Earth and student motivation to act (e.g. solve problems/change behaviors), and also determine if learning progressions are important considerations and what the ideal progressions are (e.g. use of issues/activities/solutions appropriate to introductory to advanced levels and STEM/non-STEM majors).

Recommended Research Strategies

Specific research strategies to determine how the use of societal problems impacts student learning and contributes to content goals and general geoscience literacy should include:

1. Literature reviews to identify relevant theoretical frameworks that will help explain the mechanisms through which teaching about the Earth through societal problems leads to student learning.

2. Investigations of questions on how best to integrate issues of societal relevance in a geoscience curriculum to achieve geoscience literacy among non-majors, as well as geoscience workforce knowledge and skills (e.g, from the Summit Workforce document; Mosher et al., 2014) at the upper level. For example are there important learning progressions that indicate how much and what type of attention to societal issues results in learning and changing attitudes, and if there is specific timing in which societal problems should be included (e.g. use of issues appropriate to level and STEM/non-STEM majors)?

3. Both shorter-term and longitudinal studies to examine if/how students use new-found knowledge of societal problems in their own lives and whether such issues contribute to student motivation to act (e.g. solve problems/change behaviors).

4. Investigations to determine if the use of societal problems contributes to expanding diversity in the geosciences, which may be addressed through short term or longitudinal research on the current and evolving diversity in the geosciences, along with demographic analyses and interviews with students in various stages of courses in the geosciences.

Grand Challenge 2:
What are the design principles for curriculum needed to teach with societal problems?

Rationale
An important next step in supporting teaching about the Earth with societal problems is to identify the design principles that are needed to develop additional relevant curricula. Teaching with societal problems as a means to enhance student interest, motivations, dispositions, and learning outcomes, has emerged as a common design principle (i.e. a proposed relationship between an educational design and student learning; Sandoval, 2004) in recent reform efforts. Notably, the materials design rubric for the InTeGrate project tasks materials developers to create curricula that "connect geoscience to grand challenges facing society." This design strategy has resulted in a large body of modules and courses (~40) that incorporate the grand challenges in a variety of ways.

Efforts such as the Serving Our Communities blog have collected stories about how faculty are engaging with this work in creative ways that involve communities outside the campus. While the theoretical underpinnings of this conjecture are sound (see Introduction and Grand Challenge 1), there is a wide variety of possible teaching strategies that can be used, many of which are not yet well studied (e.g. service learning; NASEM, 2017). Documenting how this design conjecture is embodied in learning environments can lead not only to information about the efficacy of these approaches, but also lead to new insights into the underlying mechanisms for learning that are at play (Sandoval, 2004).

Of particular importance for supporting development and implementation of strategies for teaching with societal problems are considerations of scale. Societal problems can be used to address issues at a variety of scales (local, regional, global), leading to questions about implications for student outcomes (e.g., how does the scale of the issue impact student motivation?). Additionally, instructors can use societal problems to engage learners at different scales (e.g., activity scale within class periods, modules, courses, cross-cutting themes across a degree program). Identification of research-based design principles that operate at different scales on both dimensions should be a principal focus of this work. Future directions for this work include determining how best to support faculty in the use of the design principles to incorporate teaching with societal problems into their courses. This could include structures for developing action plans and repositories of examples for issues on multiple scales.

Recent efforts in the GER community show promise for moving this work forward in meaningful ways, lending credence to the claim that this is a timely pursuit and providing guidance for recommended strategies. Throughout this work, we encourage researchers to consider linkages between geoscience classrooms and other entities that can support this work, such as community groups and artists.

Recommended Research Strategies

1. Inventory existing resources and promising practices that integrate issues of societal relevance in geoscience instruction. The rich body of practitioner-developed resources, coupled with the

research literature, provides an ideal starting point for this work. We recommend conducting systematic analyses of approaches and strategies identified through conducting literature reviews, developing inventories of current practices found in existing databases (e.g. InTeGrate, On the Cutting Edge Exemplary Teaching Activities collection, SENCER model courses), and collecting narratives from faculty. Kastens and Krumhansl (2017) describe a method for identifying design patterns in practitioner-developed resources that could be implemented here.

2. Determine what resources lead to student learning and engagement. Large scale investigations of the efficacy of existing resources can serve as a starting point for identifying targets for further research. For example, students who participated in InTeGrate modules demonstrated higher scores on systems thinking (Gilbert et al., 2017) and interdisciplinary essays (Awad et al., 2017) when compared to control groups. Modules with particularly high gains could be identified through further analysis of these datasets as a starting point. Determine what characteristics of approaches are effective at what scale and in what contexts. We recommend conducting design research studies of existing resources and promising practices, with a particular emphasis on identifying practices that lead to target student learning outcomes. This approach has the "dual goals of refining both theory and practice" (Collins et al., 2004) and embraces the real-world context in which teaching and learning occurs (Sandoval, 2004). Holder et al. (2017) proposed the Problem-Solving in Practice model, which identifies elements of instructional design that can be used to guide student engagement in real-world problem solving; this model could serve as the basis for design research studies.

Grand Challenge 3:

How do we assess the influence of teaching with societal problems in terms of student motivation and learning about the Earth?

Rationale

Teaching about the Earth through the use of societal issues or problems can theoretically increase student motivation, engagement, and learning. The NRC (2012) advocates for the use of societal problems in the K-12 classroom in multiple disciplines, but this can be especially useful in the geosciences at K-12 and at the undergraduate levels because our field focuses around the surface of the Earth where humans live:

> "studying and engaging in the practices of science and engineering during their K–12 schooling should help students see how science and engineering are instrumental in addressing major challenges that confront society today, such as . . . solving the problems of global environmental change'' (NRC, 2012, p. 9).

Societal issues may serve as the vehicle to increase cognitive and affective skills like problem solving, as a student may be more motivated or engaged during problem solving that has personal significance (Gilbert, 2006; Sawyer, 2006; McConnell & Van Der Hoeven Kraft, 2011). Furthermore, in today's society, students must be able to distinguish between "fake news" and scientific facts, especially when there is an issue that impacts their local community. By teaching about these types of situations early and often during students' academic careers, we can prepare them to be informed citizens that can vote accordingly:

> "Scientists must make critical judgments about their own work and that of their peers, and the scientist and the citizen alike must make evaluative judgments about the validity of science-related media reports and their implications for people's own lives and society. (NRC, 2012, p. 71)"

In order to know if teaching through the use of societal problems is valid, we as a community should produce research to substantiate the claims that we make about increases in engagement, motivation, and problem solving and learning. We should also investigate how student-centered course activities like flipped courses or service-learning could help to increase engagement and motivation:

> "... the geosciences... offer fertile ground for service-learning programs that address intersections between science and society" (National Academies, 2017, p. 6).

All of the calls for integration of societal-relevant approaches to teaching and learning, however, require that quality assessment techniques are used to measure changes in both the cognitive (e.g., problem solving and learning) and affective domains (e.g., motivation, engagement, self-efficacy). In the future, we will need to conduct multi-institutional longitudinal studies that robustly measure the impact of teaching with societal issues.

Research on the efficacy of teaching about the Earth through the use of societal problems should include student data, but should also explicitly link defined student learning outcomes to validated assessment techniques. To do this, we must first fully explain student learning outcomes and the numerous variables related to these, such as defining "geoscientific literacy" as this phrase may have different definitions. In general, GER will need to define the best ways to measure the effect of using societal problems on student learning and on resulting motivations to act (e.g. solve problems/ change behaviors). To do so, we will need to determine what instruments currently exist or need to be developed to assess the use of societal problems that allows for future meta-analysis. We suggest that although there are generalized problem solving, argumentation, engagement, and motivation surveys, it may be useful to tailor these specifically for the geosciences.

Recommended Research Strategies

1. In the cognitive domain, we should assess general problem solving skills as well as how students approach a problem, make decisions, argumentation, and solution generation. To do this, we can use validated assessment techniques like the Social Problem-Solving Inventory-Revised (SPSI-R; D'Zurilla et al., 2004). This inventory examines the ways in which students orient themselves towards the problem, rational problem solving, impulsivity, and avoidance, and self-efficacy. Instructors can also use open-ended responses to further examine problem solving-skills from a quantitative view. In some instances, new instruments may need to be developed to measure problem solving skills when societal problems are integrated into curriculum.

2. Argumentation may also be an effective way to engage students in problem solving and learning (Driver et al., 2000; Osborne et al., 2004), but needs further research. While assessment of argumentation is difficult, there are methods such as Toulmin's (1958) argumentation model, and revisions of this model, based upon warrants and claims; however, this data is much more qualitative in nature, which merits consideration of review of existing quantitative instruments (or the development of new instruments) that measure argumentation learning strategies.

3. General learning in the geosciences as a result of teaching using societal issues could be assessed using the Geoscience Concept Inventory (GCI; Libarkin and Anderson, 2005), a validated bank of questions that assess learning, or through the use of the Learning and Study Skills Inventory (LASSI; Cano, 2006). General learning can also be assessed using open ended response questions; however, these questions often take much longer to assess and rubrics are typically subjective depending upon the nature of the question.

4. Student affective domain is of equal importance when considering societal issues because of the claim that teaching with these issues may lead to increases in engagement and motivation. To measure engagement, instructors and researchers can use a variety of instruments, but one of the most popular of these is the National Survey of Student Engagement (NSSE; Kuh, 2003). However, this instrument is expensive, and fairly generalized and so it may be useful to develop additional engagement surveys that relates more directly to the geosciences. Additionally, we should investigate changes in engagement over the course of one semester, but also examine changes in students' affective domain in geoscience departments that teach primarily in the context of societal issues.

5. Examine the relationship between students' motivation and attitude and teaching with societal problem. In terms of motivation and attitude, there are several validated options including: Attitudes toward Science Survey (ATSS; Bickmore et al., 2009), Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich et al., 1991), Intrinsic Motivation Inventory (IMI; Ryan and Deci, 2000), and the Academic Motivation Scale (AMS; Vallerand et al., 1992). In addition to these instruments, there are quite a few instruments listed on the NAGT GER Toolbox (GER Toolbox, 2017). Student engagement, motivation, and attitudes can also be linked to the teaching style of the instructor (instructor centered or student centered), and so using a observation protocol like the Reformed Teaching Observation Protocol (RTOP) could be useful to gauge the impact of the instructor (Piburn and Daiyo, 2000)

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Figures

Figure 1:
Provenance: Modified from AGI (2016), *Geoscience for America's Critical Needs*.

Figure 2:
Provenance: Modified from NASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring *Teaching about Earth in the Context of Societal Problems.*