# Preparing Students to Address Societally Relevant Challenges in the Geosciences: The InTeGrate Approach

**David C. Gosselin, Cathryn A. Manduca, Timothy Bralower, and Anne E. Egger**

**Abstract** Society faces many challenges related to its long-term sustainability and resilience of the life-support system upon which Earth depends. Developing solutions to these grand challenges requires an interdisciplinary approach that demands scientific investigation of the interactions of the geological, biological, chemical, and physical environments, in combination with exploration of the human dimensions and societal institutions whose values underlie our currently unsustainable ways of living. Although geoscience literacy—the perspectives and methods of the Earth, ocean, and atmospheric sciences—is key to addressing these challenges, current educational pathways in the United States limit students' exposure to the geosciences. To increase access to interdisciplinary opportunities and improve geoscience literacy, we developed the Interdisciplinary Teaching about Earth for a Sustainable Future (InTeGrate) Science, Technology, Engineering, and Math (STEM) Talent Expansion Program (STEP) Center. InTeGrate engaged undergraduate educators in the development of interdisciplinary materials, programs, and strategies to teach geoscience in the context of societal issues. The project has reached over 100,000 students at more than 900 institutions across all 50 states and overseas. Here, we provide an overview of the InTeGrate project, its design elements, and the shared values that underpinned development of materials and model programs.

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D. C. Gosselin et al. (eds.), *Interdisciplinary Teaching About Earth and the Environment for a Sustainable Future*, AESS Interdisciplinary Environmental Studies and Sciences Series, https://doi.org/10.1007/978-3-030-03273-9_1

**Keywords** Interdisciplinary teaching · Geoscience · Sustainability · Societal issues · Education

## Introduction

As a society, we face many challenges related to the long-term sustainability and resilience of our global and local communities under the threat of human-induced environmental change. When decision-makers have a process-level understanding of Earth and environmental systems, they can address these challenges effectively and make progress toward sustainability by enacting strategies to efficiently utilize natural resources including food, water, and mineral resources; capitalize on traditional and alternative energy sources; reduce instability associated with climate change and environmental degradation; improve health and safety with respect to natural hazards, water, and air quality; and address related issues such as environmental justice. That process-level understanding is rooted in the geosciences (consisting of the Earth, oceanic, and atmospheric sciences), the disciplines that seek to elucidate the workings of the Earth and its environmental systems and provide us with an understanding of the extent to which Earth constrains our behavior and to which our behavior impacts Earth's systems.

Unfortunately, current educational pathways in the United States limit students' exposure to the geosciences. For the majority of US citizens, their most significant educational experience in geoscience was likely in middle school. With few exceptions, states do not require a course in Earth science to graduate from high school, nor do they test students in Earth science beyond middle school (Wilson 2016). As a result, students typically do not take a geoscience course in high school, and only a small fraction elects to take a geoscience course during college. This limited exposure to the geosciences as K-12 students reduces citizens' abilities to apply that knowledge to make informed personal and societal decisions about current and future Earth, environmental, and natural resources issues, a key component of geoscience literacy.

While understanding of the geosciences is necessary, it alone is not sufficient to address the challenges of sustainability and resilience, which lie at the intersection of natural and human systems. Developing solutions requires integrating knowledge, skills, and methods from the geosciences with concepts and approaches of other disciplines, including other natural sciences (e.g., biology), engineering, the social sciences, and the humanities. These interdisciplinary approaches are needed to address the complexity of twenty-first-century societal and environmental challenges; in higher education, however, institutional inertia, the strong commitment of faculty members to the disciplines in which they are trained, and the role of discipline-based departments in curricula and faculty rewards, can act as barriers to creating opportunities to develop interdisciplinary skills in students (Sunal et al. 2001; National Academy of Sciences et al. 2005).

To address these paired gaps in geoscience literacy and interdisciplinary skills, we developed the Interdisciplinary Teaching of Geoscience for a Sustainable Future

(InTeGrate) project, the STEM Talent Expansion (STEP) Center in the Geosciences. InTeGrate catalyzed and supported a community in a broad-based effort to establish opportunities throughout the undergraduate curriculum to incorporate geoscience and geoscientific approaches into addressing environmental and resource issues (Gosselin et al. 2013). The InTeGrate community engaged undergraduate educators in creating interdisciplinary materials and strategies to teach geoscience in the context of societal issues at the course, program, institution, and multi-institution levels.

The first part of this chapter provides context for the importance of (1) explicitly connecting geosciences to societally relevant and often complex problems and grand challenges; (2) creating opportunities to develop interdisciplinary problem-solving skills that connect economic, societal, and policy issues with geoscience throughout the curriculum; and (3) using systemic and comprehensive implementation approaches to incorporate geoscience into a range of undergraduate programs so as to reach a more diverse group of students. The second part of the chapter provides an overview of the project and the shared values that underpinned the development of materials and models described in the remainder of the book.

## Why Connect Grand Challenges, Societal Issues, and the Geosciences?

Several groups have defined grand challenges related to the intersection of human society and science (Table 1). These were developed for different reasons and using different criteria. In 2001, the National Research Council (NRC) was tasked by the National Science Foundation (NSF) with identifying the major environmental research challenges of the next generation—those that would yield results with both scientific and practical significance and provide guidance for funding (National Research Council 2001). The NRC committee organized these eight challenges topically (Table 1). Organizing by process rather than topic, Zoback (2001) outlined six grand challenges in Earth and environmental sciences in her 2000 Geological Society of America Presidential Address (Table 1). Zoback highlighted the need for an “integrated systems approach to solving complex environmental problems,” that not all solutions are sociopolitically acceptable and provided guidance for how Earth scientists could address those challenges.

The American Geosciences Institute (AGI) has a different outcome and approach in mind in preparing its quadrennial “critical needs” document (AGI 2008, 2012, 2016). Rather than calling for research, AGI is building on the work of the research community on those grand challenges to inform policy-makers about the role of the geosciences in major policy issues, and the documents are prepared to coincide with transitions in federal leadership. Over 12 years, the critical needs have evolved in the way they are expressed, while maintaining and expanding the topics (Table 2). All three AGI documents made a case for bringing the expertise of the geoscience

**Table 1** Grand challenges in Earth and environmental sciences

| Author | Grand challenges |
|---|---|
| NRC | *Biogeochemical cycles*: Further understanding of the Earth's major biogeochemical cycles, evaluate how they are being perturbed by human activities, and determine how they might better be stabilized |
| | *Biological diversity and ecosystem functioning*: Improve understanding of the factors affecting biological diversity and ecosystem structure and functioning, including the role of human activity |
| | *Climate variability*: Increase ability to predict climate variations, from extreme events to decadal time scales; understand how this variability may change in the future; and assess realistically the resulting impacts |
| | *Hydrologic forecasting*: Develop an improved understanding of and ability to predict changes in freshwater resources and the environment caused by floods, droughts, sedimentation, and contamination |
| | *Infectious disease and the environment*: Understand ecological and evolutionary aspects of infectious diseases; develop understanding of the interactions among pathogens, hosts/receptors, and the environment; prevent changes in infectivity and virulence of organisms that threaten plant, animal, and human health at the population level |
| | *Institutions and resource use*: Understand how human use of natural resources is shaped by markets, governments, international treaties, and formal and informal sets of rules that are established to govern resource extraction, waste disposal, and other environmentally important activities |
| | *Land-use dynamics*: Develop a systematic understanding of changes in land use and land cover that are critical to ecosystem functioning and services and human welfare |
| | *Reinventing the use of materials*: Develop a quantitative understanding of the global budgets and cycles of materials used by humanity and how the life cycles of these materials (their history from the raw-material stage through recycling or disposal) may be modified |
| Zoback | Recognizing the signal within the natural variability |
| | Defining mass flux and energy balance in natural systems |
| | Identifying feedback between natural and perturbed systems |
| | Determining proxies for biodiversity and ecosystem health |
| | Quantifying consequences, impacts, and effects |
| | Effectively communicating uncertainty and relative risk |

community to bear in fully integrating Earth observations and Earth system understanding into actions to help the nation meet the needs of a burgeoning human population, rising demand for natural resources, and a changing climate.

Although both Zoback (2001) and AGI (2008, 2012, 2016) emphasize the role of the geosciences, these authors along with NRC emphasize the need for an integrated system approach that draws on a broad range of traditional disciplines including biology, chemistry, ecology, atmospheric sciences, hydrology, oceanography, geology, and geophysics, among many others. Superimposed on the scientific frameworks are drivers fueled by the presence of humans interacting with the environment, notably the growing human population, which is expected to exceed 9 billion by 2040 in most scenarios (KC and Lutz 2017), and the subsequent increase in demand

**Table 2** Critical needs defined by the American Geosciences Institute

| 2008 | 2012 | 2016 |
|---|---|---|
| Energy and climate change: How do we secure stable energy supplies in an increasingly carbon-constrained world? | Ensure reliable energy supplies in an increasingly carbon-constrained world | Developing energy to power the nation |
| | | Confronting climate variability |
| Water: Will there be enough freshwater, and where will it come from? | Provide sufficient supplies of water | Ensuring sufficient supplies of clean water |
| | Sustain ocean, atmosphere, and space resources | Expanding opportunities and mitigating threats in the ocean and at coasts |
| | | Managing healthy soils |
| Waste: Treatment and disposal—How will we reduce and handle waste and provide a healthy environment for all? | Manage waste to maintain a healthy environment | Managing waste to maintain a healthy environment |
| Natural hazards: How will we mitigate risk and provide a safer environment? | Mitigate risk and build resilience from natural and human-made hazards | Building resiliency to natural hazards |
| Infrastructure modernization: How will we develop and integrate new technology and modernize aging infrastructure? | Improve and build needed infrastructure that couples with and uses Earth resources while integrating new technologies | |
| Raw materials: How will we ensure reliable supplies when they are needed, and where will they come from? | Ensure reliable supplies of raw materials | Providing raw materials for modern society |
| Geoscience workforce and education: Who will do the work to understand Earth processes and meet demands for resources and resiliency? Who will educate the public and train the workforce? | Inform the public and train the geoscience workforce to understand Earth processes and address these critical needs | Meeting the future demand for geoscientists |

for natural resources and environmental systems. Therefore, addressing the grand challenges requires more than scientific advances; it requires an understanding of the human and social dimensions of the challenges including economics, public policy, ethics and values, and equity issues. Individuals need the ability to conceptualize the dynamics of complex systems that are characterized by competing values, difficult to predict cause-and-effect relationships, high degrees of uncertainty, and multilevel social interactions (Rittel and Webber 1973).

Taken together, the grand challenges and critical needs outline the complexities of living sustainably on the planet. Although there are numerous conceptual definitions of sustainability, they have many common attributes that include consideration of people and environment: meeting the needs of current and future generations while maintaining the health of Earth's ecosystems, with consideration of economic, social, cultural, and ethical implications (Matson 2009). As indicated by

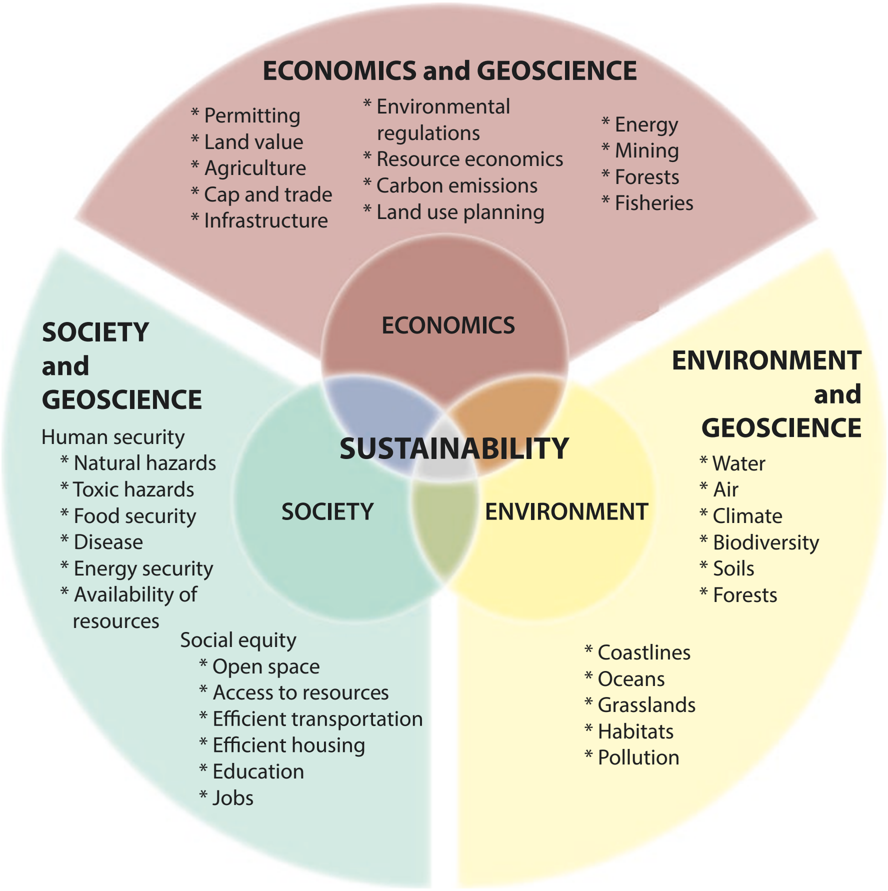

**Fig. 1** Conceptual diagram showing the intersections of the geosciences with a wide range of environmental, economic, human security, social equity, and health and safety issues (modified from InTeGrate 2017)

Zoback (2001) and AGI (2016), there are many economic, societal, and environmental issues where the geosciences provide critical insights and thus contribute to our sustainability efforts (Fig. 1). The sustainability framework situates geoscience in a social context, demonstrates the importance of developing geoscientific capacity to address these urgent problems, and provides a social imperative for geoscience literacy for all citizens. Improving geoscience literacy is one of the numerous vital factors that contribute to the creation of a sustainable and just society, in which all members of a community are empowered to engage in environmental and resource decision-making that meets their needs while maintaining a healthy environment and providing for future generations.

While the research community has responded to the grand challenges and made significant progress since 2001 (National Academies of Sciences and Medicine

2016), higher education has been slower to adapt to an integrative approach. Yet higher education plays a critical role in developing geoscience literacy and students' abilities to make use of that literacy in addressing societal issues.

To address the need for widespread geoscience literacy, we developed the InTeGrate project in response to the NSF Science, Technology, Engineering and Math Talent Expansion Program Centers solicitation (National Science Foundation 2010). It requested a comprehensive and coordinated set of activities designed to have a national impact on increasing the number of students, including STEM majors or non-STEM majors or both, enrolling in undergraduate courses in STEM. The InTeGrate project, which provides the foundation for all the papers in this volume, sought to provide students with opportunities to link learning about Earth with developing an understanding of the complex environmental and resource problems that society faces and to incorporate geoscience literacy across the undergraduate curriculum. In defining the core understanding of the Earth necessary for people to make informed personal and public decisions that move civilization toward a sustainable future (Bralower et al. 2008), InTeGrate made use of the community-developed geoscience literacy documents in climate science (Climate Literacy Network 2009), atmospheric science (University Consortium for Atmospheric Research 2007), the oceans (Ocean Literacy Network 2013), and Earth science (Earth Science Literacy Initiative 2010). These documents emphasize the interactions among Earth system components, the spatial and temporal changes in components, the impact of humans on the Earth system, the importance of prediction and the understanding of uncertainty, and the potential consequences of future changes on life on Earth.

Over its 8-year duration, InTeGrate engaged the higher education geoscience community and colleagues from allied disciplines in refocusing opportunities to learn about Earth on sustainability, with emphasis on the grand challenges (Table 1), the role that the geosciences play in addressing these grand challenges (Table 2, Fig. 1), and developing geoscience literacy for all students. By connecting grand challenges with societal issues and the geosciences (Table 2), InTeGrate sought to prepare students for the current and future workforce that is tasked with addressing these issues safely and sustainably.

## *Why Create Learning Opportunities for the Development of Interdisciplinary Problem-Solving Skills?*

Geoscience literacy is a necessary but not sufficient condition for addressing the environmental and resource issues that underlie society's grand challenges. When anyone seeks to address questions related to sustainable development, they need to integrate disciplinary expertise in the geosciences, life and physical sciences, social and behavioral sciences, community and regional planning, law and public policy, economics, and theories of social justice and social psychology, among others.

**Table 3** Definitions of disciplinary terms, modified from Pennington et al. (2016)

| Type of integration | Definition |
|---|---|
| Cross-disciplinary | *Integration where* one discipline examines another discipline through its lens (i.e., physicists explore music, sociologists focus on the purpose of religion) |
| Multidisciplinary | Integration that combines separate perspectives under a common theme, without identifying connections between perspectives |
| Interdisciplinary | Integration that combines separate perspectives through the development of connections between them |
| Transdisciplinary (1) | Integration that further develops connections between perspectives and generates new concepts, leading to an independent area of knowledge |
| Transdisciplinary (2) | Integration that extends beyond disciplinary perspectives to incorporate knowledge outside of academia |

Disciplinary perspectives can be integrated in many ways, each of which is useful for different purposes (Table 3). Addressing sustainability challenges requires going beyond cross-disciplinary and multidisciplinary approaches and moving into the domains of interdisciplinary and transdisciplinary approaches (Table 3).

Despite the recognized need for an interdisciplinary approach, higher education has not done well in producing graduates who have the levels of "cognitive, moral, intellectual and ethical development" required to effectively address the interdisciplinary nature of the grand challenges (Chickering 2010). The National Research Council's Committee on the Science of Team Science identified seven challenges that impact the effectiveness of inter- and transdisciplinary teams (National Research Council 2015a). Among these challenges are the difficulties of integrating knowledge across the boundaries of respective disciplines so that team members can combine their unique knowledge and skills to address the shared problem. To prepare current and future undergraduate students to confront the challenges of building more sustainable societies, higher education must create learning environments where, for example, scientists work with social scientists and economists to create societally acceptable solutions that utilize the best scientific information and data along with associated uncertainty to create socially workable and equitable policy and solutions. Regardless of their major, students need opportunities to reach beyond their own disciplines and work with a diverse range of individuals. As indicated above, solutions to sustainability issues of resources (e.g., food, water quantity, mineral/aggregate resources, energy), environmental stability (e.g., environmental degradation, environmental justice), and health and safety (e.g., natural hazards, climate change, water quality) all require input from the geosciences (Fig. 1). A primary motivator for the InTeGrate project was to build students' interdisciplinary problem-solving skills to help them connect the geosciences to economic, societal, and policy issues throughout the curriculum.

The InTeGrate project brought together the geoscience community with colleagues from allied 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 described in this volume by Steer et al. (this volume). The modules and courses featured in part 2 of this book employ an interdisciplinary educational framework that engages students in interdisciplinary problem-solving that requires using the tools, approaches, and/or data from two or more disciplines in a coherently integrated way (Egger et al. this volume) so as to offer a richer and deeper understanding of grand challenges. For example, in the Map Your Hazards module (Brand et al. 2014) described in this volume (Brand et al. this volume), students use the principles of social science and risk perception to design a survey that assesses their communities' knowledge about natural hazards and their perceived risks. At the same time, they make use of authentic geoscience data in their own region to determine the nature of nearby hazards. They use the results of both investigations to make recommendations to their communities to become more resilient. As a result, students are better positioned to understand and frame viable solutions to challenging problems while making *significant learning* and cognitive gains (Iverson et al. this volume). Interdisciplinary strategies better prepare students to address complex environmental problems, as members of society and in their future careers, while engaging a larger and more diverse cross section of the student population in learning about the Earth.

The creation of learning environments where students and faculty apply, integrate, and transfer knowledge and skills across not only traditional academic boundaries but also across the boundaries between the academy and its many stakeholders increases the opportunities for higher education to reach out beyond the academy and more fully and effectively contribute to developing solutions to societal issues (see the second definition of transdisciplinary in Table 3). Figure 2 shows the many interactions between those both inside and outside the academy.

Engaging students in interdisciplinary work that has real applications in the communities where they live and work helps them make connections that build interest and motivation in pursuing STEM careers in which they can also have an impact in their communities.

## *Why Focus on Diversity?*

Progress and innovation have occurred in higher education related to the development and implementation of new approaches to STEM and interdisciplinary education over the past two decades (Brint et al. 2009; National Research Council 2015b). However, higher education is challenged to meet the variable—and at times urgent—demand for a skilled workforce in STEM disciplines (Xue and Larson 2015; National Academy of Sciences et al. 2010; National Science Board 2010) and the development of Earth literacy across that workforce that will enable it to effectively address the social, political, and environmental challenges associated with sustainability.

Addressing issues associated with sustainability requires an inclusive approach that addresses the needs of all communities and brings expertise from many backgrounds to bear on the issues (Harkavy et al. 2015). Unfortunately, the nation

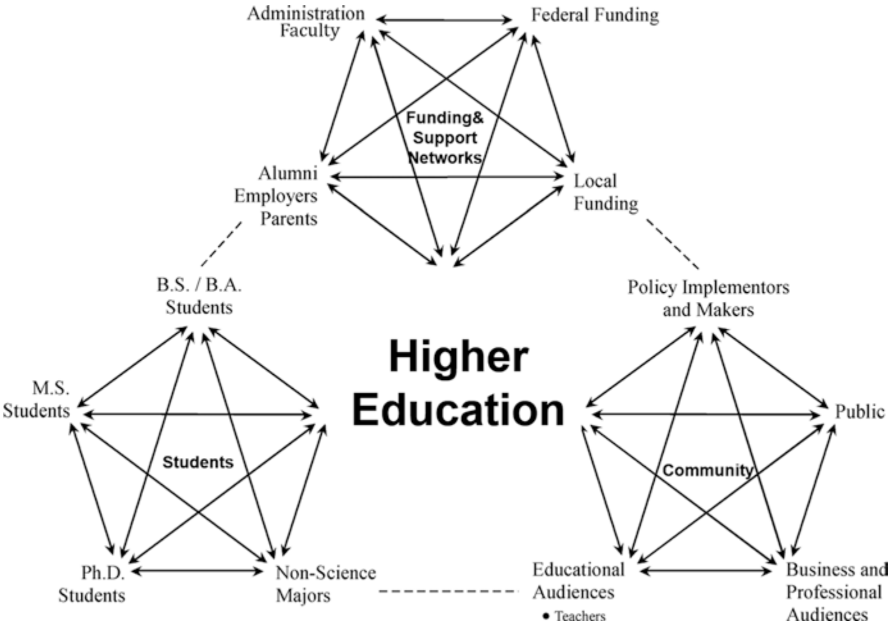

**Fig. 2** Diagram illustrating that higher education exists at the nexus of many different stakeholders (students, funding sources, and communities) that interact with it and each other as suggested by the bi-directional arrows. From Gosselin (2012)

is not yet at a point where all communities and groups are well-represented in STEM degrees or the workforce. Of the 650,000 students who graduated with bachelor's degrees in STEM disciplines in 2015, about 19% were underrepresented minority students (National Science Board 2018) compared to over 32% in the US population (U.S. Census Bureau 2017). The need for broadening participation of underrepresented groups in STEM is especially critical as a result of the changing demographics of both our society and our domestic workforce (National Academy of Sciences et al. 2011). Underrepresented groups in STEM include ethnic and racial minorities (particularly African American, Hispanic, and American Indian and Alaskan Native), women, persons with disabilities, veterans and active duty military personnel, people of low socioeconomic status, LGBTQ individuals, and others. Only when all communities have geoscience literacy will they be empowered to ensure they are treated justly in environmental and resource decision-making.

The InTeGrate project took the diversity challenges head-on by creating materials and program models that support broader participation in geoscience. Three strategies were central: (1) use of pedagogic strategies that support broad student success and specifically benefit students from groups underrepresented in the sciences (Freeman et al. 2014), (2) integration of societal issues and science content which is believed to create motivation and interest for a more diverse student population to study science (Huntoon and Lane 2007; Riggs et al. 2007), and (3) attention to students' sense of belonging, motivation to succeed, and mentoring and advising in addition to academic support (Jolly et al. 2004; National Academy of Sciences et al. 2011; InTeGrate 2018).

## The InTeGrate Approach: Design Elements

The InTeGrate leadership team hypothesized that by linking geoscience to the study of the environmental and resource issues faced by our citizenry, more students would understand the relevance of geoscience to today's society, and, by learning geoscience in the context of interdisciplinary problems, students would be better prepared to enter the modern workforce (Fig. 3). Further, this linkage would enable geoscience learning to be infused throughout the undergraduate curriculum providing more opportunities for students to be introduced to the geosciences and possibly to choose to pursue studies (or further coursework) in this field.

To achieve this transformation in undergraduate geoscience education, the project combined two strategies: (1) a system approach grounded in the notion that multiple levers are needed to make change happen in the university (Kastens and Manduca 2017b) and (2) project activities engaging large numbers of faculty from all types of institutions in extensive collaboration to rapidly create materials and models to support change and a community of leaders to institute transformation. This approach brought together principles of participatory design (Schuler and Namioka 1993; Mao et al. 2005) with change strategies focused on individuals and institutions using both prescribed and emergent approaches (Borrego and Henderson 2014; Henderson et al. 2011). Many program elements were influenced by successful programs including Project Kaleidoscope, which developed a large-scale community of transformation (Kezar and Gehrke 2015); the SENCER (Science Education for New Civic Engagements and Responsibilities) project, which engaged a large community in development and dissemination of curriculum modules (Weston et al. 2006); and the COMET, ESSEA, and DataStreme projects, which use nationwide, online delivery of curricula to increase accessibility (Schwerin et al. 2006; UCAR 2011; American Meteorological Society 2018).

### *Systems Approach*

Taking a systems approach, InTeGrate included three program elements designed to mutually reinforce one another and create feedbacks that improve the quality of the project's work and expand its reach (Fig. 4): (1) development of freely available *teaching materials and examples of their use in courses* that improve geoscience literacy, described in Egger et al. (this volume); (2) creation of evaluated program implementation models demonstrating *strategies for increasing the number and diversity of students*, including future teachers, prepared to address issues of

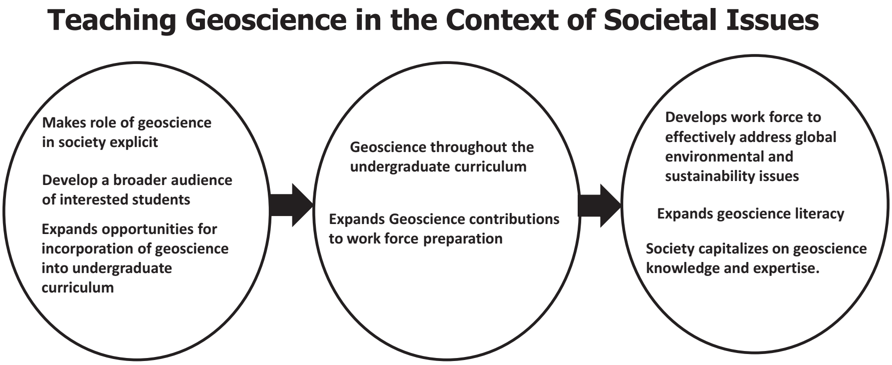

**Fig. 3** The InTeGrate project's hypothesized linkages between the geosciences and the study of environmental and resource issues and the relevance of geoscience to today's workforce and geoscience literacy. Modified from Kastens and Manduca (2017b)

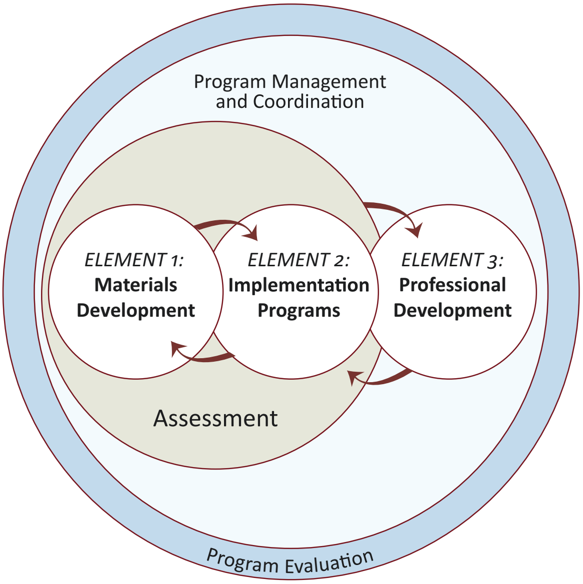

**Fig. 4** Conceptual diagram of the InTeGrate approach and its three primary program elements (InTeGrate 2018). Assessment and evaluation are described in this volume in Iverson et al. (this volume)

sustainability, described in this volume by Orr and McDaris (this volume); and (3) a *professional development* program supporting a faculty learning community focused on InTeGrate goals. These elements interact through reinforcing feedback loops to move a system to large-scale change: initial, in-gathering professional development was designed to gather expertise and needs from the community, build on prior work and educational research, capitalize on other efforts, and identify and recruit potential materials developers, all of which formed a foundation for the development of materials and programs. The materials development program directly provided teaching materials and other resources that were used in the implementation of new program models. The materials development and program model efforts created online materials describing their work that are used in further dissemination-focused professional development programming that supports broad adoption in courses and programs across the nation. This design mutually reinforces each of the elements and creates feedbacks to improve the quality of the project's work and expand its impact.

Materials development was selected as a key strategy to support transformation of teaching by reducing the effort needed to change while providing successful models. To allow rapid community development of materials in service to the InTeGrate vision, we used interinstitutional teams, supported by a materials development rubric and support process. The materials development rubric developed and implemented by the InTeGrate Assessment Team ensured the quality of the materials and their alignment with project goals. Classroom testing and the collection of student data supported evaluation of the materials and research on their impact on student learning.

The InTeGrate-developed materials employ an array of effective interdisciplinary instructional approaches that allow students to examine societally relevant issues by applying methods from the geosciences and other academic disciplines. Interdisciplinary teaching creates opportunities for both students and teachers to integrate and synthesize different perspectives. Through the use of interdisciplinary approaches, students are pushed to synthesize and integrate their perspectives with other relevant disciplines into a more complete and coherent framework of analysis. Interdisciplinary activities also provide students the opportunity to practice the broad, transferable twenty-first-century skills such as innovation, creativity, problem-solving, critical thinking, working with big datasets and complexity, communication, collaboration, self-management, and synthesis. Published with information on their use in the classes of all authors, these materials have been adapted, adopted, and used for inspiration in courses enrolling more than 100,000 students at more than 900 institutions across all 50 states and abroad.

Program-scale change was selected as a key strategy because opportunities to teach are constrained by program-level offerings, while lasting change happens at this scale. InTeGrate supported implementation programs that developed, evaluated, and showcased innovative ways to:

1. Increase the number and diversity of students developing Earth literacy
2. Prepare a diverse workforce equipped to bring geosciences to bear in addressing societal issues

Part three of this volume features examples from the 16 teams of educators from a diverse range of disciplines, institutions, and clusters of institutions who developed innovative program models. Many of these models not only build on InTeGrate ideas but also make use of the InTeGrate-developed teaching materials or the material design rubric. Collectively they demonstrate strategies for using interdisciplinary teaching of geoscience for a sustainable future to introduce geoscience across the liberal arts curriculum, collaborate across institutions to bring geoscience into institutions with no geoscience programs, strengthen the geoscience preparation of K-12 teachers, and create interdisciplinary programs with a strong geoscience component. The resulting models and the results of their evaluation were published online with detail supporting adoption or adaptation by others. To further the value of these models, the leaders of the 16 projects created a synthesis of lessons learned addressing strategies for attracting and supporting diverse learners, teaching Earth across the curriculum, strengthening connections to K-12 teaching, supporting transitions to the workforce or additional education, and strategies for making change happen. The model programs contributed substantially to the adoption of the materials and models demonstrating the importance of working at the departmental and program scales.

InTeGrate was designed as a community project heavily influenced by the *On the Cutting Edge* (SERC 2002) and Building Strong Geoscience Departments (SERC 2017) professional development programs in the geosciences, providing a wealth of experience that allowed us to emphasize professional development as third key strategy. *On the Cutting Edge* created a productive culture for improving undergraduate geoscience teaching while developing online resources supporting improvement (Manduca et al. 2010). The program engaged participants in peer-to-peer sharing and learning in workshops of 30–100 faculty and aggregated and connected the resources developed by these groups through a shared online website and digital library. Over its 15-year history, *On the Cutting Edge* created a national-scale community of practice (Kezar and Gehrke 2015) that supports transformation of teaching within undergraduate geoscience courses (Manduca et al. 2017; Teasdale et al. 2017).

The *Building Strong Geoscience Departments* project used a related approach to support improvement within departments and programs (Manduca et al. 2008). *Building Strong Geoscience Departments* also made use of workshops engaging 30–100 faculty and administrators in peer-to-peer sharing and learning. In this case, shared interests identified in early workshops were the focus of later topical workshops that produced online resources enabling individual departments to draw on the experiences of other departments and programs across the nation. The project then trained a cadre of leaders who travelled to individual departments or programs to lead strategic planning and action plan development making use of the national perspective and resources compiled by the project. InTeGrate sought to build on these combined efforts, addressing change simultaneously at the course and departmental level, while extending the capacity to create useful shared resources. By engaging more than 200 educators from diverse institutions across the country in the development and testing of materials, strategies, and program models, InTeGrate ensured that the materials would be valuable and adaptable for use in the full range of instructional settings and appropriate for a diverse range of students. Further, the community of leaders developed through this work formed the foundation needed to scale efforts across the nation's institutions of higher education. InTeGrate joined forces with the *On the Cutting Edge* and *Building Strong Geoscience Departments* programs to create an integrated professional development program offered through the National Association of Geoscience Teachers (NAGT). As of 2018, over 1800 educators are part of the InTeGrate community.

## *Commitment to Collaboration and Engagement*

An important element uniting the InTeGrate community is shared commitment to a common vision and to a set of shared values (Kezar et al. 2018; Kania and Kramer 2011). The project leadership shared a collective commitment to community engagement and collaboration as a key project strategy and structured the project to support and spread that value. Reflecting the belief that important ideas and expertise can come from every part of higher education, the project made use of an open application process for all activities. Applications were reviewed by teams of leaders against published criteria, and participants were selected for a combination of expertise and breadth of perspective.

All materials development, assessment, and professional development activities were accomplished by teams, described in further detail in this volume by Egger et al. (this volume), Orr and McDaris (this volume), and Steer et al. (this volume). In addition to bringing a breadth of experience and expertise, the team approach allowed for the development of both understanding and respect among individuals from different parts of higher education while producing materials and models of utility and a leadership for change that can reach broadly. Successful collaborative work requires that participants value and respect the contributions of others (Wilson et al. 2007; Williams Woolley et al. 2007). For example, within the materials development activity, strong team collaborations and action planning were scaffolded, and the team was recognized and rewarded as a unit (Egger et al. this volume). Their success depended on the creation of a culture that valued and supported this approach.

The quality of the project's work is underpinned by a second set of shared commitments, again established within the leadership and propagated through program design. InTeGrate combined a commitment to making use of research and past experience in the development of new materials, models, and activities with a recognition of the value of reflection, assessment, and evaluation in supporting continuous improvement. As described in several chapters in this volume, assessment and evaluation of materials and program models were an integral part of the development process. Materials were designed to the standards of a rubric encoding both the results of research on effective teaching and the project goals (Steer et al. this volume). Project funds were released only when materials were independently assessed to meet this high standard (Egger et al. this volume). Similarly, project leadership collaborated with team's developing program models to design evaluation plans (Orr and McDaris this volume). Reporting on the implementation of these plans and the resulting findings and program modifications was an integral part of the subcontracting process used to administer funds for program development. Within the professional development program, research-based practices were showcased and discussed, online resource collections developed to promote building on past experience, and peer-to-peer learning activities incorporated in both face-to-face and virtual activities.

The project also modelled reflective practices (e.g., Loughran 2002; Ghaye 2011). When project evaluation determined that extra support was needed to strengthen implementation of metacognition and systems thinking in materials, the professional development program was adapted to focus additional attention in these areas and the participants informed of the finding and response (see Steer et al. (this volume) and Iverson et al. (this volume) in this volume for further details). In the chapters on the development of InTeGrate materials and programs that follow, there are numerous examples of the ways in which these values were reinforced. Today, the professional development program, exponentially growing as of the end of the project (Kastens and Manduca 2017a) and run by community members beyond the InTeGrate leadership team, continues to propagate these values and model their implementation.

## Successes, Challenges, and Future Impact

As we reflect on the successes and challenges that accrued over the course of developing the materials and models, the community approach and the energy invested in strong communication and management structures stand out as worthwhile and paying unanticipated dividends (Kastens and Manduca 2017a). Not only will the InTeGrate participants carry on the influence of the project into the future in their attitude toward geoscience education, in their individual work, and through collaborations built on interactions during the project (Kastens et al. 2014), but the structures and tools that were built to support community development also have proven to be valuable in and of themselves. Project management tools integrating public communication and reporting, strategies for organizing numerous parallel working groups, and tools for tracking work, data, and participation have all been repurposed by new projects aimed at large-scale change in the geosciences and beyond. The design rubric and materials development management processes have become a foundation for innovations supporting team-based materials development for groups with different goals and at lower cost (Pratt-Sitaula et al. 2015). New models and tools for publishing materials, generated in response to community demands, are supporting adoption and adaptation well beyond undergraduate geoscience education with large numbers of adopters finding the materials online and putting them to use without additional intervention. The large-scale student data collection effort made possible the evaluation of the materials but also produced the first collection of student attitudinal and knowledge data at this scale in the geosciences, underpinning research beyond the project's impacts (Egger et al. 2017; Kastens and Krumhansl 2017). The large-scale material testing uncovered the overall weakness in teaching systems thinking both within our materials and more broadly in our community, while the ability to engage the community in finding solutions enabled rapid improvement underpinning strong student learning gains in this area (Iverson et al. this volume).

An additional component of the project, not included in this book, is the work that has been done to intentionally broaden participation in the InTeGrate community and spread teaching that integrates geoscience and societal issues. This work is still underway and its full results are yet to become clear. The project has had deep impact on its participants and their students—research on those impacts is also in progress and will be published elsewhere.

However, the materials and models built on a solid foundation in sustainability and interdisciplinarity are complete. This volume tells the story of their development through the voices of the creators, allowing insights into the details of their experiences and the ways in which they produced the project outcomes. These chapters will support those who take this work forward in the geoscience, as well as those who would like to learn from our experience toward other goals. A community process requires a book to tell its story from the many perspectives of those involved.

**Acknowledgments** This work is supported by the National Science Foundation (NSF) collaboration between the Directorates for Education and Human Resources (EHR) and Geosciences (GEO) under grant DUE-1125331.

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