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Interdisciplinary Teaching About Earth and the Environment for a Sustainable Future

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To our students, the interdisciplinary problem-solvers who will help create a sustainable and just society.

Foreword

Sustainability challenges, including the challenges of meeting human needs for food, energy, and water, managing climate change, increasing the resilience of society to hazards and risks, and improving education and health care opportunities, are complex challenges, and they play out in complex social-environmental systems. Disciplinary perspectives matter, but ultimately it is interdisciplinary knowledge and systems-level understanding that are most likely to lead to useful solutions that make sense to decision-makers. Given the complexity, many of us in academia working in the emerging field of sustainability science have called for interdisciplinary, collaborative, solution-oriented research programs. We have also noted the crucial role for new educational programs that develop sustainability leaders who recognize complex systems and can lead change within them.

Educational opportunities in sustainability are now emerging around the United States and world, and bright, forward-thinking, open-minded, empathetic students are flocking to them. To be successful, however, students must move beyond the linear thinking and disciplinary confines of their earlier education. Students must become systems thinkers and analysts, learn to respect many different kinds of knowledge and know-how, and build and contribute to interdisciplinary and transdisciplinary teams and collaborative groups in order to accomplish society's goals.

Higher education is evolving to help prepare students for this challenge, and many educators are forging their own paths to doing so. Interdisciplinary degree programs are prevalent on college campuses, as are increased opportunities for students in disciplinary degree programs to integrate their knowledge with others. Internships, practicums, team research projects, and public service opportunities all hold the potential to engage students not just with other disciplines but with decision-makers as well. And faculty, too, are finding new ways to engage in collaborative teaching and research focused not just on understanding but also developing solutions to sustainability challenges.

Interdisciplinary Teaching About Earth and the Environment for a Sustainable Future contributes to this effort in profound ways, providing the opportunity for all of us to learn from carefully evaluated experience rather than just by trial and error. Developed by teams of scientists and educators from a variety of fields, the materials featured in the book are the result of a rigorous process of research, assessment, and student-centered analysis. The authors and editors of this book sought to develop, test, and implement curricula and programs in institutions across the United States. In doing so, they have created an ambitious, interdisciplinary, research-based, and solution-oriented educational program that can help shift educational paradigms in higher education. In particular, they seek to transform Earth and environmental sciences in ways that support students (and all of higher education) as they prepare to support a sustainability transition. Deep knowledge of a range of Earth sciences is necessary for a sustainability transition, of course, but framing that knowledge in terms of its importance as the "natural capital" that all people live in and draw upon for well-being, today and in the future, makes its relevance clear. Moreover, the ability to integrate that knowledge of Earth with other critical knowledge bases in the social sciences, engineering, and other disciplines opens the door to understanding systems challenges and building solutions that work. This book provides a "how-to" manual for all of us interested in transforming education as we seek a transition to sustainability.

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Preface

Higher education is one of the many components of our society that has an influence on our ability to live sustainably on Earth. The paths that students take through higher education lead to jobs and careers, and how students navigate those paths is influenced by the options available to them. The options change and evolve over time, and the number of interdisciplinary courses and programs in general and those focused on environmental studies and sustainability in particular have grown significantly in recent years (Brint et al. 2009; Lyall et al. 2015; Wiek et al. 2011).

In their book, *Pursuing Sustainability*, Matson et al. (2016) note that the terms "sustainability" and "sustainable development" are used broadly and with multiple meanings across society. However, they describe that all of these meanings recognize that "our ability to prosper now and in the future requires increased attention not just to economic and social progress but also to conserving Earth's life support systems: the fundamental environmental processes and natural resources on which our hopes for prosperity depend" (p. 2).

We come at sustainability with a background in understanding those fundamental environmental processes, natural resources, and the Earth system. As geoscientists, we know the importance of our work to sustainability, yet this is often not at the forefront of our teaching or research and the relationship between geoscience and sustainability is thus far too often opaque to the students we teach and advise. The InTeGrate project, funded by the National Science Foundation, sought to change that dynamic by developing a higher education community that connects Earth science to societal issues throughout the curriculum, from individual courses to cross-institutional partnerships.

This book presents some of the outcomes of that 7-year journey, written by both the project leaders and by members of the community who joined us. The authors are faculty members, administrators and program directors, and researchers from a range of institution types across the country. Collectively, they have helped envision, instigate, and evaluate change in the way that Earth and environmental science are connected to sustainability in their classrooms, programs, institutions, and beyond. This book is designed for others interested in supporting large-scale change, infusing sustainability into the curriculum, broadening access to Earth and environmental sciences, and assessing the impacts of those changes.

The five chapters in Part I describe the InTeGrate project as a whole, its guiding principles and major efforts, overall measures of achievement, and lessons learned. In the chapter "Preparing Students to Address Societally Relevant Challenges in the Geosciences: The InTeGrate Approach," David Gosselin, Cathryn Manduca, Timothy Bralower, and Anne Egger describe the context and need for the transformation envisioned by InTeGrate and the program elements and guiding principles that were designed to address the need. In the chapter "The InTeGrate Materials Development Rubric: A Framework and Process for Developing Curricular Materials that Meet Ambitious Goals," David Steer and co-authors describe the rubric that was designed to ensure that materials developed by the project met its goals and how that rubric facilitated formative assessment for the project as a whole in addition to ensuring rigorous materials development. Chapters "Facilitating the Development of Effective Interdisciplinary Curricular Materials" and "Supporting Implementation of Program-Level Changes to Increase Learning About Earth" present the processes and results of two of the major components of InTeGrate: Anne Egger and co-authors describe the team-based development of interdisciplinary curricular materials, and Cailin Huyck Orr and John McDaris describe the support of model program development across the country that made use of InTeGrate's materials, goals, and infrastructure. Finally, Ellen Iverson and co-authors present the results of several assessment and evaluation measures across the project.

The seven chapters in Part II are all written by authors of curricular materials. Each chapter describes an interdisciplinary module or course that was developed through the process described in the chapter "Facilitating the Development of Effective Interdisciplinary Curricular Materials." The topics of these modules and courses include renewable energy; assessing hazards, vulnerability, and risk; regulating carbon emissions; the relationship between ecosystem services and water resources; global food security; major storms and community resilience; and the "critical zone" where rock meets life. They range from introductory to advanced and have been used in a variety of courses by the authors and others.

Part III includes five chapters written by leaders of model programs developed through the process described in the chapter "Supporting Implementation of Program-Level Changes to Increase Learning About Earth." These models of change range in scale from a single program to multi-institutional partnerships and include connecting geoscience, engineering, and sustainability in an engineering program, integrating sustainability into a general education curriculum at a single institution, enhancing collaboration across the higher education community in a large city, supporting the teaching professional development of graduate students and postdoctoral scholars through a multi-institution partnership, and a collaboration across historically black colleges and universities (HBCUs) to broaden participation in the geosciences and sustainability.

The work presented in this book is only part of the story. All of the curricular materials, model programs, assessment instruments, rubrics, and insights from members of the InTeGrate community are accessible on the InTeGrate website (http://serc.carleton.edu/integrate).

Whether you are a faculty member looking to try something new in your teaching, an administrator or program director looking for support to make changes, a researcher interested in sustainability education, or anyone else concerned about the role of higher education in a sustainable future, we hope you'll find something relevant for you in this book.

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The InTeGrate way would never have been captured and shared more broadly without the absolutely rock solid work of the web team at the Science Education Resources Center (SERC), primarily Monica Bruckner, John McDaris, and Kristin O'Connell, and the competence, dedication, and patience of the SERC staff, including Krista Herbstrith and MJ Davenport. Our external evaluation team showed us the growth and evolution of the InTeGrate community, and we'd like to acknowledge the insightful work of Carol Baldassari, Debra D. Bragg, Kim Kastens, Frances Lawrenz, and Lia Wetzstein.

Many of the chapters include data that was collected and analyzed by members of the assessment team, which was led by Ellen Iverson, David Steer, and Stuart Birnbaum and included Leilani Arthurs, Aida Awad, Barbara Bekken, Josh Caulkins, Megan Plenge, Mary Savina, Susan Sullivan, Karen Viskupic, and Emily Geraghty Ward. They set the tone for a culture of reflection and iterative improvement that made the project successful.

Each chapter in this volume was reviewed by external reviewers and was much improved because of their readings and comments. We would like to thank reviewers Lourdes Aviles, Tina Carrick, Stephanie Chasteen, Vince Cronin, Erin Dokter, Matt Douglass, Sarah Fortner, Christine Haney, Sarah Kruse, Meimei Lin, Rusty Low, Barbara Luke, Breanyn MacInnes, Terri Norton, Ingrid Novodvorsky, Deana Pennington, Sophia Perdikaris, Ginny Peterson, Stephanie Pfirman, Beth Pratt-Sitaula, Gigi Richard, Mary Savina, Cindy Shellito, Rachel Teasdale, Mark Turski, Shirley Vincent, Suzanne Wechsler, and Ben Wolfe.

As the leader among leaders, Cathy Manduca has pushed the InTeGrate community to have even greater impact than we thought possible. Without her vision and relentless effort, we would have a very thin book indeed.

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List of Abbreviations

2YC	Two-year colleges
AAAS	American Association for the Advancement of Science
AAG	Association of American Geographers
ACAD	Advisory Committee for Academic Diversity
AGI	American Geological Institute
AGO	ArcGIS Online
AGU	American Geophysical Union
BSU	Boise State University
CELT	Center for Excellence in Learning and Teaching
CHARTing	Collaborate to Heighten Awareness, Rejuvenate, and Train
CIRES	Cooperative Institute for Research in Environmental Sciences
COSEE	Centers for Ocean Sciences Education Excellence
CPP	Clean Power Plan
CSU	California State University
CU	Claflin University
CWI	College of Western Idaho
CWU	Central Washington University
CZ	Critical Zone
CZO	Critical Zone Observatory
CZS	Critical Zone Science
DUE	Directorate for Undergraduate Education
EER	Earth Educators Rendezvous
EHR	Education and Human Resources
EPA	Environmental Protection Agency
EPCC	El Paso Community College
EPHCC	El Paso Higher Education Community
FAMU	Florida Agricultural and Mechanical University
FEMA	Federal Emergency Management Agency
FLC	Faculty Learning Community
GCI	Geoscience Concept Inventory
GDP	Gross domestic product

GE	General education
GEO	Geosciences
GeTSI	Geodesy Tools for Societal Issues
GHC	Greenhouse gas
GLE	Geoscience Literacy Exam
GLOBE	Global Learning and Observations to Benefit the Environment
GWG	Geosciences Working Group
HBCUs	Historically black colleges and universities
HHMI	Howard Hughes Medical Institute
HMP	Hazard Mitigation Plan
HU	Hampton University
HVA	Hazard Vulnerability Analysis
IAI	InTeGrate Attitudinal Instrument
InTeGrate	Interdisciplinary Teaching About Earth for a Sustainable Future
IP	Implementation Program
IRB	Institutional Review Board
K-12	Kindergarten to 12th grade
LID	Low-impact development
MOU	Memorandum of understanding
MSI	Minority-serving institutions
NABG	National Association of Black Geoscientists
NAGT	National Association of Geoscience Teachers
NGSS	Next Generation Science Standards
NOAA	National Oceanic and Atmospheric Association
NRC	National Research Council
NSBE	National Society of Black Engineers
NSF	National Science Foundation
NTA	National Technical Association
OMA	Office of Multicultural Affairs
PISA	Program for International Student Assessment
RAFT	Role, audience, format, topic
RFP	Request for proposals
RTOP	Reform Teaching Observation Protocol
SERC	Science Education Resource Center
SIIP	Stanford InTeGrate Implementation Program
SLOs	Student learning outcomes
SSU	Savannah State University
Stanford Earth	Stanford School of Earth, Energy and Environmental Science
STEM	Science, Technology, Engineering, and Math
STEP	STEM Talent Expansion Program
SURGE	Summer Undergraduate Research in Geoscience and Engineering
SWC	Stormwater Calculator
TSU	Tennessee State University
UCAR	University Consortium for Atmospheric Research
UMES	University of Maryland, Eastern Shore

UNL	University of Nebraska – Lincoln
UNO	University of Nebraska – Omaha
URM	Underrepresented Minorities
USD	University of South Dakota
USGCRP	US Global Climate Research Program
UTEP	University of Texas at El Paso
VPGE	Vice Provost for Graduate Education
W&M	College of William and Mary

Part I
Interdisciplinary Teaching About Earth for a Sustainable Future

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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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

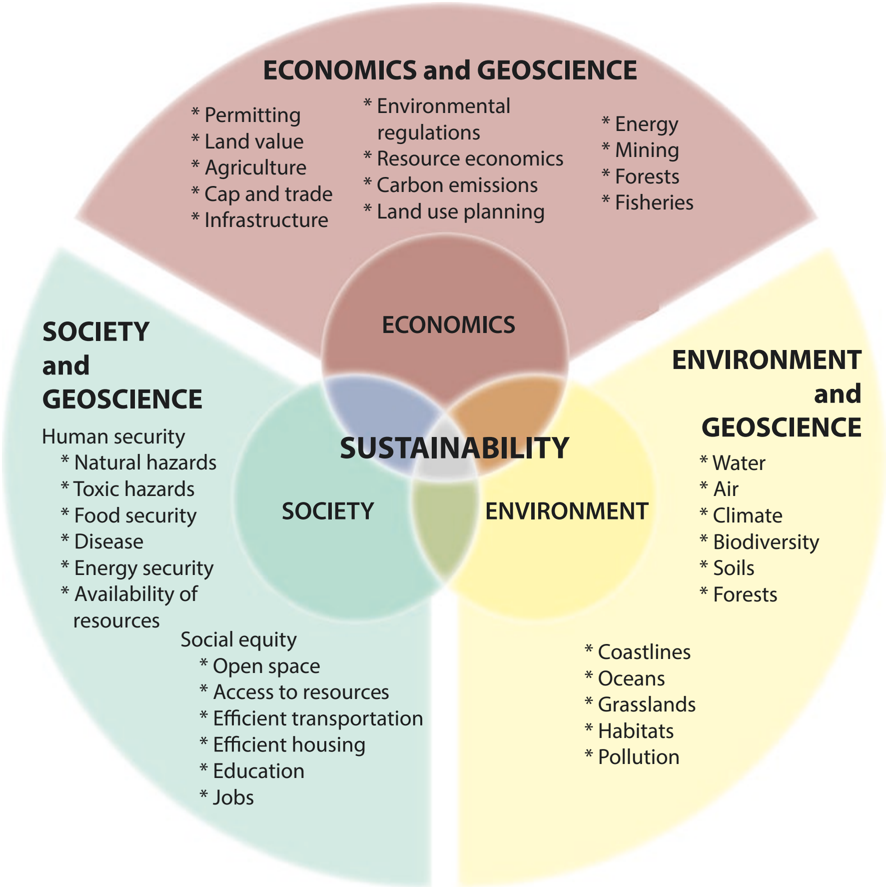

Fig. 1 Conceptual diagram showing the intersections of the geosciences with a wide range of environmental, economic, human security, social equity, and health and safety issues (modified from InTeGrate 2017)

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

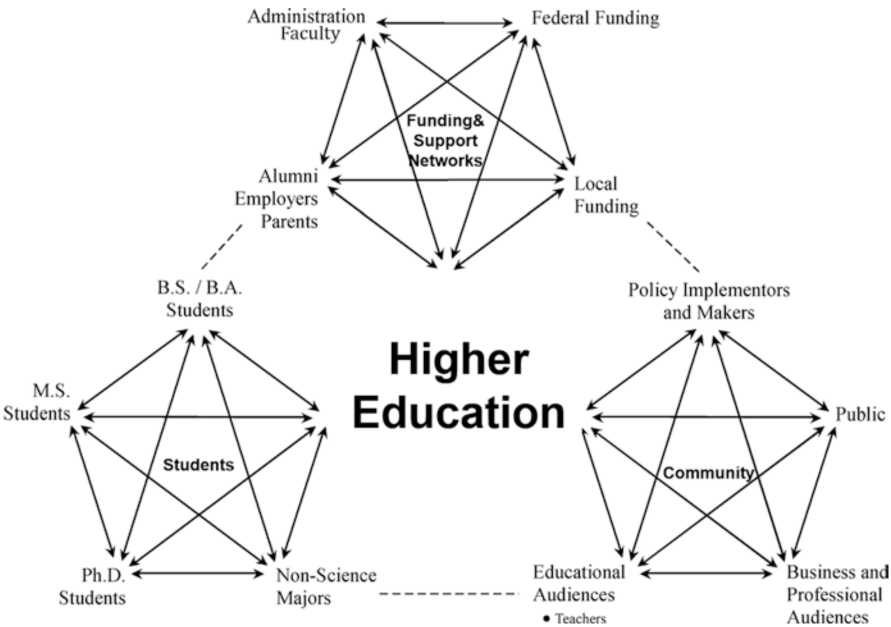

Fig. 2 Diagram illustrating that higher education exists at the nexus of many different stakeholders (students, funding sources, and communities) that interact with it and each other as suggested by the bi-directional arrows. From Gosselin (2012)

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

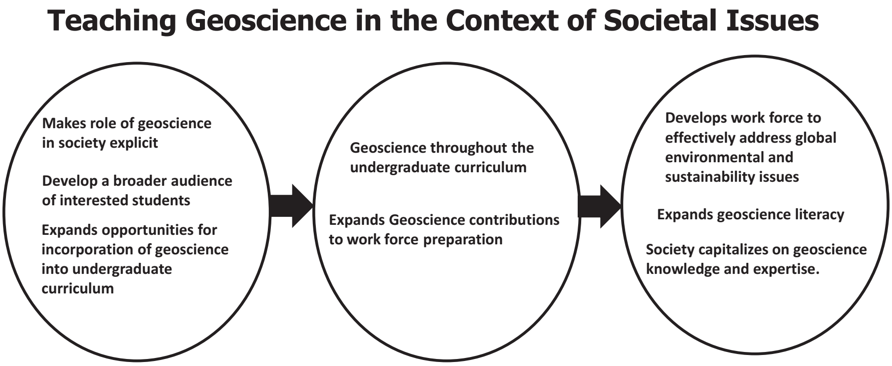

Fig. 3 The InTeGrate project's hypothesized linkages between the geosciences and the study of environmental and resource issues and the relevance of geoscience to today's workforce and geoscience literacy. Modified from Kastens and Manduca (2017b)

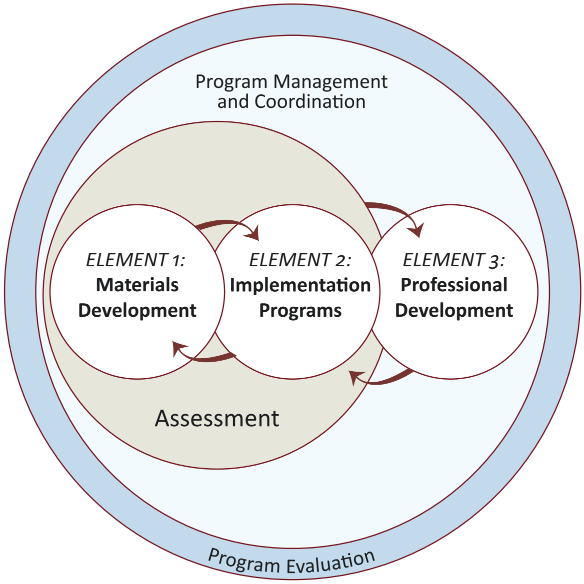

Fig. 4 Conceptual diagram of the InTeGrate approach and its three primary program elements (InTeGrate 2018). Assessment and evaluation are described in this volume in Iverson et al. (this volume)

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.

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The InTeGrate Materials Development Rubric: A Framework and Process for Developing Curricular Materials that Meet Ambitious Goals

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Abstract We designed and tested a curriculum development and auditing methodology for the Interdisciplinary Teaching about Earth for a Sustainable Future (InTeGrate) project. That process was driven and facilitated by a written rubric for curriculum development. Materials developers participated in workshops to prepare them to write and revise their materials in accordance with the rubric and were guided by an assessment consultant. Other assessment team members independently audited (reviewed) the materials before they could be tested with students. Curriculum developers encountered the most difficulty meeting criteria related to metacognition, grading rubrics, writing learning outcomes and objectives, and linking and aligning materials across the curriculum. Changes to the professional development program improved teams' abilities to meet those standards. We found the development rubric and process to be an effective methodology for developing materials addressing grand challenges facing society.

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Introduction

Grand challenges facing society in the next 50 years will require a workforce trained to tackle complex issues by making use of advanced and diverse skills across disciplines including the social sciences, economics, and communication (National Research Council 2001; Business Higher Education Forum 2011). These complex issues require Earth literacy as described in the geoscience literacy documents (Oceans: NOAA 2005; Climate: USGCRP 2009; Atmosphere: UCAR and CIRES 2008; Earth: Wysession et al. 2009). Earth literacy includes the ability to recognize situations involving knowledge about Earth, an understanding of Earth science concepts and how we know those concepts, and competency in identifying scientific issues, explaining Earth-related phenomena, and drawing scientific conclusions. It also includes the ability to effectively communicate and to make informed decisions related to the Earth and its environment and resources (Wysession et al. 2009). The Interdisciplinary Teaching about Earth for a Sustainable Future (InTeGrate) project established project-level goals related to these aspects of Earth literacy and workforce development (see Gosselin et al. Chapter "Preparing Students to Address Societally Relevant Challenges in the Geosciences: The InTeGrate Approach" of this volume).

The first goal of the InTeGrate project was to engage teams of faculty in developing and testing high-quality curricular materials for use at the undergraduate level to foster Earth literacy in all students. Traditional curricular materials are often content-rich, application-poor, and focus on confirmation inquiry even in laboratory materials (Bruck et al. 2008). In contrast, InTeGrate curriculum developers created learning resources that address Earth literacy goals and content taught in the context of societal issues using practices supported by research on learning. To assure that the curricular materials both met the literacy goals and were of high pedagogical quality, the InTeGrate leadership team developed a modified internal and external operational auditing process (Sayle 1981; English 1988; Glatthorn 1994; Foshay 2000).

This paper describes the auditing processes used to ensure the quality of the written curricula. In principle, the process begins with developing the written curricula, which are then piloted in the classroom and then revised and published to become the taught curricula, with continuous opportunities for quality control focused on improving student learning (Fig. 1).

The primary tool used in our modified curriculum audit process was the materials development rubric. The InTeGrate leadership and assessment teams designed the materials development rubric to assist faculty teams as they prepared their materials. The elements of the InTeGrate rubric and lessons learned from applying

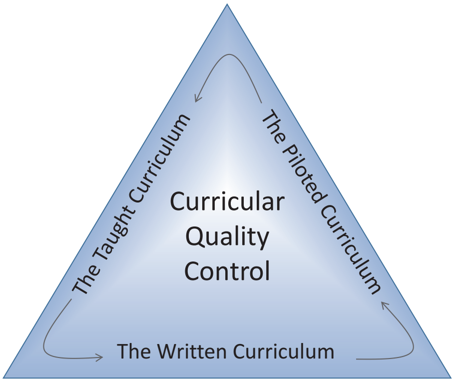

Fig. 1 Conceptual model of a curriculum audit. A full curriculum audit involves use of quality control measures before, during, and after development, teaching, and piloting of curriculum. The process is intended to improve student learning through an improved curriculum (modified from English (1988))

that rubric are described here as a model for any STEM curriculum development effort seeking to follow best practices of curriculum design. Use of the rubric allowed us to give extensive and specific feedback to materials development teams, as it was designed to do, while also allowing us to anticipate areas where new teams will have trouble and proactively provide guidance to authors in these areas. Equally important, the rubric gave authors the ability to monitor their own progress toward completion of materials that fully incorporate research on effective teaching while addressing project priorities. In this paper, we focus on lessons learned while implementing the quality control measures that were used to ensure that the written curriculum met InTeGrate goals prior to field testing.

Method: Materials Development Rubric

The primary goal of establishing the InTeGrate materials development rubric (Table 1) was to ensure that InTeGrate materials were held to a consistently high standard. Most of the materials were developed at the scale of a module, or approximately 2–3 weeks of class time in a semester system, though in some cases the materials covered an entire course. The rubric incorporates the guiding principles of the InTeGrate project into researched guidelines for best practices in curriculum development (Wiggens and McTighe 2005; CSU 2009; blackboard.com 2012; Cullen et al. 2012; qualitymatters.org 2014). InTeGrate materials development teams were held to this rubric and had to meet stringent scoring criteria that included mandatory elements as well as section minimums (see Table 1) during internal and external audits, which we called reviews. The evaluation scheme is divided into six sections: guiding principles, learning objectives and outcomes, assessment and measurement, resources and materials, instructional strategies, and alignment. What follows is a description of each of those sections, short justifications for their inclusion in the rubric, and examples of how the curricular materials met the rubric.

Table 1 InTeGrate curriculum development and refinement rubric

This rubric is designed to guide InTeGrate assessment team members as they score modules and courses to improve geoscience literacy. The evaluation scheme is divided into six subareas: overarching goals, learning objectives and outcomes, assessment and measurement, resources and materials, instructional strategies, and alignment. The six subareas have a total of 28 elements that are equally weighted at 3 points each and are evaluated using the following scoring scheme: • 3 points: rubric element explicitly and/or pervasively addressed in module/course materials • 2 points: rubric element addressed in majority of the module/course materials • 1 points: rubric element addressed in some of the module/course materials • 0 points: rubric element not addressed in the module/course materials A score of 15/15 must be achieved on the guiding principles portion of the rubric. Scores of 85% or higher must be achieved in each of the other subareas of the materials rubric. Materials meeting the above criteria will earn a minimum score of 74/84			
		Points	Score
1. Guiding Principles (must score 15/15)			
1.1	Course/module addresses one or more geoscience-related grand challenges facing society	3	
1.2	Course/module develops student ability to address interdisciplinary problems	3	
1.3	Course/module improves student understanding of the nature and methods of geoscience and developing geoscientific habits of mind	3	
1.4	Course/module makes use of authentic and credible geoscience data to learn central concepts in the context of geoscience methods of inquiry	3	
1.5	Course/module incorporates systems thinking	3	
2. Learning objectives (must score 13/15)			
2.1	Learning objectives describe measureable geoscience literacy outcomes	3	
2.2	Instructions and/or rubrics provide guidance for how students meet learning outcomes	3	
2.3	Learning objectives and outcomes are appropriate for the intended use of the course/module	3	
2.4	Learning objectives and outcomes are clearly stated for each module in language suitable for the level of the students	3	
2.5	Learning objectives and outcomes address the process and nature of science and development of scientific habits of mind	3	
3. Assessment and measurement (must score 13/15)			
3.1	Assessments measure the learning objectives	3	
3.2	Assessments are criterion referenced	3	
3.3	Assessments are consistent with course activities and resources expected	3	
3.4	Assessments are sequenced, varied, and appropriate to the content	3	
3.5	Assessments address outcomes at successively higher cognitive levels	3	
4. Resources and materials (must score 15/18)			
4.1	Instructional materials contribute to the stated learning objectives	3	

(continued)

Table 1 (continued)

4.2	Students will recognize the link between the learning objectives, the outcomes, and the learning materials	3	
4.3	Instructional materials should be sufficiently diverse and at the depth necessary for students to achieve learning objectives and outcomes	3	
4.4	Materials are appropriately cited	3	
4.5	Instructional materials are current	3	
4.6	Instructional materials and the technology to support these materials are clearly stated	3	
5. Instructional strategies (must score 13/15)			
5.1	Learning strategies and activities support stated learning objectives and outcomes	3	
5.2	Learning strategies and activities promote student engagement with the materials	3	
5.3	Learning activities develop student metacognition	3	
5.4	Learning strategies and activities provide opportunities for students to practice communicating geoscience	3	
5.5	Learning strategies and activities scaffold learning	3	
6. Alignment (must score 5/6)			
6.1	Teaching materials, assessments, resources, and learning activities align with one another	3	
6.2	All aspects of the module/course are aligned	3	
	Total	84	

Section 1: Guiding Principles

Guiding principles lay the framework for subsequent curriculum development (Krajcik et al. 2008). Such principles are used to delineate the scope of the content and specify significant compositional aspects of the materials. In the case of the InTeGrate project, the materials development rubric includes five guiding principles that align with major InTeGrate goals. Developers were required to include all five of these guiding principles explicitly and pervasively throughout their materials.

1. *Course or module must address one or more geoscience-related grand challenges facing society*: Grand challenges include resource issues (e.g., minerals, energy, water, food, sustainability) and environmental issues (e.g., climate change, hazards, waste disposal, environmental degradation, and environmental health). Grand challenges related to biogeochemical cycles, biologic diversity, environmental change impacts, resource extraction, land use and land cover, and recycling are listed in the National Academy's "Grand Challenges in Environmental Science" (NRC 2001).
2. *Course/module develops student ability to address interdisciplinary problems*: Interdisciplinary problems require diverse perspectives that promote understandings of the interactions between Earth science and economic, societal, and policy

issues (Gilbert 1998; Daily and Ehrlich 1999; Ivanitskaya et al. 2002). Such materials integrate robust geoscience with trans-disciplinary knowledge from other disciplines such as geography, social sciences, and humanities and build student capacity to work on interdisciplinary teams.

3. *Course/module improves student understanding of the nature and methods of geoscience and develops geoscientific habits of mind*: Geoscience is a discipline based on making observations of the Earth and testing hypotheses about Earth's history and processes against those observations. The methods of geoscience include comparison of cases to understand commonalities and differences attributable to process, history, and context; developing converging lines of evidence; and testing through prediction (Harrington 1970; Virgili 2007; Dodick et al. 2009; Ault and Dodick 2010). Geoscientific habits of mind include recognition of the fundamental role of observation and of a spatial and temporal organizational schema in understanding the Earth, recognition of the Earth as a complex system shaped by a continuum of long-lived low-impact processes and short-duration high-impact processes and valuing collaboration (Pyle and Brunkhorst 2009; Kastens and Rivet 2008; Kastens et al. 2009; Manduca and Kastens 2012a).
4. *Course/module makes use of authentic and credible geoscience data to learn central concepts in the context of geoscience methods of inquiry*: Curricular materials use the most appropriate data available for the topics under discussion. Large amounts of data that address societal problems are available with increasing frequency and resolution (Manduca and Mogk 2002; Taber et al. 2012).
5. *Course/module incorporates systems thinking*: Course/module develops students' abilities and propensities to use systems thinking in considering natural systems, human systems, and their interactions. A systems thinker understands basic interactions among the components of the Earth system, the difference between open and closed systems (Libarkin and Kurdziel 2006; Manduca and Kastens 2012b), possible effects of perturbations, and multiple causal factors that could influence a single observation or outcome (Ruddiman 2001; Ford 2009). As their systems thinking deepens, they also have the ability to use the concepts of positive (reinforcing) and negative (countervailing) feedback loops, flux, reservoir, residence time, lag (delay), and system thresholds (Assaraf and Orion 2005; Cabrera et al. 2008; Midgley 2008; Stillings 2012).

An example of threading guiding principles is illustrated in a module about climate change designed for an introductory undergraduate science course. The "Climate of Change: Interactions and Feedbacks between Water, Air and Ice" module (Fadem et al. 2014) explores global challenges associated with climate change and social vulnerability. Students decipher commonalities and differences of three cultures that were impacted by past climate change. They then use real data to assess the impact of climate variability on modern cultures. Lastly, they consider the roles of forced and unforced climate change and feedback in the climate system. To pass the audit, all five guiding principles had to be explicit and pervasive throughout the curricular materials, not simply mentioned in passing.

Section 2: Learning Objectives and Outcomes

Learning outcomes provide a "big picture" view of the module or course (Anderson and Krathwohl 2001). Well-articulated learning outcomes clarify what you want students to accomplish and effectively communicate expectations to students (Biggs 2003). They also help faculty select methods, materials, and assignments that are appropriate and guide development of assessments that show what students have learned. Learning objectives specify individual learning components that support student achievement of the larger outcome. Both learning outcomes and objectives must be measurable (Black and Wiliam 1998). Faculty members describe those levels by developing scoring rubrics for the student.

Learning outcomes and objectives in the InTeGrate project are required to meet the following criteria.

1. *Learning objectives relate to geoscience literacy outcomes*: For InTeGrate, the objectives and outcomes must be directly linked to one or more sub-points of the major big ideas published in the Earth Science, Climate, Ocean, and/or Atmosphere literacy documents.
2. *Instructions and/or rubrics provide guidance for how students meet learning outcomes*: When appropriate, rubrics are developed that provide the student a clear indication of the performance conditions and standards necessary to meet learning outcomes. The metrics used to measure indications of such change must be described for the student unless this degree of specificity is not possible (e.g., internal cognition, affective changes).
3. *Learning objectives and outcomes are appropriate for the intended use of the course/module*: Lower-division courses should address content mastery, critical thinking skills, and core learning skills related to introducing guiding principles. Upper-division and graduate courses may focus on advanced guiding principles related to global interdisciplinary problems.
4. *Learning objectives and outcomes are clearly stated for each module in language suitable for the level of the students*: Learning objectives and outcomes should avoid jargon and highly technical language unless required. They should be written at a level that the student can aspire to achieve the outcome and recognize when it has been achieved.
5. *Learning objectives and outcomes address the process and nature of science and development of scientific habits of mind*: According to the AAAS (2009), the process of science and scientific inquiry (or habits of mind) include the notions that science demands evidence, science is a blend of logic and imagination, science explains and predicts, scientists attempt to avoid bias, and there are accepted criteria for evaluating the credibility of data. Scientific habits of mind also include recognition that science is a complex social activity underpinned by accepted ethical principles (Wynne 1991; Lederman 2007). The nature of science purports that the world is understandable, there are credible and non-credible scientific arguments, scientific knowledge is long-lasting but subject to change, and science cannot answer all questions (Linkens 1999; Bell 2004).

For example, Fortner et al. (2014) developed a module entitled "A Growing Concern: Sustaining Soil Resources through Local Decision Making" that included learning outcomes related to using geological data to develop sustainable soil management plans and to predict agricultural challenges related to future climate change. Each unit of the module had supporting learning objectives.

Section 3: Assessment and Measurement

Properly written learning goals and objectives are measurable (Biggs 2003), allowing instructors to use formative and summative assessment strategies throughout the curriculum to monitor learning and progress toward mastery. Assessments should include clear standards that instructors can use to grade the student work. Additionally, assessments should be consistent with the content covered, be logically organized in the flow of the instruction, and address multiple cognitive levels (Anderson and Krathwohl 2001). Materials developed for the InTeGrate project were evaluated using the following criteria.

1. *Assessments measure the learning outcomes*: Embedded formative assessments (Black and Wiliam 1998; Boyle and Charles 2014) and summative assessments and assignments (Popham 1999) provide logical tools to determine the extent to which students have met the course/module outcomes. These assessments must match course content such that these tools help the student achieve the outcomes.
2. *Assessments are criterion referenced*: Assessments include a clear and meaningful articulation of criteria used to judge the quality of student products and performances. This could involve a rubric for each type of assignment, a list of criteria and associated point values for specific assignments, or a sample of acceptable or unacceptable student work (Popham 1997).
3. *Assessments are consistent with course activities and resources expected*: Assessments and assignments should support course activities and be designed to measure the extent to which the student has accomplished one or more of the outcomes. Resources (e.g., materials, equipment) needed for learning activities, assignments, and assessments are clearly stated (Popham 2008).
4. *Assessments are sequenced, varied, and appropriate to the content*: The sequence and schedule or pace of the assessments match the content. Assessments should vary in type and duration and can build on previously acquired knowledge within the course or in prerequisite courses.
5. *Assessments address objectives and/or outcomes at successively higher cognitive levels*: If appropriate, assessments progress from lower-level knowledge recall and understanding to higher-order thinking, application of knowledge, and even knowledge generation (Anderson and Krathwohl 2001). Feedback from these assessments informs the student of their level of learning.

The module "Humans' Dependence on Earth's Mineral Resources" (Bhattacharyya et al. 2014) includes many examples of the types of assessments required. Students analyze scenarios related to resource use, population, and development; they explore the economics of rare Earth elements during an in-class exercise. These exercises are all assessed on a formative basis, low-stakes, but checked for understanding and prompting feedback and reflection. As a summative exercise, students construct concept maps to illustrate major concepts and interconnections related to the geologic nature of a resource, the factors that determine demand, the mining processes involved, and the potential environmental impacts. Concept maps were evaluated using a criterion-based rubric that included elements related to overall organization of the concept map, completeness and quality of the content, and the nature of the connections (see serc.carleton.edu/integrate/teaching_materials/mineral_resources/assessment.html).

Section 4: Resources and Materials

There are several characteristics of curricular resources and materials that contribute to a successful curriculum. Primarily, curricula must link to the broad learning goals and underlying learning objectives—and that linkage should be obvious to students. In addition, effective curricula use methods that scaffold learning and engage multiple modalities that support learning (Zeegers 2001). The resources used to support curricula should be current, be scientifically rigorous, and follow accepted scholarly documentation practices. Special materials (e.g., software, instruments, or technology) should be clearly stated. Materials were reviewed to ensure the following:

1. *Instructional materials contribute to the stated learning objectives*: Course materials such as textbooks, monographs, articles, lecture notes, audio or video recordings, games, or websites should directly support one or more overarching goals, literacy goals, or core concepts embedded in learning objectives and outcomes (Gagne et al. 2004).
2. *Students will recognize the link between the learning objectives, outcomes, and the learning materials*: Curriculum should be designed such that students can recognize the purpose of all content, materials, resources, technologies, and instructional methods used in the course; how each resource helps them achieve the stated learning outcomes; and which materials are required and which are recommended resources.
3. *Instructional materials should be sufficiently diverse and at the depth necessary for students to achieve learning objectives and outcomes*: Instructors should provide meaningful content using a variety of sources (e.g., text, articles, presentations, websites, lecture notes, outlines, and multimedia). The level of detail in supporting materials is appropriate for the level of the course and provides depth sufficient for students to achieve the learning outcomes (Honebein 1996).

4. *Materials are appropriately cited*: All learning materials, software, and learning resources must conform to copyright law and proper citation protocols unless there is a specific statement attached to the materials stating that they are in the public domain.
5. *Instructional materials are current*: The materials represent up-to-date thinking and practice in the discipline.
6. *Instructional materials and the technology to support these materials are clearly stated*: If specific technology is needed, what is required is clearly stated, e.g., computer lab with licenses to a specific software application.

The types of resources developed and used vary widely in InTeGrate materials based on the content. In the module "Environmental Justice and Freshwater Resources" (Perez et al. 2018), students explore authoritative web resources to discover concepts related to environmental equity, environmental justice, and environmental racism. Students then expand on these concepts using Google Earth activities and exercises linked to case studies from Trinidad, Kenya, and India. The linkages between curricular resources, activities, and assessments are provided on a "Student Materials" page.

Section 5: Instructional Strategies

InTeGrate materials are designed using student-centered pedagogy (Trigwell and Prosser 1991). Ideally, there are ample opportunities for student-student and student-instructor interactions. Additionally, students are provided opportunities to reflect on their learning as they complete various activities that scaffold from lower- to higher-level cognitive tasks (Anderson and Krathwohl 2001). Specifically, materials developers were required to meet the following instructional criteria.

1. *Learning strategies and activities support stated learning objectives and outcomes*: The learning activities promote the achievement of the stated learning objectives and outcomes using evidenced-based teaching and learning practices (Edelson 2001; Handelsman et al. 2004; National Research Council 2012). The strategies should actively engage students with the course content using a variety of different types of activities that support reinforcement and mastery in multiple ways.
2. *Learning strategies and activities promote student engagement with the materials*: Activities should connect to personal experiences of students, motivate and engage students, connect to real-world experiences, and build on what they know and address their initial beliefs. Activities should foster instructor-student, content-student, and student-student interactions where appropriate (e.g., group discussions or blogs, small-group projects, peer critiques).
3. *Learning activities develop student metacognition*: Students should be given opportunities to reflect on and think about their own actions and ideas as compared to others and confirm that they are on the right track (Flavell 1979). The

activities should provide opportunities for students to iterate and improve their understanding incrementally.

4. *Learning strategies and activities provide opportunities for students to practice communicating geoscience*: It should be clear that the students at all levels will be engaged in independent thinking, problem-solving, and communicating their understanding. Activities should challenge misconceptions and provide opportunities for students to practice judging what constitutes credible evidence and opportunities to practice effectively communicating geoscience concepts verbally and in writing (Hurd 2000; Weigold 2001). This rubric element is also motivated by research showing that organizing one's thoughts for communicating can trigger the self-explanation effect, in which the quality of thinking and problem-solving improves (Chi et al. 1994; Deleeuw and Chi 2003).
5. *Learning strategies and activities scaffold learning*: Activities should promote deep learning by stimulating student intellectual growth from an initial point to more advanced levels, considering the needs of nontraditional students, as appropriate (Hatano and Oura 2003; Bransford 2000). Activities should be structured to allow students to first note obvious connections and then grasp the significance of those connections (Bransford and Schwartz 1999; Engle et al. 2011). At higher levels, students should be challenged to appreciate the significance of the parts as related to the larger concept and eventually extend those concepts to general principles outside the discipline (Crawford et al. 2008).

The instructional aspects of the rubric are exemplified in the "Interactions Between Water, Earth's Surface, and Human Activity" module (Debari et al. 2015) designed for preservice elementary teachers. In this curriculum, students are organized into small groups that work collaboratively to collect and interpret data during several activities. The hands-on activities involve experiments, stream table analyses, computer exercises, and analyses of authentic data. Students communicate their results to each other while using the activities to develop K-5 lesson plans. They reflect on their own learning by first describing their initial ideas and then revisiting those ideas near the end of the module and describing how they have changed. Overall, the materials support strategies that recognize students' backgrounds and help them reflect on and develop their own skills and knowledge.

Section 6: Alignment

A constructive alignment approach (Biggs 1996) is one in which outcomes, learning activities, and assessments within each section of the module or course directly align with one another and with stated learning objectives and outcomes. This last category in the rubric serves as a final check to ensure all aspects of the curricula are integrated.

1. *Teaching materials, assessments, resources, and learning activities align with one another*: A curriculum map that identifies core skills and content, learning

strategies, and resources can be used as an effective way to ensure alignment *within a unit* of the curriculum.

2. *All aspects of the module/course are aligned*: An alignment approach suggests that curricular materials align directly with stated module/course goals holistically *across the entire module/course*.

This last category facilitated identification of missing or unused content, assessments, or curricular materials and helped streamline all of the materials.

Application of the Materials Development Methodology

The materials development process (described in detail in Egger et al. in this volume) included materials developer recruitment and training, ongoing guidance from assessment consultants and team leaders, independent curriculum audits, classroom testing, revisions, and external science review. At the beginning of the process, the leadership team used a face-to-face workshop to facilitate interactions within the three- to five-person author teams, to describe the materials development rubric and to allow time for the teams to clearly define the learning goals and assessment plans underpinning their planned curriculum. These teams then worked collaboratively, albeit at their home institutions, under the guidance of an InTeGrate leadership team member and an assessment consultant assigned to that team. The InTeGrate leader was responsible for reviewing curricular materials and advising to the team throughout curriculum development, providing the continuous quality control illustrated in Fig. 1. The internal assessment consultant reviewed materials and provided formal guidance at the 50% and 75–90% complete stages.

Once the materials were complete, the internal assessment consultant and others from the assessment team who had not previously viewed the curriculum (external auditors) independently audited the curriculum using the rubric. Early in the project, assessment team members independently rated a test curriculum to establish inter-rater reliability before scoring materials. External auditors were essential to the process because, unlike the internal auditor, they had no prior knowledge of the materials under review. As such, they brought unbiased views from the perspectives of different disciplinary experts to the evaluation. This resulted in substantial improvements to the curriculum in areas that may have been overlooked by the internal auditor. Two independent external auditors scored the materials during the 2012–2014 time period. Due to resource and time constraints, one external auditor was used from 2015–2016 unless there were significant discrepancies between the internal and external auditor, in which case a second external auditor was brought in. Scores were compiled and used to determine if the materials required revisions or were ready for testing with students.

Assessment team members used the 28 elements of the rubric (Table 1) to evaluate materials on a scale from 0 to 3. A score of 3 points meant the rubric element was explicitly and extensively addressed in module/course materials; 2 points indicated the rubric element was addressed in majority of the materials; 1 point indicated the rubric element was addressed in some of the materials; and 0 points implied the element was not addressed in the module/course materials. Individual element scores were converted to a composite score by comparing points awarded. If all three scores or two-of-three scores matched, and the nonmatching score only varied by 1 point, the matching score was awarded. If the nonmatching score varied by two or more or the three scores did not match, the assessment team discussed that element until they came to a consensus. The composite score was used to determine if the module passed the rubric or required revisions. In order to pass, materials had to score 100% on Section "Introduction" (guiding principles) and ~85% or higher on each of the other five sections; materials were required to pass the rubric prior to being testing in the classroom. If the materials failed to meet the passing criteria, the assessment consultant provided constructive comments to the development team, who revised materials as needed. After the development team revised the materials, the assessment consultant re-reviewed them to ensure the curricula met standards in those areas that had fallen short.

Once the materials passed the rubric, they were tested in the materials development team members' classrooms. Team members testing the curriculum collected a common set of project-wide assessments as well as assessments tailored to the content of their curriculum (see Iverson et al. in this volume). Instructors also kept personal journals where they reflected on those aspects of the curriculum that work well and those that needed improvement. The student and instructor data guided revisions to the curriculum that were discussed at a second and final, face-to-face meeting. Revised materials were externally reviewed by content-level experts and underwent final revisions before being published.

Lessons Learned From Auditing Materials

The first sets of materials development teams (cohort 1: teams formed in 2012; year 1 of the project) were marginally successful at meeting requirements when audited against rubric standards (Fig. 2). Of the six modules assessed against the rubric in year 1, two passed on the first attempt, two passed after minor revisions, and two required substantial revision and reassessment (Fig. 2; gray bars). Three of the four module author teams that did not pass on the first audit did not meet the mandatory three out of three score for the systems thinking guiding principle (Table 1: rubric item 1.5). In general, all teams had difficulty meeting requirements in areas related to developing grading rubrics (Table 1: rubric item 2.2) that were criterion referenced (Table 1: rubric item 3.2), linking materials to learning outcomes (Table 1: rubric item 4.2) and fostering student metacognition (Table 1: rubric item 5.3). Assessment team members were also less likely to agree when scoring those elements in the rubric.

The second cohort (cohort 2: teams formed in 2013–2014; years 2–3 of the project) was more successful at meeting all rubric requirements compared to the first

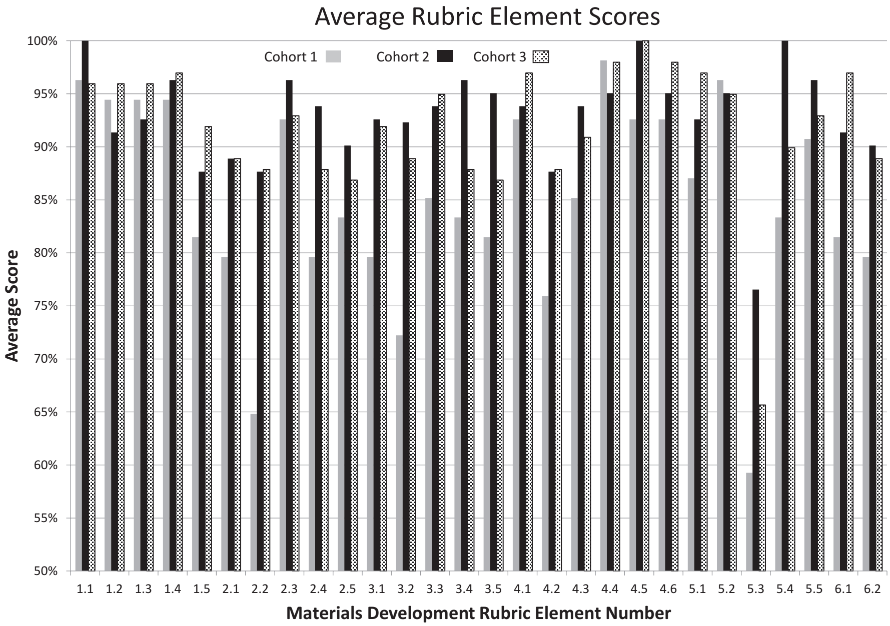

Fig. 2 Average rubric scores. Average materials development scores by element (linked to Table 1). Cohort 1 (gray), cohort 2 (black), and cohort 3 (stippled pattern)

group of teams (Fig. 2 – black compared to gray bars). Of the ten sets of materials reviewed in years 2–3, seven passed on the first attempt, one passed after minor revisions, and two required substantial revision and reassessment. Of the three that did not pass on the first audit, all missed key metrics related to guiding principles (which require 100% compliance). More broadly, materials development teams in the second cohort continued to experience difficulty meeting the requirement to include metacognitive strategies in their materials (Fig. 2: item 5.3). Eleven teams formed in years 4–5 (cohort 3: teams formed in 2015–2016; years 4 and 5 of the project) performed similarly to those in cohort 2 (see patterned bars Fig. 2).

Discussion

We interpret low performance in some rubric elements for cohort 1 as areas where materials development teams (and perhaps some assessors based on scoring discrepancies) struggled to understand what was described in the rubric. The element dealing with metacognition was the most difficult criteria for the first cohort of teams to achieve (Table 1: element 5.3; 59% met criteria). Metacognition deals with one's ability to self-assess and monitor one's own learning (NRC 2000). There are two main components to metacognition: knowledge and regulation (Schraw and

Moshman 1995). Knowing includes procedural aspects related to recognizing one's self as a learner and what factors influence our learning. For example, metacognitive students would realize that taking an exam when external distractions were present might negatively affect their scores (Fox et al. 2008). Such a learner also generally knows which learning procedures have been most effective for him/her in the past (e.g., memorization, outlining, summarizing) and when each strategy is most effective (Schraw et al. 2006). Regulation of cognition involves selecting learning strategies, planning when and where to use them, and evaluating if the strategy is working (Schraw et al. 2006). In many cases, students engage in these processes without even being aware they are using them (Pressley et al. 1989). Often, curriculum developers simply overlooked the importance and complexity of this element. Once the values of these practices were recognized, developers met the criterion by including techniques such as minute papers, muddiest points, and knowledge surveys (Angelo and Cross 1993) in their instructional materials.

Cohort 1 materials developers had difficulty meeting other standards in the rubric (Fig. 2). Grading rubrics were sometimes omitted, or the criteria being assessed was not clearly identified and/or there was not a clear differentiation between achievement levels (Table 1 and Fig. 2: elements 2.2 and 3.2; 65% and 72%, respectively). Other areas of weakness included the mandatory 100% score element related to systems thinking (Table 1 and Fig. 2: element 1.5; 81%) and linkages between curricula, activities, and assessments (Table 1 and Fig. 2: element 4.2; 76%). For the most part, these deficiencies were readily corrected once they were pointed out by the assessment team.

The identification of these areas of weakness allowed the InTeGrate leadership team to be proactive in providing professional development and guidance for subsequent materials development teams. First, a series of professional development webinars were conducted prior to the first meeting for materials developers. Those webinars included topics related to backward design, designing and using rubrics, incorporating metacognitive skills into curriculum, and designing and aligning learning outcomes and assessments—the elements of the rubric with which teams had struggled the most. The webinars were recorded and remained available for reference or use by subsequent teams. Next, the initial meeting of materials development teams was reorganized to more explicitly cover major elements of the rubric. Following a short description of the elements, materials development teams worked with their team leader and internal assessment consultant to apply what they learned to their own project. By the end of the 2-day meeting, participants had been apprised of the rubric standard, developed ideas for their own project, and received formative feedback from their assessment consultant and the leadership team. We attribute improved scores for cohorts two and three to these interventions (Fig. 2 black and patterned bars). Despite these efforts, teams continued to have difficulty addressing the metacognition element (Fig. 2; element 5.3). Since metacognition can be linked to student achievement (Young and Fry 2008), additional research should explore more effective ways to assist faculty in building metacognitive strategies in their curriculum.

This rubric and auditing process can be adopted by others interested in developing high-quality curricular materials. For example, the GEodesy Tools for Societal Issues (GETSI) leadership team slightly modified the InTeGrate rubric for their project. They changed and refined some of the guiding principles as needed to meet the goals of their project (GETSI 2018). The remaining elements of the rubric, scoring methodology, and auditing process were essentially unchanged from the original InTeGrate process.

Conclusions

A curricular auditing system coupling well-defined standards with mentoring and coaching support was found to be an effective approach for developing and refining curricula. Use of the materials development rubric allowed evaluators to give specific, constructive feedback to individual curriculum development teams. Materials developers who used this rubric and had access to aligned professional development produced pedagogically robust curricula that address Earth-related grand challenges facing society. Overall, the InTeGrate materials development and refinement rubric has proved a valuable component of the project and one that could be easily used or adapted for other curriculum development projects.

Comparing rubric scores across all modules allowed us to proactively prepare professional development opportunities that improved subsequent evaluations. We found curriculum developers had the most difficulty meeting standards related to metacognition, including attributes of high-quality rubrics and writing of clear learning outcomes and objectives that align well with the broader curriculum. An important implication of this work is that novice curriculum developers who have not previously been involved in creating new course materials can be successful at meeting high standards when guidance is provided.

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Facilitating the Development of Effective Interdisciplinary Curricular Materials

Anne E. Egger, Monica Z. Bruckner, Stuart J. Birnbaum, and Lisa A. Gilbert

Abstract Development of strong interdisciplinary curricular materials requires bringing together teams of instructors with diverse disciplinary expertise around complex and compelling topics. Many faculty lack the experience and support needed to effectively develop curricula as part of a team. To address these needs and to meet its own goal of engaging students in learning about Earth in the context of societal issues, the InTeGrate project designed a process that (1) constructed diverse and interdisciplinary materials development teams; (2) structured the materials development around a detailed rubric that included grand challenges and interdisciplinary problem-solving; (3) supported materials development teams through a semiflexible, scaffolded development timeline with several checkpoints; and (4) developed an extensive website to support both development teams and adopting instructors. Through this process, 32 interdisciplinary teams of 113 unique authors from around the country and many institution types produced 26 modules and 6 courses that are published on the InTeGrate website. The materials address a wide range of Earth-related grand challenges and contain explicitly interdisciplinary components. Authors and project leadership used the website heavily to support the development process. The rubric, timeline, and web-based tools that facilitated team-based curriculum development encode research-based practices in curriculum design and teaching and learning, and all components can be adapted for use by other projects.

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Introduction

The challenges that we face as a society cross social, economic, scientific, and political boundaries. Gosselin et al. (this volume) describe the ultimate challenge of living sustainably on our planet and the need for interdisciplinary approaches that include the geosciences to address environmental and resource issues that contribute to sustainability. To make progress on these and other challenges, we need *interdisciplinarians* who can bring disciplinary knowledge to bear on communities' needs (Frodeman 2017).

One of the leverage points for developing interdisciplinarians is at the undergraduate level, as students choose majors and begin to specialize. Institutes of higher education are largely built around disciplines (Jacobs 2017). Within this disciplinary structure, however, the number of interdisciplinary courses, programs, and research agendas is growing, in response to the need for graduates with interdisciplinary skill sets both to enter the workforce and to engage in cutting-edge, interdisciplinary research (Lyall et al. 2015; Knight et al. 2013; Gosselin et al. this volume). In a review of interdisciplinary teaching and learning in higher education, Spelt et al. (2009) note that students (and faculty) struggle in working across and synthesizing disciplines. In order to overcome these challenges, interdisciplinary curricula should be designed from the ground up to address both broad and narrow interdisciplinary thinking skills, where "narrow" skills are focused on a particular interdisciplinary problem, such as mitigating and adapting to the effects of climate change, and "broad" skills involve integrating across disciplines, explicitly recognizing and drawing on the differences in perspectives and methods of, for example, climate science, behavioral science, and political science. A narrow focus, also called "problem-centering" (Nikitina 2006), appears to offer the most accessible entry point for developing interdisciplinary skills, provided that it is centered on an interdisciplinary anchor that students and teacher consider worth addressing and that the anchor is complex enough—not simply complicated—to allow multiple different perspectives and solutions (Barab and Landa 1997; Newell 1994).

While complex and worthwhile topics are critical for effective interdisciplinary curricula, the pedagogic strategies employed are equally important. Several recent reports highlight evidence-based practices that promote student learning, including allowing students to actively construct new knowledge, engage in interactive collaboration, and reflect on their learning process (National Research Council 2012a, 2015). Although most of the evidence for these practices emerged out of discipline-based education research (National Research Council 2012a), several studies indicate their effectiveness in interdisciplinary courses as well (Spelt et al. 2009).

In his widely cited book chapter entitled *Designing Interdisciplinary Courses*, Newell (1994) lays out eight steps for curriculum design, the first of which is assembling an interdisciplinary team. He notes that:

> An interdisciplinary topic takes more than one person's interest, even expertise, because an interdisciplinary course requires multiple different perspectives. However broad a faculty member's training may be, it is still a human trait to seek cognitive order, to create a single coherent perspective on how the world works. But contrast if not conflict is essential to interdisciplinary study. To bring two or more perspectives to bear on a single topic, an individual working alone would need to have two minds. (p. 37)

True interdisciplinary teams coordinate frequently and consistently throughout a project (Morse et al. 2007).

Despite the importance of teamwork in both interdisciplinary education and research (Spelt et al. 2009; Morse et al. 2007; Hall and Weaver 2001), most faculty are not accustomed to developing curricula as part of a team and may struggle to work with colleagues outside of their own discipline (Vanasupa et al. 2012). Many faculty involved in interdisciplinary teaching are themselves products of a disciplinary education. In light of this reality, Klein and Newell (1996) noted that interdisciplinary teaching provides an opportunity for faculty development and education on how to function well as an interdisciplinary team (Hall and Weaver 2001).

In summary, interdisciplinary curricular materials should be designed by well-supported teams around a compelling topic and make use of research-based practices known to support student learning. The InTeGrate (Interdisciplinary Teaching about Earth for a Sustainable Future) project, funded by the National Science Foundation, supports integrated, interdisciplinary learning about resource and environmental issues across the undergraduate curriculum to create a sustainable and just civilization, taking a system approach to improving teaching and learning about Earth (Kastens and Manduca 2017; Gosselin et al. this volume). One of the strategies employed was to work with faculty to change the "what and how" of their teaching at the course level: InTeGrate supported the development of new curricular materials across the undergraduate curriculum that integrates teaching about Earth with societal issues.

The InTeGrate leadership, which includes 5 co-principal investigators, 11 senior personnel, and an external evaluation team, recognized the inherent challenges in developing widely adoptable, interdisciplinary curricula at the undergraduate level: faculty may lack the time or resources to engage in rigorous curriculum development (Sunal et al. 2001), lack the expertise to test the effectiveness of the materials, have trouble identifying colleagues to work with on a team, and/or struggle to adapt existing curricula to their institutional and regional setting (Sunal et al. 2001; Henderson and Dancy 2007). To address those challenges, InTeGrate designed a process to support faculty in developing effective curricular materials using practices suggested throughout the interdisciplinary studies literature (Spelt et al. 2009; Klein and Newell 1996; Newell 1994). The use of this process resulted in successful engagement of undergraduate faculty from across the United States in team-based development and testing of curricular materials that address a wide range of interdisciplinary, Earth-related topics throughout the undergraduate curriculum. In this chapter, we describe the process InTeGrate developed, analyze the resulting materials, and provide recommendations for future curriculum development projects. Part 2 of this volume highlights some of the materials developed through this process.

Methods: The Materials Development Process

One of InTeGrate's primary goals was to develop curricula that will increase Earth literacy of all undergraduate students, including the large majority that do not major in the geosciences, so that they are better positioned to make sustainable decisions in their lives and as part of the broader society. To meet that goal, new curricular materials needed to be designed in a way that would engage all students in a variety of settings, address the grand challenges we face as a society, use rigorous science and research-based practices in learning, and include educative materials for instructors in order to be adaptable and adoptable in many types of institutions and environments (e.g., Ball and Cohen 1996).

InTeGrate implemented four strategies to ensure these conditions were met in the materials developed. Specifically, the InTeGrate leadership (1) constructed diverse and interdisciplinary materials development teams; (2) structured the materials development around a detailed rubric (described in Steer et al. this volume); (3) supported materials development teams through a semiflexible, scaffolded development timeline with several checkpoints; and (4) developed an extensive website to support both development teams and adopting instructors.

Materials Development Teams

Materials development teams were proactively designed to promote interdisciplinarity and diversity of institutional settings and geographic locations. Team members were solicited through four open calls for proposals as well as targeted invitations to complete teams' needed expertise. Proposals could be submitted by complete teams of three to five people, partners seeking other team members, or individuals. To facilitate team building for individuals or partners seeking co-authors, the project also provided a "Seeking Team Members" forum on the website that served to match potential authors with similar interests.

The InTeGrate leadership read the proposals and worked with applicants to ensure teams consisted of at least three instructors (and up to five for courses) from at least three different institutions—usually different types of institutions that were also geographically distributed. For example, a team might consist of instructors from a community college, a regional comprehensive university, and a 4-year liberal arts college. Given their different institutional settings, each team member typically had unique constraints: class size, classroom design, and length of class meetings. In most cases, at least one team member had to be a geoscientist, and at least one team member had to be a non-geoscientist. For this study, we assessed the extent to which the teams met our goals for both institution type and for interdisciplinarity by coding team members by institution and discipline.

Each team was supported by a content area leader who was part of the InTeGrate leadership and acted as editor, an assessment consultant who was a member of

InTeGrate's assessment team, and a web consultant who was part of the Science Education Resource Center (SERC) web team (InTeGrate 2012c). The content area leader served in a similar capacity to a journal editor, providing high-level guidance on content, editorial review and input, and tracking and approving each team's progress. The assessment consultant worked with the team to assure that the materials they developed met the guidelines encoded in the rubric (described below and in Steer et al. this volume), led the review of the materials prior to their pilot testing in the classroom, was part of a team who analyzed student data collected during the pilots (described in Iverson et al. this volume), and provided post-pilot revision guidance to the team based on that analysis. The web consultant provided technical support for the team throughout the development and testing process, designing the appropriate web pages and providing technical assistance, assisting with setting up the piloting dashboard, data collection, and data ingest site, reviewing materials for formatting and copyright compliance, and developing additional supporting web materials as needed. The web consultant also acted as project manager, keeping track of teams' progression through the checkpoints, coordinating communication, and ensuring project leads signed off on the materials before they were published.

Rubric

The InTeGrate leadership and assessment teams developed a detailed, 28-criteria rubric to guide these materials development teams in creating their modules and courses (InTeGrate 2013). The materials development rubric consists of six sections: guiding principles, learning objectives and outcomes, assessment and measurement, resources and materials, instructional strategies, and alignment, described in detail in Steer et al. (this volume). The guiding principles, which must be incorporated explicitly and pervasively in the materials, are unique to InTeGrate, while the other five sections are drawn from research-based teaching practices (National Research Council 2011, 2012a) and curriculum development (Cullen et al. 2012; Wiggins and McTighe 2005).

One of the guiding principles requires that InTeGrate courses and modules address one or more Earth-related grand challenges facing society. These grand challenges provide a strong interdisciplinary anchor (Barab and Landa 1997) for the materials. To meet the standard encoded in the rubric, materials development teams had to incorporate at least one Earth-related grand challenge explicitly and pervasively throughout their materials, approaching the topic from multiple perspectives. Many groups have defined "grand challenges" (see, e.g., National Research Council 2001a, b; Zoback 2001; AGI 2016). The rubric did not limit the grand challenges that authors could choose but states that, "Grand challenges include resource issues (e.g., minerals, energy, water, food, sustainability) and environmental issues (e.g., climate change, hazards, waste disposal, environmental degradation and environmental health)." Given InTeGrate's emphasis on integrating geoscience and societal issues, for this study we chose to categorize the challenges addressed in each set of materials according to the American Geosciences Institute's 2016 report *Geoscience for America's Critical Needs* (AGI 2016), a quadrennial policy document meant to inform voters and legislators in presidential election years.

In addition to providing a grand challenge as a motivating, complex topic, teams had to develop materials that would explicitly engage students in interdisciplinary problem-solving around that grand challenge—another guiding principle in the materials development rubric. Our definition of *interdisciplinary* requires using the tools, approaches, and/or data from two or more disciplines in a coherently integrated way (Meeth 1978; Klein and Newell 1996; Lyall et al. 2015; Pennington et al. 2016). We distinguish this from *multidisciplinary*, which makes use of the tools or approaches from two or more disciplines, but without integrating them (Meeth 1978; Pennington et al. 2016), and from *integrative*, which is a much broader term that indicates any sort of bridging (e.g., integrating theory and practice, which may remain in a single discipline) (Klein 2005). To engage in interdisciplinary problem-solving, therefore, students need to integrate and synthesize knowledge from multiple disciplines to solve a problem that cannot be addressed through a single discipline (Boix Mansilla et al. 2000). In order to know if students have developed these skills, interdisciplinary assessments are needed (Boix Mansilla and Duraisingh 2007), and the rubric also required substantive assessments that were aligned with learning goals. The InTeGrate project emerged from the geosciences, so the inclusion of at least one of the geosciences (Earth, ocean, atmospheric, or climate science) was implicit, and thus interdisciplinary problem-solving involved integrating disciplines beyond the geosciences. For this study, we evaluated the interdisciplinary components present in the materials, coding for the extent to which activities and assessments require the use of multiple disciplines and emphasize interdisciplinary content using four criteria:

1. Does the module or course home page explicitly mention interdisciplinary aspects?
2. Do the student activities within the module or course explicitly describe interdisciplinary components?
3. Do the student activities and assessments emphasize relationships between scientific disciplines, either implicitly or explicitly?
4. Do the student activities and assessments emphasize relationships between science and relevant social, political, or economic issues, either implicitly or explicitly?

The first two criteria were selected based on the literature on the importance of metacognition for both instructors and students (e.g., Pintrich 2002) and were assessed by searching for the presence of the word "interdisciplinary" and/or text that describes an interdisciplinary approach. If the goal is for faculty to teach interdisciplinary materials and students to learn interdisciplinary skills, it is important to emphasize that goal explicitly. The last two criteria were used to measure the specific types of interdisciplinary learning students were doing: both between sciences and between science and other fields. To answer these questions positively, the activities had to describe opportunities for students to use the tools, methods, and/

or approaches from two or more disciplines together to address a single question or outcome.

The rubric also includes several criteria that address instructional strategies (see Steer et al. this volume), specifying that students should be actively engaged in learning using research-based strategies. Describing the strategies used in the materials is beyond the scope of this paper; examples can be seen in Part 2 of this volume. Elsewhere, Kastens and Krumhansl (2017) describe the strategies used in the introductory modules (Table 1) to engage students in working with data; McConnell et al. (2017) describe the efficacy of several active learning strategies using examples from the InTeGrate materials.

Table 1 Integrate materials developed and disciplines of authors

Modules	Level	Geoscientist(s)	Other scientist(s)	Non-scientist(s)
Climate of Change	Introductory	x	–	–
Natural Hazards and Risks: Hurricanes	Introductory	x	–	–
Human's Dependence on Earth's Mineral Resources	Introductory	x	–	–
A Growing Concern: Sustaining Soil Resources through Local Decision-Making	Introductory	x	x	–
Map Your Hazards! Assessing Hazards, Vulnerability and Risk	Introductory	x	–	x
Living on the Edge	Introductory	x	–	–
Environmental Justice and Freshwater Resources	Introductory	x	–	–
Carbon, Climate, and Energy Resources	Introductory	x	–	–
Systems Thinking	Introductory	x	x	–
Earth's Thermostat	Introductory	x	x	–
Ocean Sustainability	Introductory	x	x	–
The Wicked Problem of Global Food Security	Introductory	x	x	x
Changing Biosphere	Introductory	x	x	–
Exploring Geoscience Methods	Pre-service teachers	x	–	–
Interactions Between Water, Earth's Surface, and Human Activity	Pre-service teachers	x	–	–
Soils, Systems, and Society	Pre-service teachers	x	x	x
Cli-Fi: Climate Science in Literary Texts	Intro-intermediate	x	–	x

(continued)

Table 1 (continued)

Modules	Level	Geoscientist(s)	Other scientist(s)	Non-scientist(s)
Mapping the Environment with Sensory Perception	Intro-intermediate	x	–	x
An Ecosystem Services Approach to Water Resources	Intro-intermediate	x	x	x
Water, Agriculture, and Sustainability	Intro-intermediate	x	–	–
Food as the Foundation for Healthy Communities	Intro-intermediate	x	x	x
Regulating Carbon Emissions	Intro-intermediate	x	–	x
Major Storms and Community Resilience	Intro-intermediate	x	x	x
Environmental Justice and Freshwater Resources—Spanish Version	Intro-intermediate	x	–	x
Lead in the Environment	Intermediate-advanced	x	x	–
Water Sustainability in Cities	Advanced	x	x	–
Courses				
Coastal Processes, Hazards, and Society	Introductory	x	–	–
Water: Science and Society	Introductory	x	–	–
Future of Food	Introductory	x	x	–
Renewable Energy and Environmental Sustainability	Intro-intermediate	x	x	–
Critical Zone Science	Intermediate-advanced	x	x	–
Modeling Earth Systems	Intermediate-advanced	x	–	–
	Totals	32	15	10

Timeline

A timeline with three phases, seven intermediate checkpoints, and four assessment data collection points was developed to guide teams through the development process and help ensure they make timely progress (Fig. 1). The details of each phase and checkpoint are described elsewhere (InTeGrate 2012d); here we provide an overview of key aspects of the timeline.

Each cohort of materials development teams began on the timeline with a two-and-a-half-day, face-to-face meeting. These initial meetings were structured around the materials development rubric, with time for teams to work together to establish

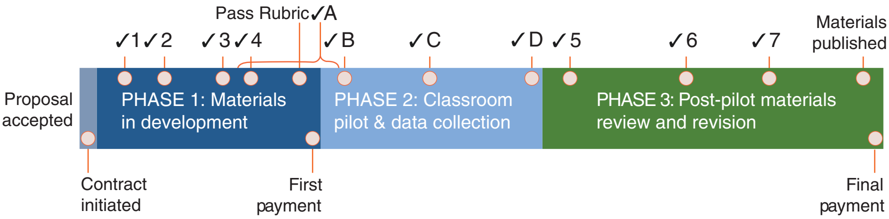

Fig. 1 Timeline of materials development showing three phases (in color), seven checkpoints (numbers), and assessment data collection points (letters) (InTeGrate 2012d)

overall learning goals for their materials and to define how their materials would meet InTeGrate's guiding principles (see InTeGrate 2015, for a sample agenda). A set of web pages with planning worksheets and templates for each team were created in advance to get the author teams immediately familiar with using the content management system.

The initial face-to-face meetings enabled teams to meet one another, the project leadership, the assessment team, and the SERC staff, establishing a sense of community with common goals. Teams met their content area leader, assessment consultant, and web consultant and worked with them to establish a development plan with a robust outline of their materials. Following a backward design model (Wiggins and McTighe 2005), teams focused upon learning goals and assessments that would measure students' progress toward these goals and activities that would help students succeed on the assessments. The team, in conjunction with the content area leader and assessment consultant, also set target dates for reaching checkpoints 1–4 (Fig. 1)—ultimately driven by when they planned to pilot the materials in their classroom (or, in a few cases, when others planned to pilot the materials)—and established a communication plan to make progress in between the checkpoints. By the end of these initial meetings—or shortly after—each author team had reached checkpoint 1 (Fig. 1) by establishing their timeline and communication plan, defining the goals and scope of the materials, and writing a description of a summative assessment for their course or module.

After the initial face-to-face meeting, teams were responsible for making progress, with support as needed from the content area leader, assessment consultant, and web consultant. Each team had an email list that included the authors as well as the content area leaders and assessment and web consultants so any questions or issues could be addressed promptly.

In order to for a team to enter Phase 2 and pilot their materials in the classroom (Fig. 1), the materials had to pass review against the materials development rubric by two members of the assessment team. Most authors piloted their materials in their own course, but in a few cases, a nonauthor piloted the materials. Each piloting instructor was responsible for obtaining approval from their own Institutional Review Board (IRB) and collecting data in their classroom using the assessment instruments that InTeGrate developed (InTeGrate 2012a).

Teams were invited to a second face-to-face meeting once all members of the team had piloted their materials and collected student data from those pilots (letter D in Fig. 1). Prior to this second meeting, the assessment consultant and two additional assessment team members reviewed the student answers to the formative (first team cohort only) and summative assessment and the project-wide assessments (described further in Iverson et al. this volume) to evaluate the efficacy and effectiveness of the assessment and module materials and determine what to communicate to the materials development teams to improve their materials. At this second meeting, the assessment consultant presented the results of the analyzed student data and provided suggestions for revising the materials. Teams then developed revision plans and established target deadlines for reaching the remaining checkpoints and publishing the materials.

Once revisions were complete and the content area leader had approved them, the materials underwent an internal technical review and copy-editing, which addressed copyright, links, and writing style. Concurrently, materials went out for external science review, in which reviewers were asked to review the science covered in the materials. Specifically, reviewers were asked to comment on whether content, statistical analysis, analogies, and/or figures, images, and data were missing or misleading; if the materials were up to date and properly referenced with the most recent available literature; and whether any assumptions, interpretations, or hypotheses were clearly labeled as such rather than presented as facts or observations. Pedagogical strategies were not part of the external review as they were addressed through the review by the assessment team.

Overall, the curriculum development process involved a significant commitment of time and intellectual energy on the part of the authors. In recognition of this commitment, stipends were substantial (up to $15,000 per author), and payments were disbursed at two stages of development and provided incentive to reach important milestones. The first stipend payment was disbursed after the assessment team determined that the team's materials had met the materials development rubric and just before they began piloting the materials; the second was disbursed upon publication of the materials, after all technical and science revisions were complete and the materials were published (Fig. 1). For this study, we evaluated the time it took for materials development teams to make progress along the timeline, identifying critical events for success and steps that took the longest.

Supporting Website

All of the InTeGrate curricular materials were developed natively as web pages. Teams worked within private workspaces accessible only by them and project leadership; workspaces included the pages where teams developed their curricular materials and a reporting page, where teams reported on their progress and received feedback. The development process was supported and managed using Serckit, a content management system developed by SERC to "create websites that support communities engaged in improving educational practice" (SERC 2016).

The InTeGrate project website is hosted by SERC, which hosts several other project sites, including:

- *Pedagogy in Action*, a project that provides descriptions of engaged (i.e., student-centered) pedagogies with examples of their use (SERC 2015)
- *On the Cutting Edge*, a project that supports professional development of undergraduate geoscience faculty and hosts 1000 of reviewed activities along with resources about concepts such as the affective domain, metacognition, and spatial thinking (SERC 2002; Manduca et al. 2010)

Within these two projects are community-developed resources that provide support for faculty to improve teaching including concepts such as teaching with data, quantitative reasoning, developing systems thinking skills, and many others. During the initial face-to-face meeting, authors were introduced to the scope of the resources available through SERC, and links to some of the most commonly used resources were embedded within the agenda (InTeGrate 2015). Authors were encouraged to make use of the resources in these sites in developing their own materials and encouraged to link to resources within those sites when possible and relevant.

In addition, the InTeGrate website serves several other purposes beyond a repository for the materials (O'Connell et al. 2016). An inward-facing site accessible only to materials developers and project leadership tracked progress of teams, provided tools for uploading and organizing assessment data, and provided a portal to additional support resources. The outward-facing site provides numerous supporting resources for those adopting and adapting materials, including instructor stories, information about the pedagogical strategies employed in the materials, and supporting information from the literature and the larger community (O'Connell et al. 2016).

Inward-Facing Site

Project leadership and the web team developed a large set of informational pages (>50) and professional development webinars for authors as they developed their materials (InTeGrate 2012b). The pages cover concepts such as working with the rubric, obtaining approval from an author's Institutional Review Board, and collecting data in the classroom. In response to common problems that teams experienced in passing the rubric (see Steer et al. this volume), the leadership team also developed a series of webinars and interactive web pages designed specifically for authors. These cover five topics that authors found most challenging: designing measurable learning goals, developing assessments that align with learning goals, metacognition, rubrics, and systems thinking. For this study, we used Google Analytics to assess the use of the inward-facing pages.

In addition, the web team developed several web-based tools that allowed the web and assessment teams to easily track progress of the materials development teams (an overview of tools is provided at SERC 2017). The review tool and data collection tool in particular facilitated the materials development process.

The review tool facilitated the review of materials against the rubric by the assessment team prior to piloting (Checkpoint 4). Using the review tool, the leader of the InTeGrate assessment team assigned modules and courses to assessment team members; assessment team members entered their scores and feedback into the tool. The review tool dashboard allowed leadership to quickly see where the teams were on Phase 1 of the timeline (Fig. 1), making use of a red, yellow, and green color scheme to indicate if reviewers had been assigned, how many reviews had been completed, and how the materials fared in their review and revisions stemming from review (Kastens and Manduca 2017).

The data collection tool allowed each instructor to set up a site for uploading student data collected in their classroom during piloting. Each instructor filled out a web form to create a course dashboard that would serve as the data repository during their pilot. Instructors could then upload assessment data as it became available. Student data were automatically encrypted to ensure anonymity; in addition, all data from students opting out of the study were automatically discarded. The dashboard also allowed project staff to track progress as well as download the student data to prepare it for analysis.

Outward-Facing Site

One of InTeGrate's primary goals was to develop materials that are easily adaptable and adoptable by instructors. A key to achieving that goal is that all materials are free and easily available on the web, following a common structure. InTeGrate also developed several outward-facing web pages meant to facilitate adoption of the materials by others beyond the authors. First, each instructor who was a member of a materials development team and/or piloted materials in their classroom produced an "instructor story," a web page that describes the course in which the materials were used and any modifications the instructor made to accommodate their specific needs or setting. Potential adopters of the materials can browse these stories for an instructor at a similar institution type or teaching a similar course and see how their colleague implemented the materials.

Additional supporting resources were developed to help potential users navigate and search the materials according to their particular needs. The leadership and web team developed an overview web page entitled "Using InTeGrate Modules and Courses," including a video and description of the types of resources included in the materials (InTeGrate 2014). Additional web pages provide guidance for instructors teaching introductory courses, online and hybrid courses, courses for future teachers, and more. The collection of materials can also be searched by sustainability topics, level, and alignment with the Next Generation Science Standards (InTeGrate 2017).

Many of these components of the outward-facing site have been thoroughly revised within the 6 months prior to this study, and as yet, we do not have sufficient data to assess the extent to which they are being used, so these are not further addressed within this study.

Results

Over the life of the project, 35 teams comprising 127 individual authors initiated the materials development process. Thirty-two teams comprising 115 authors (113 unique authors) completed the curriculum development process. The three teams that did not complete the process terminated their contracts early in the process by mutual agreement with the leadership.

Of the 32 sets of curricular materials developed through this process, 26 are modules, which consist of 2–5 weeks of classroom time, and 6 are courses, meant to cover an entire quarter- or semester-long course (Table 1). The use of the materials span a wide range of courses across the undergraduate curriculum, including introductory and general education courses in geoscience, biology, and environmental science; courses designed for pre-service teachers; courses in engineering, sociology, public policy, history, literature, Spanish-language learning; and introductory and advanced interdisciplinary courses. All of the materials are available on the web (InTeGrate 2017) under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 license.

Each set of materials follows a similar design, aimed toward instructors, and consists of:

- A home page with a short summary of the materials, learning goals, table of contents, and other easily scanned information
- An overview page with summaries for each unit, or subsection, of the materials
- Pages for each unit that use a common format that includes a summary, context for use, learning goals, a description of the activity/activities with relevant files and resources, teaching notes and tips, assessment that aligns with the learning goals, and references and resources
- An assessment page that lists the formative and summative assessments used in the module or course and how they align with the learning goals
- A set of instructor stories that document how the authors used the materials in their course, including changes they made to adapt it to their particular teaching environment
- A community page where users can sign up for an email list and participate in a discussion thread about the module

All assignments, activities, assessments, answer keys, and rubrics are available for download; most answer keys are protected behind a wall that requires registration and verification as an instructor. In addition, the curriculum materials include a set of pages written for students with the surrounding InTeGrate navigation removed, so that students can access them independent of the instructor guidance pages.

Materials Development Teams

Nearly two-thirds of the 32 materials development teams (63%) included at least one non-geoscientist author (Table 1). Non-geoscience authors included scientists from chemistry, biology, physics, agriculture, engineering, and medicine as well as those outside the natural sciences, from fields such as such as history, philosophy, English, sociology, Spanish, and economics. Five teams (16%) included both non-geoscience scientist(s) and non-science authors in addition to one or more geoscientists.

Team members represented the full range of US higher education institution types (Fig. 2) in 28 different states (Fig. 3), with the largest numbers of authors from Pennsylvania, New York, and Washington. Except for Alaska and Hawaii, all regions of the country are represented among the authors (Fig. 3). About a third of team members were from Doctoral universities, with a slightly higher percentage from Master's universities (Fig. 2). Authors from associate's colleges were primarily involved in the development of introductory modules, while authors from all other institution types were spread out among the different levels of modules and courses.

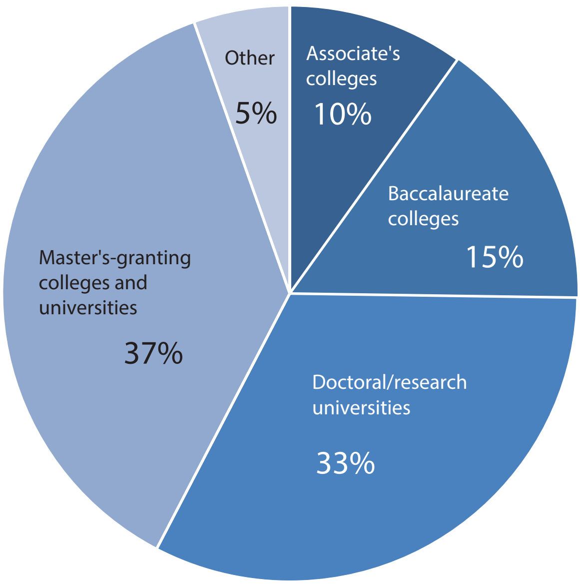

Fig. 2 Institution type of authors, based on a modified Carnegie classification scheme. "Other" includes authors from government agencies, tribal colleges, research institutions, and museums

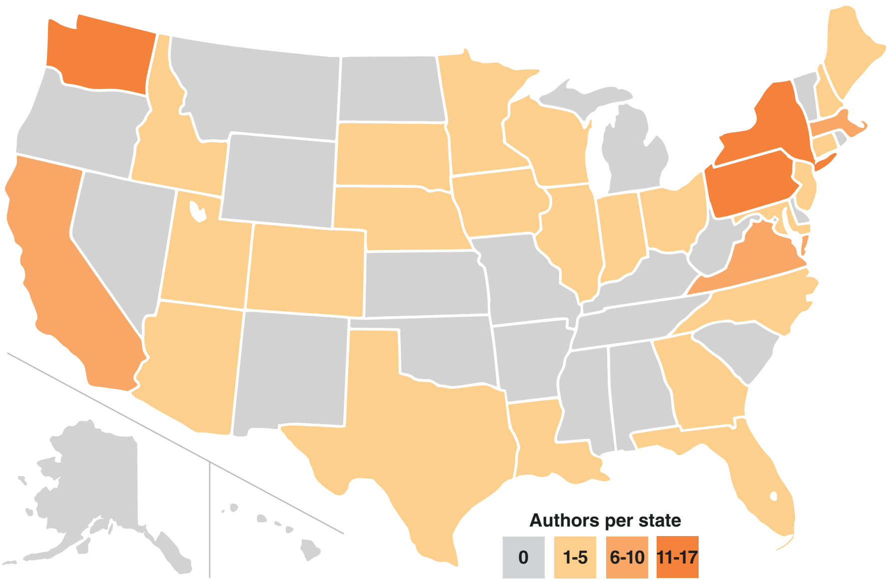

Fig. 3 Geographic distribution of authors

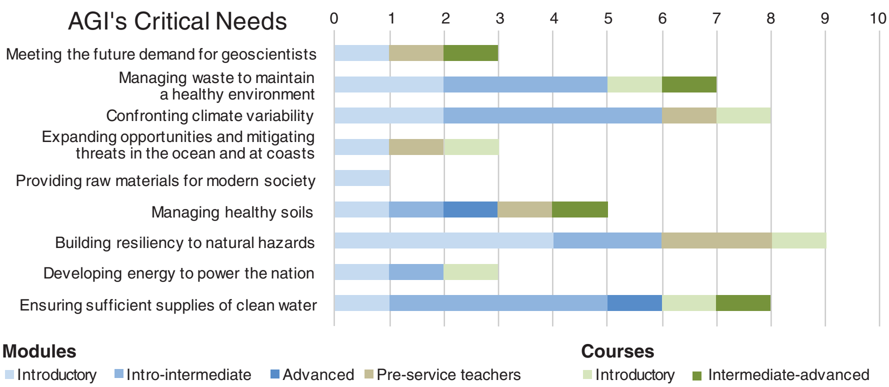

Fig. 4 The number of InTeGrate courses and modules that address critical needs for geoscientists as defined by AGI (2016). Some materials address more than one critical need; thus the sum total of the histogram (47) is more than the total number of courses and modules (32)

Rubric

Grand Challenges

Each team defined at least one grand challenge, or Earth-related societal issue, that they addressed in their materials. Figure 4 shows the extent to which the materials developed address the critical needs for geoscientists defined by the American

Geoscience Institute (AGI 2016). It is important to note that this document was published near the end of the InTeGrate project and was not provided to authors as a list of grand challenges to select from; Gosselin et al. (this volume) describe additional grand challenge documents that were available when the project began.

The suite of introductory modules covers all nine critical needs; "providing raw materials for modern society" is only addressed at the introductory level in one module. The most commonly addressed critical need is "building resiliency to natural hazards"—in the InTeGrate materials, natural hazards include earthquakes, river flooding, coastal flooding from sea level rise, hurricanes and major storms, and volcanic eruptions. Modules and courses at all levels address the critical need of "ensuring sufficient supplies of clean water," and almost all levels cover "managing waste to maintain a healthy environment." Modules for pre-service teachers emphasize natural hazards, climate variability, and soils, all of which feature prominently in the disciplinary core ideas defined in the Framework for K-12 Science Education (National Research Council 2012b) and science standards developed based on the framework (e.g., NGSS Lead States 2013).

Interdisciplinary Problem-Solving

The societal grand challenges addressed in the curricular materials are by definition interdisciplinary and require using the tools, approaches, and/or data from two or more disciplines in a coherently integrated way. The materials development rubric ensured that all modules and courses—even those whose authors were solely from the geosciences—included interdisciplinary materials to address these grand challenges. Instructor materials and the student materials describe the interdisciplinary approaches both on the front pages and within the activities, usually in explicit terms, and the materials all include opportunities for students to make connections between different types of scientific issues and also to consider relevant economic, social, political, or esthetic issues. Comparing the modules and courses with only geoscience authors ($n = 12$; Table 1) to those with a broader mix of author expertise ($n = 20$; Table 1), there was no significant difference between the single discipline and multidiscipline teams for the strength of interdisciplinary materials according to the four criteria we described in the methods (Mann-Whitney U test, alpha = 0.05, $p = 0.75$).

All of the InTeGrate materials incorporate the methods of geoscience, but many of them also include methods from other fields. When students use the approaches of other sciences—and social sciences and humanities—they gain multiple perspectives on how to address complex problems. Modules and courses include using geoscience data in the context of sociological data, simulated stakeholder meetings, environmental literature, environmental policy-making, and emergency management plans. The non-geoscience methods learned are central to the materials and students are assessed accordingly. Every course or module has at least one interdisciplinary assessment, and most have several, ranging from short formative quiz-type questions to semester-long projects.

Timeline

The InTeGrate leadership envisioned the materials development process taking place over approximately two academic years, starting with a face-to-face meeting in the early summer and teams piloting their materials during the following academic year. In reality, teams took 1.5–4.5 years to complete their materials, with an average of 2.6 years. Teams developing courses took longer to complete their work than teams developing modules: course teams averaged 3.6 years and module teams averaged 2.4 years. For module teams, the average time is still slightly more than our idealized time frame of 2 years for development, while course teams took significantly longer.

The longest delays in the timeline for most teams came during the external science review, when it took time to find external reviewers and receive reviews in a timely fashion. The number of requests to review a module ranged from 1 to 19 requests for a single module. Eleven modules required 1 to 2 invitations before acceptance, while 5 modules required more than 6 invitations, and 1 module required 19 invitations. Courses were divided into pieces for review that were analogous to a module, typically resulting in a need for four reviewers per course. The range of number of review requests for courses was 4–55, with an average of 30 invitations for review.

It was no more difficult to find reviewers for materials that had more interdisciplinary titles than for those with titles more familiar to disciplinary scientists. Similarly, we did not find that the interdisciplinary strength of materials had any significant impact on the difficulty of finding reviewers. Reviews were requested as materials were submitted, and other factors, such as time of year (e.g., summer field work, end of terms) may have played a more important role in determining the difficulty of securing reviewers.

Website

The web pages designed to support materials developers received significant use, especially around times of face-to-face meetings (Fig. 5). During face-to-face meetings (lettered spikes in Fig. 5), inward-facing pages often received more than 1000 page views a day, suggesting that authors were using the information there to support their progress. Over the entire life of the project, average daily page views of the top 50 inward-facing pages was 70 page views per day; when the large spikes associated with face-to-face meetings are removed, average page views per day was 61.

Many pages within the information section were visited, but some received more page views and/or visitors stayed for longer. The index page received the most unique page views—21,781—and visitors stayed on average 89 s. Among the pages that received the most views with the longest average times spent, suggesting visitors were engaged with the material on the page, were the interactive pages we

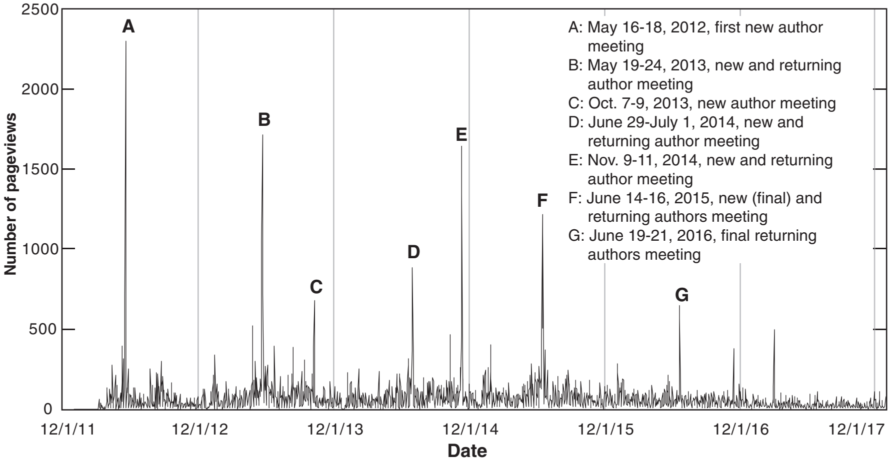

Fig. 5 Total daily page views over time for the top 50 pages within the inward-facing "Information for Materials Developers" section of the InTeGrate website. Project funding began on December 1, 2011, and the first internal pages were launched on March 7, 2012. Gray vertical lines fall on subsequent December 1 days, representing project years. Lettered spikes in usage correspond with new and returning face-to-face author meetings, with steady usage in between meetings

developed in response to authors' needs. From January 1, 2012, to December 27, 2017, the page on writing effective learning goals had 366 unique page views with an average time spent of 373 s, or over 6 min. The page on metacognition had 1619 unique page views with an average time spent of 290 seconds, or almost 5 min.

Discussion and Conclusions

The highly structured, goal-driven materials development process developed by InTeGrate has been successful in producing a set of interdisciplinary materials that have been implemented in a wide variety of institutions and courses at the undergraduate level. Our approach focused on supporting interdisciplinary and inter-institutional teams in development of resources, which was an unfamiliar process for most materials authors, who indicated that the process was "more ambitious, more rigorous, and more intense" than their previous experiences developing curriculum materials (Kastens et al. 2014). By design, the teams were diverse not only in terms of disciplinary knowledge (Table 1) but by institution type (Fig. 2) and geography (Fig. 3). Although team members described challenges working across time zones and institution types, nearly all indicated that working in collaborative teams across institutions was a new, productive, and valuable experience (Kastens et al. 2014). The value they found in collaboration went beyond their different disciplinary perspectives to include learning from each other about pedagogical strategies and reaching all students and proved to be a deep and valuable professional learning experience for them.

Going beyond the team members, the web-based materials themselves provide a form of professional learning for instructors who adopt them in the educative supports they include, such as detailed instructions and rationales for particular pedagogic strategies and background information for tools and approaches from disciplines other than the instructor's own (e.g., analysis of survey data by geoscientists). These supports allow nonauthor instructors to implement the modules and courses with a high degree of fidelity to the evidence-based practices while also allowing for (and encouraging) modification to meet the needs of students in their setting and region.

Grand challenges provided a strong framework for teams to anchor their module or course, helping them develop materials that required interdisciplinary problem-solving skills. The concept of "Earth-related grand challenges facing society" provided flexibility to teams while also requiring them to focus on a significant, worthwhile, and complex issue in their materials to facilitate interdisciplinary work by students. Iverson et al. (this volume) show student learning gains in interdisciplinary problem-solving skills as a result of this emphasis in the development process.

The timeline and rubric provided structure for teams in their development process, but the length of time it took to complete the materials varied by a factor of about three among teams. Authors noted that a key to success in the materials development stage was having regular (weekly or biweekly) conference calls, which motivated them to make progress for each meeting. Several teams faced unique situations that challenged their ability to meet timeline goals (e.g., changes in teaching loads, taking on of administrative duties, unanticipated health, and family issues), but virtually all teams faced the longest delay in receiving external reviews. The external review process, while perceived as a roadblock in the publication process, was not significantly slower than the manuscript review process for a journal (Björk and Solomon 2013).

Lessons Learned

Importantly, team members' attendance at the initial face-to-face meeting was critical to the success of the development process. The three teams that did not complete their materials were either not able to attend or didn't have their whole team present at that first meeting. Spending two-and-a-half days working closely with team members and the larger project helps develop a sense of a community to which authors become committed. The shared goals outlined explicitly at that meeting were one of the components that began to establish an enduring community of practice (Wenger 1998).

The extensive inward-facing website and tools designed to facilitate the review and data collection processes were critical to the overall success of the project.

Individual authors sometimes struggled to use the content management system and/or upload student data from their pilots. However, the website and tools facilitated project management for the assessment team, web team, and project leadership, all of whom were able to easily move between modules and courses, track progress, and answer teams' questions.

The Value of Rigorous Curriculum Development

Underlying the InTeGrate process is the assumption that rigorous curriculum development is *valuable* and should be compensated and recognized accordingly. Authors received significant stipends and travel support to attend the two face-to-face meetings, as well as profound professional learning. When their materials were published, authors (and their chairs or deans) received a letter detailing the work that went into the project and equating it to a first-authored paper in a peer-reviewed journal.

Rigorously developed and tested curricular materials are also valuable to the *user*, and the fact that some materials (and not others) were developed through this rubric-based process should be apparent to users. As described earlier, the InTeGrate materials are hosted on the SERC website, which also hosts 1000 of other resources. A user can search all materials available on the site, and the relevant results they receive are ordered according to the review processes the materials have gone through. The InTeGrate-developed materials display a "badge," as do other review processes (Fig. 6), which provides a visual cue for the value of these resources. Each page of the modules and courses also includes a brief description of the review process, again highlighting the value of the materials and why an instructor might want to use these materials over others that they find or have created.

InTeGrate's materials development process is adaptable to any interdisciplinary curriculum project. Internally, the InTeGrate implementation programs utilized course and module materials to meet programmatic goals (see Part 3 of this volume). Outside of InTeGrate, GeTSI (Geodesy Tools for Societal Issues) has made use of the proposal process for selecting team members, the rubric (modified slightly to emphasize geodesy), timeline, and course dashboard to support the development of several modules that use the same format as the InTeGrate modules.

The project also provided a powerful community building and professional development opportunity for all involved by taking a systems approach to complex change (Kastens and Manduca 2017). The process and tools developed by InTeGrate embody best practices in curriculum design and interdisciplinarity and have been successfully adopted or adapted by other projects interested in designing effective curricula.

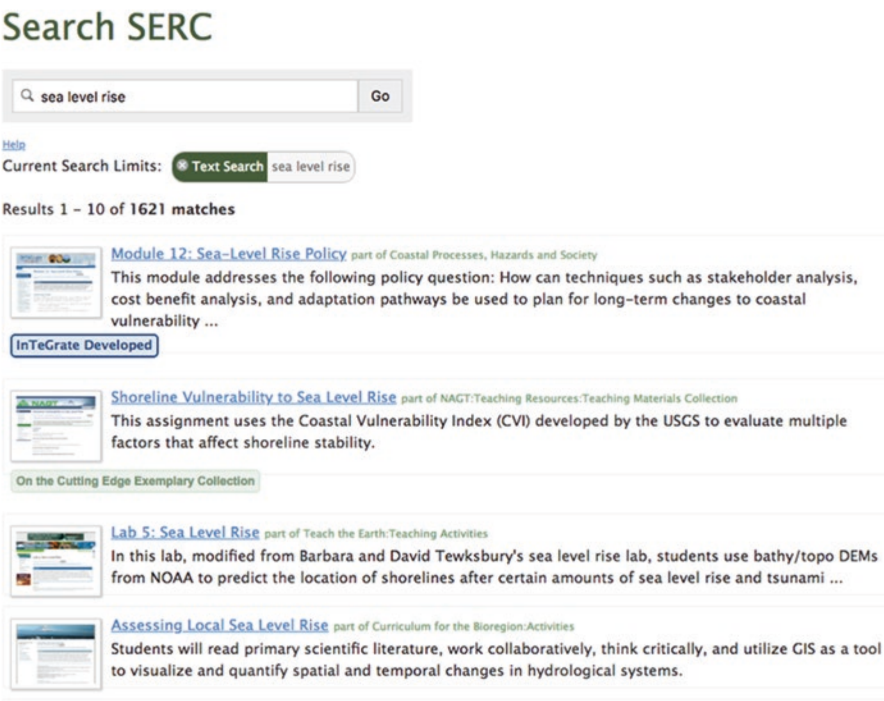

Fig. 6 A screenshot of the SERC search page showing the results of a search on "sea level rise" and the "InTeGrate Developed" badge

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Supporting Implementation of Program-Level Changes to Increase Learning About Earth

Cailin Huyck Orr and John R. McDaris

Abstract InTeGrate partnered with teams of educators to develop new models of ways to bring geoscience to a diverse range of disciplines, institutions, and networks. These program models consisted of institutions, or clusters of institutions, that applied for grants to develop and evaluate programs demonstrating innovative ways of (1) increasing the diversity of students developing Earth literacy and/or (2) teaching students to bring the geosciences to bear on societal issues. The 16 teams that were selected to be a part of the project all sought to use InTeGrate materials to effect change on their campuses or regions. These programs made use of, and built upon, information on effective practices compiled by InTeGrate and particularly the InTeGrate-developed teaching materials and/or the materials design rubric. The teams produced detailed program descriptions designed to serve as guides for implementing similar programs in new settings and also synthesized their experience across projects in making changes at the program scale.

Keywords Institutional change · Environmental sustainability · Broadening participation · Institutional collaboration · Interdisciplinary teaching

Introduction

Institutions nationally are faced with common challenges related to meeting current workforce demands, meeting student needs as demographics change, and operating within constrained budgets. These challenges are leading many institutions to experiment with new types of programming such as distance learning, partnerships

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between institutions, and curricular pathways from high school to college. Universities and colleges can benefit from evaluating programmatic experiments to determine their impact and from sharing the results of successful experiments as potential models for other institutions as they move to address similar issues (Bralower et al. 2008; Manduca et al. 2008; Ramaley 2016). While the current climate of rapid change in the education landscape includes challenges such as shifting student demographics and changing funding sources, it also fosters creativity and change and the opportunity for new collaboration with community and workforce partners (Ramaley 2016).

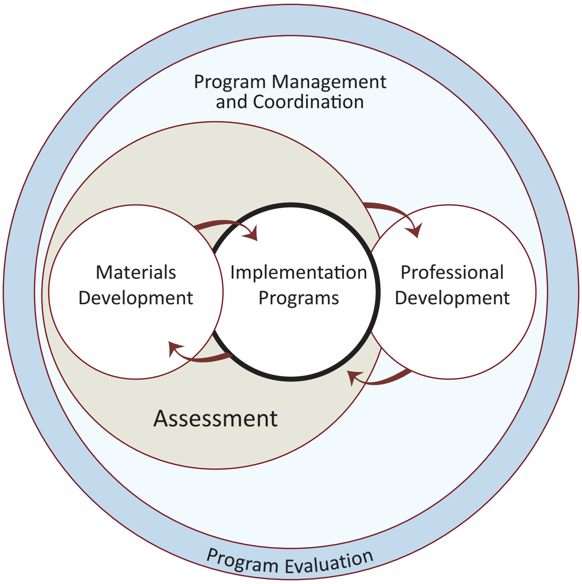
Lasting change in higher education, such as improving student experiences and outcomes in the STEM pipeline, requires work at the department, program, and institutional level (Bernstein-Sierra and Kezar 2017; Henderson et al. 2011; Seymour 2001), and innovative changes are more likely to be sustained when ideas are adapted to the local context (Kezar 2011). Work to broaden participation in STEM fields has demonstrated that to increase the numbers of well-prepared graduates, efforts need to be program-wide, not concentrated in individual courses (Seymour and Hewitt 1997; Tinto and Engstrom 2008; Crossling et al. 2008). Ongoing efforts to prepare students to address the sustainability challenges facing society are likely to require elements such as promoting student motivation and enthusiasm for learning about Earth; providing academic supports for students in the form of strong curricula, supporting services, and cocurricular activities; and cultivating a sense of belonging both within their program of study and in the larger professional community that they will enter.

The InTeGrate project (InTeGrate 2018a) is an NSF-funded STEM Talent Expansion Program (STEP) Center with two goals:

1. Develop curricula that will dramatically increase Earth literacy of all undergraduate students.
2. Increase the number of majors in the geosciences and related fields who are able to work with other scientists, social scientists, business people, and policymakers to develop viable solutions to current and future environmental and resource challenges.

The InTeGrate STEP Center was conceived of as a system where individual components were mutually reinforcing (Fig. 1). Feedbacks between the major program elements (production of curricular materials, creation and evaluation of institutional change models, and faculty professional development) reinforce the project's efforts to extend its reach. These components are themselves embedded in layers of assessment, program management, and program evaluation to ensure alignment with the program's overarching goals and guiding principles (Egger et al. this volume; Gosselin et al. this volume-b). In this context, the implementation programs provided examples of how the developed materials could be used to instigate changes at scales bigger than a course and move programs toward the InTeGrate programmatic goals.

Fig. 1 A conceptual diagram demonstrating how the major components of InTeGrate function as a system. The three inner circles represent the central program elements acting at three different scales of impact. The arrows between these circles represent feedback mechanisms between the various components. All of the main elements and feedbacks are embedded in pervasive assessment, management, and program evaluation activities



Excellent curricular materials are necessary but not sufficient for engendering the kind of lasting, transformational change that InTeGrate set as its goal. In light of the research available on making change happen, the project set about developing and implementing cross-disciplinary programs as educational models that could be adopted or customized at other colleges and universities as a way to increase the number of students learning about Earth across disciplines, the number of majors in the geosciences, and exposure in associated fields that seek to incorporate interdisciplinary efforts to address sustainability.

To this end, InTeGrate supported the development of 16 "implementation programs" which used the InTeGrate curricular materials and guiding principles to develop innovative approaches that incorporate geoscience into materials and programs designed to reach a diverse array of students, including those from groups underrepresented in the geosciences and students whose dominant interest or field of study lies outside the geosciences. The implementation program component of InTeGrate was designed to foster the development of multiple models for implementation of InTeGrate materials and programs across a diverse range of disciplines, institutions, and networks, as well as the documentation and resources necessary to help other groups implement similar programs. This allowed the possibility of adaptation and adoption of the materials in a wide array of contexts and put the emphasis on adhering to project principles instead of requiring specific program elements. A more open-ended set of guidelines was used to foster creativity in approach and context (Patton 2017). Our collaborative, well-supported approach addressed many of the commonly cited barriers to institutional change, including the shortage of materials, the lack of communication between reform efforts, and adhering to a rigid program structure that does not adapt to local context (Brainard 2007; Henderson et al. 2011; Seymour 2001; Kezar 2011).

The implementation programs also served important functions for the InTeGrate project as a whole. The work of these programs addressed objectives that were proposed by InTeGrate leadership. Programs were required to work at scales larger than single courses to:

- Support program implementations that demonstrate approaches to teaching geoscience literacy to diverse students in different institutional types and instructional settings.
- Develop, document, and disseminate a robust understanding of current practices, characteristics of successful programmatic models, and perceived needs and barriers.
- Support development, documentation, and dissemination of a set of new model programs based on an understanding of current practice.
- Assess impact of programs on the number of majors in the geosciences and associated fields as well as on students' ability and motivation to use insights from the geosciences in addressing grand challenges of sustainability.

The use of the curricular materials would also increase their reach and dissemination, stimulating more adoption in both geoscience education, allied fields such as environmental science, and also across the undergraduate curriculum.

The implementation programs, collectively, were tasked with creating a vision for how the materials and principles being developed by InTeGrate could be used to make changes at scales bigger than a course. The community needed examples to demonstrate the potential of this scale-up with specific instantiations of programmatic change being initiated and sustained. The goal of this effort was not only to create a template for how one might replicate these specific programs in new contexts but also to serve as a proof of concept for this approach to making changes.

Methods

Identifying and Selecting Programs

Beginning in 2014, InTeGrate solicited applications to develop and evaluate program-scale interventions that would model innovative ways of increasing the number and diversity of students developing Earth literacy and/or preparing a diverse workforce equipped to bring geosciences to bear in addressing societal issues (Kastens et al. 2014). These programs would make use of curricular materials under development by InTeGrate to tackle issues of particular importance in their context.

The programs were intentionally chosen to create a portfolio of diverse, creative approaches to addressing common challenges. As such, each program takes a different approach to meeting the overarching program goals. Five programs were proposed in the initial conception of the InTeGrate project. Of these, three moved forward once the Center was funded including Stanford University, Washington State Consortium, and University of Texas at El Paso. The other 13 programs were selected through 3 consecutive application cycles. The request for proposals was refined in each successive solicitation in order to both strengthen the quality of applications and to ensure that the final set of programs covered a full range of priority areas. To this end, later solicitations sought programs in progressively narrower bands of focus in order to achieve the desired coverage.

Institutions or groups of institutions could apply for grants of up to $50,000 to support program development to increase the number of students who developed geoscience literacy and would be equipped to bring geosciences to bear in solving societal issues. Proposed projects were required to have leadership teams of at least five faculty members and administrators and outline a plan to use the InTeGrate materials and/or guiding principles to make changes in programs at scales larger than a course.

Proposals were reviewed by a combination of members of the InTeGrate advisory board, InTeGrate leadership team (InTeGrate 2018b), and the leadership of the National Association of Geoscience Teachers (NAGT). NAGT leaders were included in this process to draw from their experience in the NAGT professional development program that helped inform the design of InTeGrate programming (NAGT 2018a). Implementation program proposals were selected for funding based on the likely success of the program, potential to model a new and transferable approach, and ability to support a diversity of institutional settings and a diversity of students.

Proposal Refinement and Assessment Consulting

Because one purpose of the implementation programs was to serve as a model for others interested in making similar changes, the project development process included steps to prompt the teams to both reflect on and document their process of change. They did this with support from the InTeGrate leadership team and using a private website workspace to both coordinate the communication between the leadership team and the implementation program team and keep a written record of events and outcomes through the duration of the project.

An early step in this support structure came between the time a proposed program was selected for funding and when the granting period and work began. Each team was paired with a consultant from the InTeGrate assessment team to guide them through a process of creating a detailed project plan and timeline. The team leads wrote a vision statement or "desired end state" of what would be different in their program or institution at the end of the proposed project. This was used to develop a short set of project goals which were written in a way that they could be assessed with data or evidence the project could produce on a reasonable timeline. The assessment consultant and teams worked together to develop an assessment plan, by which the teams could determine if they were making progress toward their goals. The resulting vision statement, goals, and assessment results are captured on the programs' individual websites (InTeGrate 2018c). These activities were also designed to develop evaluation skills among the teams' leadership and expand the capacity of the InTeGrate community to engage in program evaluation. The assessment consultants worked with the teams over the duration of their projects, revisiting their progress and evidence, and helping them adapt their plans as the projects evolved.

Team Meetings and Webinars

Eight virtual meetings over 2 years, including all leaders across the programs, provided an avenue where experiences and lessons learned coming out of individual programs could be shared across all the programs. The agendas for these meetings included topics relevant to all the leaders, such as the mechanics of recording and publishing their progress and findings, as well as opportunities for leaders to share accomplishments or request input from other leaders. Team leaders were asked to reflect on their experience and relay lessons learned. Topics included strategies for building and maintaining a strong team, bringing new faculty members into the program and keeping their attention, making time for collecting program and student data, and working toward program evaluation. The InTeGrate leadership also presented its emerging vision for publishing and dissemination of implementation program outcomes early in the process so teams could understand and help shape how the eventual products would come together. This provided feedback on what would be useful to someone coming new to the idea of making changes at this scale and also helped the team leads conceptualize what they needed to document about their process for people coming after them in this process.

Building on workshops offered by the Building Strong Geoscience Departments program (NAGT 2018b) and On the Cutting Edge (Manduca et al. 2006), InTeGrate hosted a series of webinars open to a broader audience than just the implementation program leaders to extend understanding the relationship between program offerings and the diverse workforce equipped to address the resource and environmental challenges faced by society. These webinars and the web resources they produced formed a foundation for teams as they developed proposals for implementation programs. As the implementation program matured, new webinars were produced to meet the emerging needs of the team leads. These were offered both as topical programs available to a public audience and virtual meetings private to the teams. The private meetings were designed to encourage discussion and transfer of information across teams and to foster interaction among and between cohorts.

Ongoing, Iterative Information Gathering

As the implementation programs developed, one of our goals was for the project teams to be able to learn from each other and for the individual program evolutions to be documented, so they could become part of the record left for future implementations. In order to achieve that goal, the team leads were asked to provide information on a quarterly basis about progress toward the checkpoints they had laid out for themselves so that (1) the overarching project management understand how the programs were progressing and (2) to allow project management to determine common barriers across the programs and provide additional support or professional development as needed. This information was submitted by the program leaders to the InTeGrate leadership and assessment teams via a web-based form that prompted for progress toward stated goals, any evidence of impact or products from the program, numbers of people and courses involved, and any changes to the program planned activities. The leads also reported on the impact their activities were having on their institution or target program and any specific evidence or data they had that was helping them understand their impact.

The final piece of information the team leads provided was a structured reflection they conducted with their team. The questions prompted teams to consider the progress they had made in the context of the program goals and to consider the successes they had had and barriers they had faced over the period of record. The specific prompts included:

- What strategies have you used to (1) expand the number of faculty in your program and (2) involve program or department leaders and/or deans?
- What aspects of your plan and implementation strategies have been most successful to date?
- What are you finding difficult to accomplish? Were these challenges anticipated or did they come as a surprise to you?
- Fostering change within an institution, and/or across institutions, is difficult work. What are you learning or what new insights have you gained from your experiences?
- Are/how are those insights informing the next steps you plan to take?

Program Descriptions

Each team completed a detailed program description on the web that is designed to help users understand what the programs did and to serve as a guide for future projects. These program descriptions follow a structure that starts with an overview understanding of the approach and then provide increasingly more detailed descriptions of program components and outcomes. The descriptions were intended to provide sufficient information about what was done, the evidence for which practices lead to the intended outcomes, and the unexpected events that a future implementation program could build on what was learned in these programs (InTeGrate 2018c). Each description includes the following sections:

Motivation and context—institution type, history, and synergistic events

Improving programs—activities focused at the program scale and relevant evidence of the impact these activities had

Improving teaching and learning—specific changes made to courses, faculty professional development or instructional approaches, as well as how InTeGrate materials and guiding principles were adapted or adopted for the program

Making change happen—the steps, approaches, or collaborations needed to make changes successful

Advice for future implementations—from team leads to others trying this type of change

The program descriptions serve as 16 visions for how using the InTeGrate materials and guiding principles can lead to programmatic changes over the relatively short time scale of a few years. They serve as concrete examples that this mechanism for change is viable and that it is possible to use this approach in a wide variety of contexts. In many cases, these changes were initiated by small groups of people and are now being sustained after the InTeGrate funding has ended because there is a shared vision at the institution or group of institutions for how the change the implementation program made is aligned with the goals of the group, program, or institutions. For example, the Wittenberg University team of five people (InTeGrate 2018d) used a shared leadership approach while developing programming to embed sustainability programming across their campus (InTeGrate 2018e). Their programming aligned with the university goals and student demand for more sustainability programming, causing their program to be institutionalized after InTeGrate funding ended (InTeGrate 2018f). Similar instances of impactful and sustained programming can be found across the program descriptions (InTeGrate 2018c) and in Part III of this volume (Gosselin et al. this volume-a).

The goal in publishing the program descriptions is not only so that they can serve as a guide for replicating these specific programs in new locations. Ideally they will also serve as a jumping-off point for others who are interested in initiating other changes at this scale who may need an example of how to start and the assurance that it is possible. Each of the program descriptions details not just the program activities but also the impact of those activities, the bigger-picture outcomes of the programs as related to their initial goals, and a description of the evidence supporting the claims that changes have occurred. The types of evidence range widely as they were tailored to program goals and include things like changes in student learning outcomes, changes in faculty attitudes toward teaching about sustainability, the existence and use of faculty learning networks, a record of cross-institutional communication and programming, and sustained institutional support of new programming put in place by the implementation programs (see program descriptions InTeGrate 2018c).

Supporting Website

The implementation programs also made use of both an internal facing and external facing website support structure, similar to the module development process (Egger et al. this volume). Each team had a private, password-protected website that was accessible to the project leads, the InTeGrate leadership, assessment and evaluation teams, but not to the general public. This internal site was used to document the goals, activities, and assessment plan for each team as well as to communicate with the assessment consultant and track project progress. This structure served as an important mechanism for project management, supporting communication between the implementation programs and InTeGrate leadership. Team leaders were asked to update their sites at least quarterly, but because they had direct access to editing their pages, they had the ability to make changes at any time and to use their pages to track their own meetings, workshops, and data collection. Because the program planning, data collection, and reporting was done in a centralized, online location on the content management system (Serckit) developed by the Science Education Resource Center at Carleton College (SERC 2018), the assessment consultants could review and comment on progress and challenges asynchronously and from a distance. This also allowed the leadership team to monitor the status and progress of activities distributed across the 16 programs (Kastens et al. 2014). The website provided structure for organizing project materials and archiving products over several years. This made synthesizing and web publishing of the program descriptions an exercise in editing the materials, reports, and reflections that were collected in the same location.

Each team also had a public-facing, external site, which allowed the programs to describe their project to their potential collaborators, their community, and others at their institution. The public sites are presented together as a set of web pages (InTeGrate 2018c), showcasing how the individual projects were part of the larger InTeGrate center's system approach. Individual program leads were encouraged to update their sites frequently and to highlight their progress and successes.

Outcomes

There are three components of lasting outcomes from the implementation programs: the programs themselves in their settings, the descriptions of the programs on the website, and a cross-program synthesis developed by the programs together.

The Implementation Programs

The 16 implementation programs (Table 1) were engaged in different aspects of improving learning about the Earth at an institution or collection of institutions (Table 2). Each program has provided extensive information about what they were trying to accomplish, what actions they took to do so, the results of those actions, and what they have learned as a consequence. In addition, the faculty involved in the

Table 1 The 16 implementation program teams and how many faculty, students, courses, and institutions were involved in the work of the team

Lead institution	Location	# Faculty	# Students	Courses	Institutions
California State University—Chico	Chico, CA	9	3572	67	1
Claflin University	Orangeburg, SC	11	485	28	1
Grand Valley State University	Allendale, MI	10	480	4	1
Gustavus Adolphus College	St. Peter, MN	25	501	19	1
Mercer University	Atlanta, GA	9	808	50	1
Middle Tennessee State University	Murfreesboro, TN	7	1204	26	1
Pennsylvania State University	University Park, PA	25	2039	70	7
Savannah State University	Savannah, GA	10	665	30	1
Shippensburg University	Shippensburg, PA	8	1774	26	1
Stanford University	Stanford, CA	26	1549	35	9
University of Illinois at Chicago	Chicago, IL	6	3248	30	1
University of Northern Colorado	Greeley, CO	19	519	15	1
University of South Dakota	Vermillion, SD	16	2131	76	1
University of Texas El Paso	El Paso, TX	44	7579	155	2
Washington State Consortium	Statewide, WA	93	0	0	39[a]
Wittenberg University	Springfield, OH	33	1258	53	2

[a]Beyond the 39 educational institutions, additional 22 organizations or companies were involved in the work of the Washington State Consortium team

Table 2 The 16 implementation program teams and the main goals of the programs

Lead institution	Inter-disc[a]	Broadening participation[b]	Liberal arts[c]	Inst. without geology program[d]	K-12[e]	Non-geology majors[f]	Workforce prep[g]
California State University—Chico	x	x		x		x	
Claflin University		x		x		x	x
Grand Valley State University		x		x	x	x	
Gustavus Adolphus College	x		x			x	
Mercer University		x		x	x	x	
Middle Tennessee State University		x				x	
Pennsylvania State University	x			x		x	
Savannah State University		x		x		x	x
Shippensburg University						x	x
Stanford University		x		x		x	
University of Illinois at Chicago		x					x
University of Northern Colorado		x					
University of South Dakota	x					x	
University of Texas El Paso		x					
Washington State Consortium					x		
Wittenberg University	x		x			x	

[a]Interdisciplinary—programs, majors, or certificate programs with a strong geoscience component designed to prepare students for careers addressing challenges of sustainability
[b]Broadening participation—programs that increase the enrollment and graduation of students from groups underrepresented in the geosciences
[c]Liberal arts—programs that broaden access to science by introducing geoscience across the liberal arts curriculum

(continued)

Table 2 (continued)

[d]Institution without geology program—inter-institutional programs that bring geoscience into courses at institutions without geoscience faculty
[e]K-12—programs that strengthen the role of geoscience in the preparation and professional development of K-12 teachers
[f]Non-geology majors—programs that introduce or strengthen the role of geoscience in the preparation of STEM majors outside of the geosciences
[g]Workforce preparation—programs that facilitate the transition from college or university to the workforce

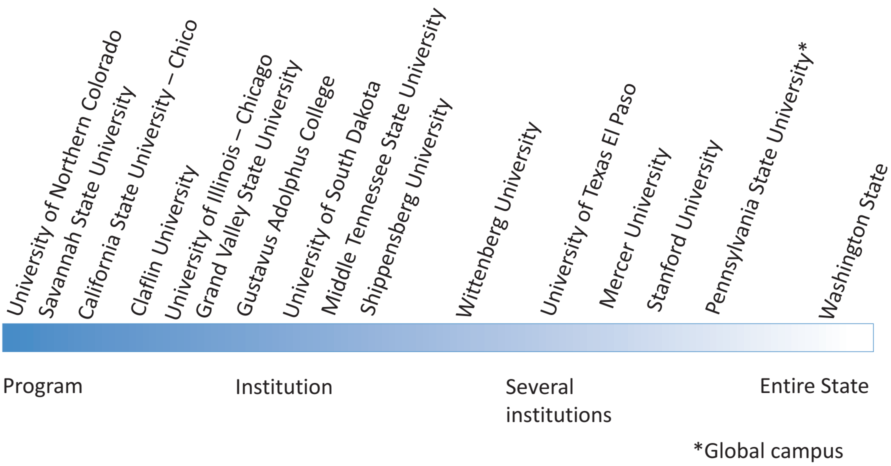


Fig. 2 Scale of project reach. The implementation programs ranged in scale from involving several courses within a single degree program or curricular pathway all the way to influencing institutional programming statewide, as was the case with the Washington State teacher preparation program

efforts have provided advice and guidance for anyone wishing to begin similar work on their own campuses as well as reflections about their experiences.

The programs worked across a range of scales bigger than a course (Fig. 2). These ranged widely from material additions to courses in an existing sequence (Savannah State University, University of Northern Colorado), to developing new pathways through an existing curriculum (California State University—Chico), and to development of completely new curriculum (Penn State University). There were several programs that brought together faculty from multiple disciplines across campus around a common interest (Gustavus Adolphus College, University of South Dakota, Middle Tennessee State University). Another approach is to make connections between institutions (Stanford University, University of Texas El Paso) or between the institution outreach and community partners (Wittenberg University, University of Illinois—Chicago, Mercer University, Shippensburg

University) to facilitate new opportunities for students moving between these spheres. The Washington State consortium is unique in that it focused on bringing together educators around issues of teacher preparation to influence teaching at the scale of the entire state.

Increased Reach of InTeGrate Materials

Of the 1113 unique instructors teaching with InTeGrate materials, 189 are at institutions with implementation programs and 258 are known to be directly involved in the programs themselves. That translates into the inclusion of InTeGrate materials in some 700 courses reaching more than 28,000 students to date. So these 16 institutions (about 1.5% of the total involved) are responsible for about 23% of the faculty involved in teaching InTeGrate materials, about a quarter of the courses influenced, and more than a quarter of the students reached for the project as a whole.

Implementation program leaders have also taken a large role in the public professional development webinar series that InTeGrate has run since the spring of 2015. Beginning in February 2016, presentations on implementation program activities and lessons learned have been included in 11 webinars which directly reached over 450 participants.

Importance of Vision

This stage of project refinement and assessment consulting moved the project leadership teams to having clear and compelling model for change. Having a clear vision that is appropriate for the culture of the institution and can be adapted to multiple audiences is critical to achieving institutional change (Ramaley 2002). At the stage of being accepted as an implementation program, each of the proposals had a clear statement of the challenge they were hoping to address with their project. They also clearly outlined the approach they would take and set of staged activities and a timeline for carrying out the activities. Less clear in many of the proposals was a vision that described how the program (institution, group, etc.) would be different at the end of the projects. Also not robustly described was how the team leaders or the InTeGrate community would understand what impact the implementation program would have. Specifically, more detail was needed on what evidence would be available at the end of the program to demonstrate if and how the program met each of its stated goals.

Working with the assessment consultants, before program activities were begun, meant each leadership team had a vision statement that articulated what changes could exist at the end of their program. This vision was shared among the program team and was used as a communication tool when bringing new people into the program and building new partnerships. For example, in the Stanford Implementation program (Bellamy et al. this volume), the vision was used to build partnerships with local 2-year institutions and allow joint programming. The CSU-Chico vision was articulated as building a model for a suite of possible curricular pathways at their institution. Their vision informed how they structured the faculty professional development and curriculum activities that were part of the implementation program development and ongoing programming, as well as communication with administration as they worked to institutionalize the program (Teasdale et al. this volume).

Synthesis Across Approaches

The implementation programs were all engaged in using InTeGrate materials and structures to address different combinations of local problems and issues. Given the nature of the proposal selection process, it was not surprising that there were several areas issues of interest to multiple teams. Also due to the proposal selection process, the approaches the programs took in addressing these problems were creative and different from each other. To understand where there were overarching lessons that could be learned across programs, the team leaders worked together to synthesize what they learned and document that information for a broader audience.

To achieve the synthesis (Table 3), InTeGrate brought representatives from the teams together for a face-to-face meeting in December 2016 to learn from each other and document their experiences relating to a set of crosscutting topics. The process of constructing the synthesis was an adaptation of one piloted by SERC with the Supporting STEM Success in a Liberal Arts Context project (see Dibartolo et al. (2016) and the project website (HHMI Capstone Institutions 2018) for more information).

Common topics emerged out of discussions among project leaders (Table 3). There were overlaps in the goals of the programs and that represented places where a critical mass of teams had experience to contribute. The resulting list included:

- Attracting and supporting diverse learners
- Teaching Earth across the curriculum
- Building connections to strengthen K-12 teaching
- Supporting transitions to the workforce, transfer, and careers

In addition, all teams took part in sharing their experiences related to making change happen on the large scale.

Documenting this high-level information was the first task of the groups during the meeting. The groups worked inside of a private workspace to lay out everything

Table 3 The suite of web pages resulting from the synthesis process in 2016 (InTeGrate 2018g)

Attract and support diverse learners
Demonstrate cultural relevance
Generate community involvement
Collaborate with other institutions
Teach Earth across the curriculum
Build interdisciplinary networks
Develop interdisciplinary curricula
Foster institutional change
Engage students in active learning
Build connections to strengthen K-12 teaching
Use Earth science topics as themes
Collaborate broadly and deeply
Plan at scale
Support transitions to workforce, transfer, and careers
Support transition at the course level
Support transitions at the program or departmental level
Support transitions beyond the institutional level
Make change happen
Design to maximize impact
Support implementation of change
Sustain change and scale up
Connect Earth and societal issues

they had learned in their reading each other's program descriptions as well as new information that arose during their conversation. With this skeleton in place, the whole group of participants was able to review, comment on, and offer refinements to the themes identified by each group as well as provide additional examples from their own work. This process recognized that everyone present had expertise in multiple areas and allowed them to contribute to the development of the synthesis outside their primary focus area. The groups used the feedback to refine their themes into directive statements (e.g., Demonstrate Cultural Relevance or Develop Interdisciplinary Curricula) and then fleshed out guidance based on their collective experience. It was important that this guidance be rooted in the information and materials documented on their program descriptions as this provided "ground truth" for their recommendations.

The set of public web pages that resulted from this process of collective writing and review complements the program descriptions (Table 3). The pages were co-written by the leaders of the implementation programs and organize lessons learned by the teams about making change happen across five broad areas. The pages give concrete guidance about what worked in each area and are underpinned by examples from the teams' work published in their program descriptions. The descriptions document the vertical integration of each program's activities and assessment in service to a specific set of goals. The synthesis pages allow a horizontal look at these particular topics across the whole collection with links to specific parts of the program descriptions that support the synthesis. Together with the 16 unique program models, the synthetic material can help make these change initiatives possible in a wider array of contexts.

Example Synthesis Topic: Attract and Support Diverse Learners

At the level of whole departments or programs, a recurring challenge is to attract and support diverse learners in Earth-related fields. A methodical effort to synthesize lessons learned across the implementation programs found recurring approaches to this challenge used by multiple teams across widely different institutional contexts. Two widely used approaches are "Demonstrate Cultural Relevance" and "Generate Community Involvement."

Demonstrate Cultural Relevance (InTeGrate 2018h)

Engaging student interest is a crucial step in improving learning outcomes (Freeman et al. 2014). Showing how geoscience and sustainability are relevant to students' lives and things they care about are key ways of doing that. Looking at important local issues, examining how socioeconomic differences affect environmental challenges and outcomes, and ensuring that faculty make use of good active learning teaching methods can go a long way to hooking student interest.

Examples:

University of South Dakota (Utilize Local Context)

Listen to community voices: At USD (Missouri River project) students were able to hear from NICC students and Santee Sioux elders about the impact of the dams on their land.

Claflin University (Explore the Impacts of Socioeconomic Differences)

At Claflin University, the InTeGrate-infused courses used the catastrophic flash floods striking South Carolina in 2015 as a comparison to the Katrina example provided by the "Map Your Hazards" module. The political environment dealing with the extreme weather event was pointed out in both cases along with the outcomes (positive and negative). Students could also learn how diverse populations deal with catastrophes.

Generate Community Involvement (InTeGrate 2018i)

Student learning benefits from connections to the community in which they live (see NAS 2017). Activities like service learning, field trips, and connections with local businesses and agencies who may hire them one day are important parts of generating and strengthening those connections.

Examples:

University of Illinois—Chicago (Involve Local Industry and Government)

The UIC team worked with students in cocurricular activities to make connections to the workforce. These activities featured interviews with diverse alumni (gender, ethnicity/nationality, discipline, etc.) still residing in the Chicago area as a way of connecting students with people from similar backgrounds who are engaged in local industries.

Savannah State University (Employ Service Learning)

The Savannah implementation team, in conjunction with students, developed a series of service learning project options that can be engaged through classes, clubs, and other events/activities. Additionally, by maintaining a journal of the projects completed and who was involved, future activities can be shaped using lessons learned, and as projects are completed, the running roster of participants will be easier to acknowledge.

Guidance for Making Change Happen

The topic of how to instigate and sustain change at the program scale or larger ran through multiple threads of the implementation programs. Each of the 16 programs was working to do this in their individual context. The team leads were asked to reflect and write about what the critical elements were in making the changes they were successful in for their program, and this is an important section in each of the program descriptions. Making change happen became one of the five main topics of the synthesis exercise. The implementation programs are an integral component of the overall InTeGrate system for promoting change for a sustainable future. The lessons learned from the implementation programs about making this type of institutional change toward the guiding principles of InTeGrate comes less from the academic study of institutional change than from the experience of the teams on the ground working to make these changes. In their synthesis, the teams felt the following components were most important to understand about their experiences:

1. Change plays out differently at different institutions and for different programs and courses. To be able to adapt InTeGrate models, resources, and tools to support a desired change in a particular context, change agents need to understand the current institutional culture, program context, and existing resources and

then identify factors that are likely to support or inhibit change. It is particularly effective to align the desired change with existing institutional goals and to situate a new project in such a way that it enhances rather than competes with other efforts on campus. In this way the project can become part of a larger body of work engaging faculty, staff, and administration. The synthesis includes examples of how the implementation programs each considered their own context when planning for change (InTeGrate 2018j).

2. An involved leadership team that can monitor progress toward meeting jointly developed and well-articulated goals. A leadership team can also bring together leaders from multiple disciplines or networks to extend the reach of the project. Thus, identifying a small, core leadership team that shares a common vision for the project and its rationale is a strong initial step. Building a community of practice (InTeGrate 2018k) and also providing opportunities for new people to become involved and increase their own capacity (InTeGrate 2018l) were both identified by the implementation program leaders and strategies for creating and sustaining leadership.
3. The design of a change effort will affect how things roll out. Understanding how a particular problem plays out in a particular context, the initial change strategy, and establishing a method to make course corrections when necessary are necessary pieces of a successful design. Developing a beginning strategy that includes a common vision among the people involved in change activities and also having a clear plan for changing that strategy in response to new information or early results were discussed as important to longer-term change (InTeGrate 2018j).
4. Simply setting things in motion will not achieve the outcomes you want for the work. The implementation teams found that regular evaluation of their progress toward stated goals caused them to change their programming as they learned more about what was working or as new opportunities emerged (InTeGrate 2018l). They also emphasized the importance of communicating mid-program progress and new ideas to the program participants (InTeGrate 2018k). Maintaining lines of communication and developing a community of practice among the people involved in the change effort can help sustain the program through to success.
5. Maintaining momentum and institutionalizing changes to continue after an initiating project has run its course is often a challenge. Having a way to continually adjust course in response to data, building capacity among faculty and staff, and thinking about how to have a wider impact through scaling up the work can help institutionalize a program to live on (InTeGrate 2018l).

Conclusions

The InTeGrate Implementation programs were intentionally selected to represent a broad diversity of approaches, contexts, and goals. This programmatic diversity makes it difficult to compare their impact or relative success, but the goal of the program was to provide a range of possible, novel models. The diverse efforts provide an array of strategies and insights into necessary elements for changing programming for undergraduate learning about Earth. And they share the common attribute of using InTeGrate materials and guiding principles to achieve their goals. InTeGrate's focus on geoscience in service to societal issues has left its imprint on the work of the implementation programs. It has provided motivation, a unifying focus, and a lever to use in moving the needle on institutional change.

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Measuring Literacy, Attitudes, and Capacities to Solve Societal Problems

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Abstract Effective assessments offer more than just a measurement of learning. When sequenced and aligned to evidence-based curriculum, assessments can facilitate learning and inform instruction. The Interdisciplinary Teaching about Earth for a Sustainable Future (InTeGrate) project viewed assessment as a core strategy of the curriculum being developed. InTeGrate used a community-based approach to assessment. An assessment team engaged with materials development teams to facilitate module and course assessment design, developed common instruments to assess student learning, analyzed student data from pilot tests to inform curriculum revisions, and used the findings to fine-tune assessment instruments and to shed light on opportunities for faculty development within the geoscience education community. The community approach ensured high-quality curricula and assessments and strategies to investigate learning at the module, course, and project level. Perhaps more importantly, the approach increased the capacity of the geoscience education community by harnessing the expertise from within the community to promote a culture of evaluative thinking.

Keywords Assessment · Science literacy · Developmental evaluation · Summative assessment

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Introduction

Effective assessments define and measure student success and, when well-aligned to curriculum, can yield new insights about student learning experiences (Wiggins and McTighe 1998). To produce a citizenry equipped with the skills needed to address the grand challenges of the future, such learning experiences must increase student abilities in interdisciplinary problem-solving and include instruction that draws on multiple disciplinary modes of thinking and knowledge from the natural sciences, social sciences, and humanities (described in this volume in Gosselin et al. this volume and Egger et al. this volume). The goal of these learning experiences is to promote students' enduring understanding of problems or phenomena that are difficult to investigate through a single disciplinary lens (Boix Mansilla and Duraising 2007). To evaluate student learning involving multiple perspectives and interdisciplinary modes of thinking, assessments should evaluate both the quality of a students' understanding and how meaning is constructed from curricula (Novak et al. 2000; Wiggins and McTighe 1998). Such assessments examine student learning with the understanding that "knowledge has *organization* and potential for *application* in problem solving" (Novak et al. 2000, p. 9), illuminating how students think and apply their knowledge in ways that recognize interdisciplinary ways of knowing. They evaluate how students demonstrate scientific habits and use data and systems thinking to address grand challenges.

Understanding what knowledge is gained through these interdisciplinary learning experiences is one productive assessment strategy. The Program for International Student Assessment (PISA) defines *science literacy* as the ability to engage in science-related issues or ideas as a reflective citizen (PISA 2015). Science literacy is essential for equipping students to make sense of the natural world, making connections across scientific disciplines, and applying critical thinking to solve grand interdisciplinary problems (National Academies of Sciences, Engineering, and Medicine 2016; AAAS 1993, 2011). Earth system literacies can provide an accessible means for students to integrate science with societal issues (LaDue and Clark 2012). Indeed, addressing societal challenges related to sustainability, climate, and resource scarcity may depend on a workforce and citizenry prepared to use Earth systems literacies for problem-solving and decision-making (Wysession et al. 2012).

To design and develop assessments that evaluate interdisciplinary learning and Earth system literacy, we took an approach that draws on multiple perspectives and uses data to inform design decisions. A developmental evaluation approach provides a means of iteratively improving assessments and being open to understanding new patterns related to student learning, so that the thinking about assessment is as much about the learning process and the context for using assessments as the actual outcomes from such measures (Patton 2010). In contrast, multi-site, large-scale assessments have typically used a centralized, top-down approach as implemented by institutional assessment offices and national testing organizations. Building on the success of other community-based faculty geoscience education and assessment efforts (Manduca et al. 2017; Rockman 2013), the InTeGrate project took a community of practice approach to developing and implementing assessment strategies across the project. The community approach used developmental evaluation strategies and allowed an efficient division of labor. It allowed the project to develop student learning measurements and simultaneously ensure quality control of curricula (see Steer et al. this volume). Additionally and with a potentially longer lasting impact, it increased the capacity of the collective geoscience education community to contribute to change through co-constructed products (Kastens and Manduca 2018) and helped to spread a culture of evaluation (Janzen et al. 2017; Labin et al. 2012) throughout the geoscience education community.

The InTeGrate project developed and used assessments to evaluate impacts on both student and faculty. This paper focuses on the student assessments and describes the community process in four sections: the community process used to identify, develop, implement, and analyze assessments; the process development, history, and evolution for each of the type of student assessment; how the assessments were implemented, the community process for analysis, and how analyses informed curricular revisions and overall project assessment; and the lessons learned through the process and future implications.

Community Process for Assessment

From the onset of the InTeGrate project, a team approach was envisioned for assessment. By design, the assessment team included leaders in geoscience higher education with a range of assessment expertise in instrument design, analysis methods, and research in geoscience education curriculum. The assessment team was responsible for assessing the quality of InTeGrate materials and developing project-wide student assessment measures.

To facilitate the assessment of the quality of the materials, each assessment consultant was assigned to a specific materials development team. In this role, they acted as gatekeepers to ensure materials developers met the written standards upon which the community had come to agree (see Steer et al. this volume for a description of these standards). To streamline this process, the assessment consultant provided feedback at regular intervals to their assigned team. A community checkpoint process and the use of 28-criteria from the materials development rubric guided these communications and set milestones. Assessment team members conducted a formal audit of the curriculum prior to the materials being tested in materials development team members' classrooms (as described in this volume in Steer et al. this volume).

To develop project-wide student learning assessment measures, the assessment team worked with materials developers to determine what student measures were needed, when such measures would be collected, and how the data from these measures would inform material revision and overall project evaluation. The two aspects of the assessment team work ensured high-quality curriculum and student learning measures that aligned to the overall project.

Assessment Team Formation and Community Norms

Like the InTeGrate materials development teams and the implementation programs (described in this volume in Egger et al. this volume and Orr and McDaris this volume), assessment team members were solicited by invitation and through an open call. The assessment team included geoscience educators at different career stages from pre-tenured faculty to those nearing retirement, and representing different institutional settings, including 2-year, 4-year, master's-granting, and PhD-granting institutions. The ten-person assessment team and its two team leaders (Iverson and Steer) consulted and collaborated with the external evaluation team. The external evaluation team included a geoscientist who was independent of the project (Kastens) and a professional evaluation group with expertise in science education programs. The external evaluation team attended to the full suite of project objectives, with a particular focus on gauging students' attitudes, behaviors, and motivations around environmental issues and Earth-related careers (InTeGrate 2018a). The external evaluation team collaborated with the assessment team on the design of project-wide assessments and project-wide analyses.

From its early inception, the assessment team members established a shared vision for their role, routine communication channels, and milestones for measuring progress. Assessment team communications were facilitated through face-to-face meetings, virtual team meetings, and ongoing electronic communications supported by the Serckit content management system (SERC 2017). Annual face-to-face meetings were co-located with and capitalized on materials development team meetings. In this way, each assessment consultant established a working relationship with new materials development team members early in the materials development process (see Fig. 1 in Egger et al. this volume). After materials developers had conducted classroom pilots of their materials, they held a post-implementation meeting, which overlapped with an assessment team meeting. This allowed assessment team members to provide feedback based on student data analyses to those teams through face-to-face dialogue. Between meetings, assessment team communication was sustained through an email list, and virtual meetings with an enduring record of communications maintained on the email list archives and internal workspace pages on the Serckit system.

To establish a common approach for building collaborative relationships, the assessment team documented the strategies that would be used during their first team meeting. Email lists ensured that all materials development team members received timely feedback. Additionally, checkpoint reviews were documented on Serckit web pages that were accessible to the given team. Prior to the development of the full materials development rubric, the assessment team instituted norms for providing feedback. Those norms specified that feedback to materials development

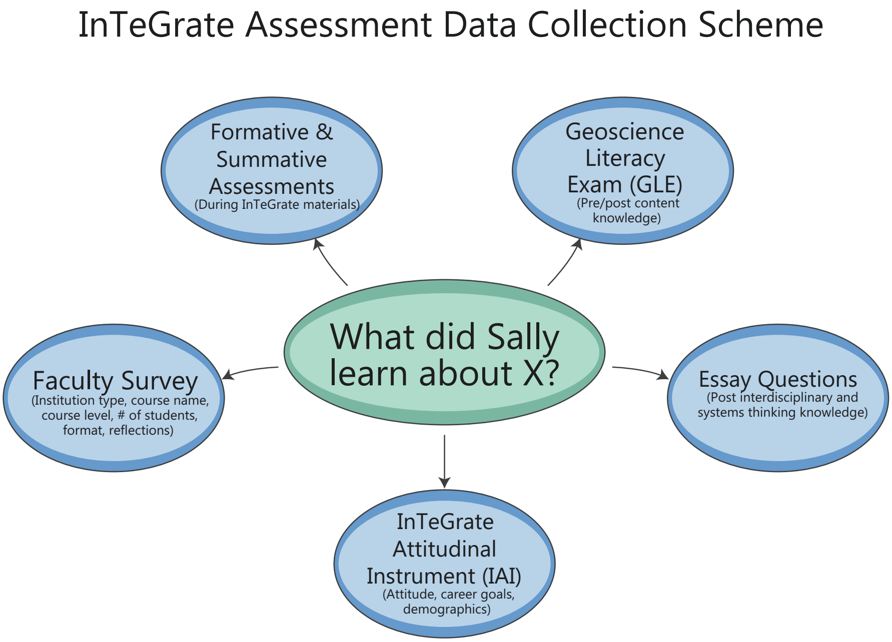

Fig. 1 InTeGrate assessment data collection scheme (from InTeGrate 2018a). The initial schema also included a student engagement measure (e.g., attendance, classroom participation, and so on) supplied by the field tester

teams would be constructive, specific, and linked to curricular materials, measurable so that implementation of feedback would be visible, and sensitive and balanced by highlighting both strengths and weaknesses. These norms were encoded through the checkpoint and rubric documentation (InTeGrate 2012b).

The shared understanding about their role and the agreed-upon processes and communication channels underpinned a cohesive team. Over the course of the 5 years of assessment work, 15 geoscience educators participated as assessment team members. The collaborative nature of the team helped sustain active participation of its members. Eight of the original assessment team members participated for all 5 years. Comments reported by assessment team members as part of the evaluation of the first face-to-face meeting were indicative of the establishment of a productive community of practice. As one assessment consultant summed up the experience, "… great, productive meeting. I haven't had this much 'work' fun in a long time." Another assessment consultant valued the pre-team meeting organization and who was on board to participate, "The number and type of tasks we had to do were reasonable…. Presence of all the SERC people and a bunch of fabulous materials developers and assessment people was also great. This bodes well for the success of the whole project."

Like the materials development team members, the assessment team members received a stipend for their efforts. Each assessment team member documented their individual contributions and participation in the project through internal workspace pages. For their contributions, assessment team members received up to $5000 per year.

Schema of Measures

Our two-pronged approach to assessing InTeGrate materials involved (1) the materials development rubric and community checkpoint process (discussed in this volume in Egger et al. this volume and Steer et al. this volume) and (2) identifying and developing methods for assessing student work related to the materials. The materials development rubric and checkpoints were developed prior to the formation of the assessment team through a collaborative effort involving the InTeGrate assessment team leads, the external evaluation team, and the InTeGrate leadership team. A schema of methods for assessing student work was designed in order to provide a set of data which would yield a thorough picture of InTeGrate learning for students enrolled in a course enactment (Fig. 1). The schema was reviewed, revised, and vetted by the entire assessment team at the first face-to-face meeting. As documented in meeting notes early in the project, both the leadership group and the assessment team reported a desire for the schema and methods to be evaluated after the first year. For example, following the first materials development team's field testing, the methods by which student learning was assessed were adjusted. This developmental evaluation approach (Patton 2010) was thought to be particularly suited to the innovative nature of the InTeGrate project, the desire to be responsive to field testing, and the need for the assessment to surface critical issues early in the project.

The assessment team developed the common project assessments (Table 1) for this schema while also supporting the initial materials development teams through the newly designed community checkpoint process (InTeGrate 2012b). Thus, all of the instruments evolved to varying degrees after the first year of student data collection (described below). The student engagement measure was the only measurement from the initial schema that was removed as a requirement for later materials development teams, in part, because the measures provided by faculty (primarily attendance) were not consistent across materials and failed to demonstrate any discrimination related to learning.

Geoscience Literacy Exam (GLE)

The Geoscience Literacy Exam (GLE) was developed as a pre- and post-course measure to test students' knowledge gains related to the geoscience literacies (Wysession et al. 2009; U.S. Global Change Research Program 2009; NOAA, National Geographic Society, COSEE, National Marine Educators Association

Table 1 InTeGrate common project assessments

Assessment	Format and use	Type of insights yielded
InTeGrate Attitudinal Instrument (IAI)	• Pre- and post-course attitudinal survey given to all students • Used as a project-wide measure to characterize shifts in student attitudes in courses that use InTeGrate materials	• Characterize learning by different student populations through student demographic data • Differentiate pre- and post-course perceptions about career goals and attitudes and motivations to take action related to InTeGrate's sustainability goals
Geoscience Literacy Exam (GLE common-8)	• Multiple choice pre- and post-course assessment given to all students • Used as a project-wide measure to assess shifts in learning for students in courses with InTeGrate materials vs. courses where no InTeGrate materials are used	• Identify changes in pre- and post-course knowledge related to geoscience literacies • Pre-course knowledge used as a project-wide measure to characterize student baseline knowledge between comparison groups (such as InTeGrate vs. no InTeGrate courses)
Module/course formative and summative assessments	• Formats unique to each module/course- include essays, concept maps, presentations, etc. • Used by assessment team to evaluate student learning within the course related to specific InTeGrate guiding principles	• Gauge achievement within the course related to the specific InTeGrate module or course learning objectives and goals
Essay questions	• Short post-course only essays given to all students • Used as a project-wide measure to evaluate student ability related to these two guiding principles for courses with InTeGrate materials vs. courses where no InTeGrate materials are used	• Evaluate student ability post-course related to two of the project guiding principles: interdisciplinary problem-solving and systems thinking
Faculty surveys[a]	• Reflection prompts for faculty • Used for all faculty pilot tests	• Identify context of course enactments (e.g., institutional type, enrollment, course title) • Differentiate faculty perceptions about InTeGrate materials development processes and organization • Describe use and advice related to InTeGrate materials within a course design • Evaluate influence of materials on professional practice • Gauge continued use of materials

[a]See InTeGrate (2018c) for more details on faculty surveys

2005; Johnson et al. 2009). GLE was designed to measure a given geoscience foundational concept at increasingly deeper cognitive domains (e.g., recall, comprehend, apply). This exam was envisioned to serve the dual purpose of a project-wide measure to test the impact of InTeGrate materials on students' foundational geoscience knowledge, while also serving as a potential vehicle for program assessment and curricular reform within a geoscience department.

Basis for Exam

The design of the GLE was built upon the prior work of the On the Cutting Edge Embedded Assessment project (On the Cutting Edge 2016). As part of the On the Cutting Edge project, a team of faculty worked to develop a set of questions that could be used to assess geoscience students' progress of learning throughout a geoscience major. This framework expanded upon previous efforts of the published Geoscience Concept Inventory (GCI), which focuses on assessing knowledge gains in entry-level geoscience courses (Libarkin and Anderson 2005). The Cutting Edge approach contrasted with the design of GLE in that it required questions that would cover introductory and upper-level topics. The Cutting Edge assessment questions were written to probe students' deeper understanding of key concepts and aspects of geoscience reasoning identified by the Cutting Edge researcher team (Viskupic et al. 2014). The Cutting Edge questions were also informed by the atmospheric, climate, Earth, and ocean science literacy documents (Wysession et al. 2009; U.S. Global Change Research Program 2009; NOAA, National Geographic Society, COSEE, National Marine Educators Association 2005; Johnson et al. 2009).

The questions in the GLE instrument align directly with each of the foundational concepts, or "big ideas," presented in the atmospheric, climate, Earth, and ocean science literacy documents (Wysession et al. 2009; U.S. Global Change Research Program 2009; NOAA, National Geographic Society, COSEE, National Marine Educators Association 2005; Johnson et al. 2009). The literacy documents were written collaboratively with input from hundreds of federal agency scientists, science educators, and representatives from nongovernmental science organizations. As a result of the community process, these documents represent a comprehensive compilation of the key ideas needed to develop a well-informed citizen in each field. These literacy documents are beginning to have impact on student learning priorities, including influencing the development of the Next Generation Science Standards for K-12 science education (Wysession 2012). Leaders of the InTeGrate assessment team recognized that a standardized exam aligned with these literacies would have multiple potential uses beyond understanding the role of InTeGrate materials on student learning, such as its potential use as a tool to address reform across the curriculum. This stance influenced the structure of the GLE, where each literacy "big idea" is encoded within the GLE questions. The full exam includes 60 multiple-choice questions and 30 essay questions (InTeGrate 2018d).

Table 2 GLE format, scoring totals, and Bloom's level scheme

	GLE standardized questioning scheme		
	Question type	Scoring total	Bloom's level
Level 1	Single-select multiple choice	1 point	Low (understanding and application)
Level 2	"Select all that apply" multi-select multiple choice	2 points	Moderate (understanding to analyzing)
Level 3	Short essay/constructed response with rubric	3 points	Upper (analyzing to evaluating)

Role of Bloom's Taxonomy

The GLE probes each of the literacy "big ideas" by organizing the exam items in sets of three questions (two multiple choice plus an essay prompt) that increase from lower to higher Bloom's taxonomy levels (Table 2, InTeGrate 2018d). The full exam includes 30 of these sets and builds on the structure of the Cutting Edge questions, which includes sets of four questions of increasing Bloom's levels.

When the set of three questions is used together, it is intended to measure student understanding of a concept from a basic to a more advanced level. The assessment team noted that using level 3 questions on their own might limit an instructor from understanding where a student had gone astray; while the questions are each standalone, there are benefits to using them as a set.

Community Development of Questions

The first draft of the GLE was written by one of the InTeGrate assessment team leads and leadership team members, David Steer, prior to the formation of the assessment team. In this draft, the question design was guided by aspects of other existing literacy exams that included single-select multiple choice items, multi-select multiple choice items, and more involved open/constructed-response items. One example is the Program for International Student Assessment (PISA) test, which aims to measure students' scientific literacy through students' ability to identify scientific issues, explain phenomena scientifically, and use scientific evidence. The PISA includes these three different question formats (Bybee et al. 2009). This tiered format enables measurement of different ability levels as well as longitudinal gains, making it useful in introductory and upper-level courses, as well as a pre- and post-course measure.

The initial draft of the GLE went through its first round of face validity when reviewed and subsequently revised by the InTeGrate assessment team during their first meeting in May 2012 (InTeGrate 2012a). The revisions were guided by the materials development rubric, which encodes the InTeGrate guiding principles, learning outcomes, assessment and measurement, active learning pedagogies, and alignment (Steer et al. 2013; Steer et al. this volume). Questions were then reviewed by content experts in each of the four areas which led to further revisions before the first field tests occurred (InTeGrate 2012a).

Community Testing of Questions

Once the initial set of GLE questions had passed the community and content expert review process, the assessment team used a community approach to field test the questions. The goal was to identify a smaller, common set of questions from the GLE to use in classroom pilots across any course enactments using InTeGrate materials. The initial 2012 materials development teams voted on which GLE questions to use based upon which questions aligned most closely with the InTeGrate project level goals and which questions they could imagine asking in their diverse class settings. The resulting set included eight level 1 and level 2 multiple-choice questions across the four literacy documents. These questions were administered as pre- and post-course measures for each InTeGrate materials developer course enactment. This set of questions is referred to as the GLE common-8 (Table 1, Appendix). To provide a comparison set of student data, a set of student responses was collected in courses where InTeGrate materials were not used. Student data from these control course enactments were contributed from project leadership and other recruited instructors who were not teaching with InTeGrate materials. Initial analysis of the student responses from GLE included a review of the multiple choice responses using standard test theory protocols (InTeGrate 2018d). Think-aloud interviews with students were not conducted and that limitation could be addressed in future studies.

InTeGrate Attitudinal Instrument (IAI)

The InTeGrate Attitudinal Instrument was developed as a project-wide assessment aimed at measuring shifts in students' perceptions in two domains: (1) students' interest in careers and college majors related to Earth and the environment and (2) students' level of concern about and motivation toward solving environmental problems (InTeGrate 2018f). This instrument serves a secondary purpose as a means to collect demographic information about students enrolled in InTeGrate-related courses (e.g., courses using InTeGrate materials, InTeGrate assessments, or inspired by InTeGrate in some way). The IAI includes a pre- and post-course survey.

The development of the IAI instrument capitalized on both the expertise of InTeGrate community members and knowledge from the broader geoscience community. The items for the IAI were developed through a process of selecting, vetting, and testing items by the external evaluation team in collaboration with the InTeGrate leadership team and involved a subcommittee of the assessment team (InTeGrate 2018f). The evaluation team adapted question items related to college professional lives to create a more environmentally sustainable society," and how they envision using what they learned in the course to overcome environmental grand challenges (Table 3).

InTeGrate Essay Assessments

As part of the early development of the InTeGrate program, project leadership deliberated over how to best demonstrate students' ability to use geoscience knowledge and skills to address societal problems relating to sustainability and environmental issues. Essay-type questions with explicit rubrics were viewed as a strong assessment strategy. As an assessment strategy, student writing can show how students reflect on their new knowledge, construct meaning from curricula, and

Table 3 InTeGrate attitudinal instrument pre and post-instruction items

	Comparison of IAI pre- and post-instruction forms	
	Pre-instruction	Post-instruction
	1. What was your reason for taking this course? [list]	
Career	2a. Have you chosen a college major yet? 2b. Please indicate whether you have or intend to declare a major in each of the following areas of study [list]	1a. Have you chosen a college major yet? 1b. Please indicate whether you have or intend to declare a major in each of the following areas of study [list]
	3. How interested are you in each of the following professions? [list]	2. How interested are you in each of the following professions? [list]
	4a. As you consider career directions after graduation, how important is it to you to do work in which you use your knowledge of the Earth and environment? [7 point scale] 4b. As you consider employment after graduation, how important is it to you to work in an organization committed to environmentally sustainable practices (independent of the field)? Examples of environmentally sustainable practices would include minimizing energy and water use in the workplace [7 point scale]	3a. As you consider career directions after graduation, how important is it to you to do work in which you use your knowledge of the Earth and environment? [7 point scale] 3b. As you consider employment after graduation, how important is it to you to work in an organization committed to environmentally sustainable practices (independent of the field)? Examples of environmentally sustainable practices would include minimizing energy and water use in the workplace [7 point scale]
		4. Which of the following graphs most accurately depicts your level of interest in a career in earth or environmental sciences before and after taking this course or studying this module? [4 graphs]

(continued)

Table 3 (continued)

	Comparison of IAI pre- and post-instruction forms	
	Pre-instruction	Post-instruction
Environment	5. Please indicate your level of concern about each of the following potential developments on Earth. Focus on the impact on your region in your lifetime [list]	5. Please indicate your level of concern about each of the following potential developments on Earth. Focus on the impact on your region in your lifetime. [list]
	5a. Please indicate the extent to which you engaged in each of the following activities during the past week [list]	6a. Please indicate the extent to which you engaged in each of the following activities during the past week [list] 6b. When you engage in behaviors such as those listed in the previous question, what factors or sources of information influence your decision to do so? [list]
		7. People differ in how motivated they are to take action in their personal and professional lives to create a more environmentally sustainable society. Which of the following graphs best represents your degree of motivation before and after taking this course or studying this module? [4 graphs]
		8. As you think about your future, can you envision using what you have learned in this course to help society overcome problems of environmental degradation, natural resources limitations, or other environmental issues? If yes, how? If not, why not? [open response]
Demographics	• Gender [list] • Ethnicity [list] • Race [list] • Year in college: [list] • Age [open]	

majors from a survey developed for the Opportunities for the Advancement of Diversity in the Geosciences program (Fuhrman n.d.). The list of career aspiration items was adapted from items from both Houlton (2010) and the American Geosciences Institute (2009). For the items related to environmental concerns and motivation, the team considered items from a range of assessment and survey instruments in order to develop a set that aligned with the needs of InTeGrate (see InTeGrate 2018f for a complete list of sources). The set of environmental items probe students' level of concern about various grand challenges and students' self-report of environmentally sustainable behaviors. In addition, the post-survey queries students' reasons for various behaviors, students' perception of their degree of motivation before and after the course "to take action in their personal and connect scientific knowledge to societal problems (Champagne and Kouba 2000). Essay-type questions could provide a means of testing students' deeper learning more effectively than the GLE multiple-choice items.

With advice from the external evaluation team, two constructs were chosen as indicative of students' ability to address societal problems: interdisciplinary problem-solving and systems thinking. These two constructs were considered to be (a) important, (b) teachable, and (c) assessable. The essay questions and IAI were intended to be complementary, with the IAI probing student *motivation* to address societal problems of the Earth, while the essay questions would probe their *ability* to address those same problems.

Problems of environmental sustainability, resources depletion, pollution, and other environmental grand challenges all require interdisciplinary problem-solving. As described elsewhere in this volume (Egger et al. this volume), a primary approach of the InTeGrate project was to support student interdisciplinary learning using an evidence-based approach, and the materials development rubric requires that materials "Develop students' ability to address interdisciplinary problems." Although the InTeGrate materials span a wide range of topics, all have student activities in which evidence and priorities from multiple disciplines must be combined to address real-world problems.

In addition to interdisciplinary problem-solving, the materials development rubric required that InTeGrate materials "foster systems thinking." Kastens, the external evaluator, argued that deploying systems thinking "spans across various types of geoscience content, and that truly would be a meaningful indicator of students' readiness to contribute to issues of sustainability throughout their lives and careers" (InTeGrate leadership communication, 2/13/12).

From the outset of the project, the assessment team used a community approach to gather initial impressions of the usefulness and face validity of the essay questions. Both the interdisciplinary problem-solving essay prompt and the systems thinking essay prompt needed to measure students' understanding from students enrolled in the full range of courses that would use InTeGrate materials (Table 4). These courses could be within geoscience programs or within interdisciplinary courses in a range of fields (engineering, humanities, and social science), and thus the prompt needed to be broadly understandable. Input from materials development teams was sought to ensure that the prompts would have utility outside of traditional geoscience courses.

During their first face-to-face meeting, the assessment team sought input from the materials developers as a first means of community input. Materials development teams were asked to review the GLE level 3 essay questions and identify an essay that would most clearly demonstrate student's geoscience literacy related to their materials content and differentiate between introductory to advanced students. The interdisciplinary problem-solving essay prompt was adapted from one of the essays identified by the first sets of materials development teams (Table 4).

A systems thinking prompt (Table 4) that elicited and differentiated this type of student thinking proved more challenging to develop. Additional insights were sought from participants of the *2012 InTeGrate Systems, Society, Sustainability and*

Table 4 InTeGrate interdisciplinary and systems thinking essay prompts

Question	Rubric (for students and grading)	Purpose
Knowledge of Earth system interactions can influence how people make decisions about global challenges. Identify and describe a global challenge that society will likely face in the next 50 years. Explain how the science related to that challenge informs economic, social, and/or political decision-making related to the global challenge you described	Your answer will be evaluated on the following 4-point scale: • 1pt: Student correctly states and suitably describes a global challenge • 1pt: Student correctly identifies and explains one or more scientific implications related to the problem • 1pt: Student appropriately connects the science to economic, social, and/or political decisions • 1pt: Student response is constructed in a coherent and logical manner	Measure students' ability to solve interdisciplinary problem
A systems thinker can identify a system (a natural system, a human system, a linked human/environment system), understand how that system can be divided into interacting parts, and recognize that changes in one part of the system will affect other parts of the system 1. Give an example of a real-world system and describe its parts 2. Explain how parts of the system interact. Use systems concepts in your explanation (e.g., positive and negative feedbacks, equilibrium, rates, etc.) 3. Using your example system, discuss how an effect in one part of that system can be influenced by multiple causal factors	• 1pt: Student correctly identifies and describes a real-world system including its parts • 1pt: Student correctly describes how a change in one part of the system, in turn, alters other parts of the system • 1pt: Student correctly explains how parts of the system interact using systems concepts such as feedbacks, equilibrium, rates, etc. • 1pt: Student describes how an effect can be influenced by multiple causal factors	Measure students' systems thinking ability

the Geosciences workshop and from other collegial connections identified by InTeGrate advisory board members and leadership team. To study the efficacy of the systems thinking prompt, student data was collected from materials development pilot courses, materials developers who were teaching summer courses, courses where geoscience faculty explicitly taught systems thinking, and just-in-time course opportunities where assessment team members had IRB permission to collect student responses.

A point-based rubric was developed for each essay that was thought to be straightforward for students to understand and for instructors to apply consistently (Table 4). The assessment team analyzed student data from the pilots to ensure that the prompts differentiated student learning and allowed students to demonstrate the full scale of learning across the rubric. The assessment team developed the prompts and accompanying rubrics through an iterative process that used community input and student data to inform revisions. To investigate how the prompts applied across the range of fields, the team used the accompanying rubric to score a purposive sampling of student work. In addition to rubric scores, each student essay response was coded by topical area (e.g., climate change, soils, sea level).

More information about the development, testing, and usage of the essay prompts can be found on the InTeGrate website (InTeGrate 2018b).

Role of Module/Course Assessments

Materials developers were required to include in their curriculum both formative assessments that reveal where students were in their learning during the course of instruction and summative assessments to evaluate student learning against a benchmark. Of the two types, summative assessments were of greater interest at a project level. Summative assessments were intended to be the measure of students' progress toward meeting course or module goals. The materials development rubric identifies *assessment* as one of its six main sections for judging the quality of the materials. Materials developers were required to meet a threshold of 13 of 15 for the five criteria for *assessment* in the materials development rubric (described in this volume in Steer et al. this volume). One of the criteria was that "Assessments are criterion-referenced;" in practice, this meant that the assessment consultant required the developers to include a scoring rubric in the instructors' materials. In addition to these criteria, summative assessments were required to be administered at the end of the course or module and be used by all the materials developers (InTeGrate 2012b).

The first materials development teams were required to submit student work from *embedded assessments* for their pilot courses. These assessments were intended to be part of the flow of the class. The format varied depending on what aligned best with the given module or course and could include homework, quiz or exam questions, or lab or field exercises. Teams were instructed to identify embedded assessments that demonstrated students' summative level of understanding of the module objectives. In reviewing the student work from the embedded assessments of the first pilots, the assessment team determined that it was difficult to detect summative mastery of the overall learning goals for the module because the embedded assessments were aligned with specific objectives but not always with a summative demonstration of module goals. The assessment and leadership team members determined that a summative assessment that demonstrated student learning of the module or course learning goals would be required for future materials development teams.

To ensure that student learning was at the level desired by the project, student work from the summative assessments in pilot courses were evaluated. Materials developers submitted student work from the summative assessments to the InTeGrate project from their courses. As part of the community process, multiple assessment team members independently scored the submitted individual student work sampled across all pilots for the given module or course. The student artifacts were scored on a 4-point scale (0–3) against each of the specific module or course goals. A score of 3 indicated that the student work clearly addressed major elements of the goal, 2 indicated that the student work addressed the goal but lacked one or more major elements related to the goal, 1 indicated that the student work mentions aspect of the goal but is missing multiple key elements, and a 0 indicated that the student work did not appear to address the goal. In addition to scoring the student work, the scorers rated the assessment itself as to what extent it could potentially yield student work that met the particular goal. In this way, the assessment team was able to provide an independent conclusion about student learning for the module. The assessment team members provided feedback to the materials development team about the student work and a judgment as to how effective and sensitive the assessment was at detecting mastery of the stated learning goals of the course or module.

The goals for each module or course were linked to the guiding principles of InTeGrate. Therefore, the summative assessments, which aligned to these goals, demonstrated student mastery associated with the guiding principles. As a secondary check, the assessment team also scored all of the individual student work using the same 4-point scale against the five InTeGrate guiding principles. This secondary scoring served as a safeguard to ensure that student work demonstrated all the guiding principles, albeit to varying degrees. The assessment team used these secondary scores to inform the revision feedback they gave to the materials development teams. Additionally, these data highlighted common areas of curricular deficiency specific to guiding principles (e.g., systems thinking).

Implementation of Measures

To test the success of the materials in effecting student learning and to measure the sensitivity of the project-wide assessments, student assessment data was collected from classroom pilots of InTeGrate materials by materials developers. The independent analyses of data by the assessment team served multiple purposes:

- Analyses were used to make informed decisions regarding the need for revisions for the materials.
- Analyses of IAI, GLE, and InTeGrate essays were used during the iterative process to refine the common project assessments.

- Analyses from the early development teams identified shortcomings that informed professional development for subsequent development teams on topics such as systems thinking and metacognition.
- In later years, the student work analysis contributed to the overall evaluation of the InTeGrate project.

To assess student learning related to InTeGrate materials beyond the students enrolled in materials development team courses, student work was collected from other faculty involved in the InTeGrate project. Implementation programs that adapted InTeGrate-related materials developed their own program assessments which could include collection of student work using the common project assessments (see Orr and McDaris this volume). To have a collection of comparative student work for analysis where InTeGrate materials were not used, faculty interested in piloting the InTeGrate common project assessments without teaching with InTeGrate materials provided an important source of data. Finally, eight faculty formed a research team that collected student work using common project assessments over three consecutive academic terms. First, these faculty collected student work in courses without the use of InTeGrate material and then collected student data when piloting InTeGrate materials for two consecutive terms.

Pilot Data Collection Processes

The materials development team classroom pilot and data collection phase (see Fig. 1 in Egger et al. this volume) was the primary source for student work for the project. Instructors collected pre-course measures (GLE and IAI) at the start of the academic term, administered the summative assessment related to the specific InTeGrate module in conjunction with teaching the InTeGrate materials, and collected the post-course measures (GLE, IAI, systems essay, interdisciplinary essay) in the final weeks of class or as part of a final exam.

As part of the pre-course measures, instructors from materials development teams sought IRB approval at their own institution so they could collect and use student work from the project. Each materials developer determined a student identifier coding strategy to use for their courses as no student names were inputted into the central project database. Students would use these identifiers in place of names on all assessments collected for the project so that instructors could track student completion by student identifier for course grades. In the first week of the course, instructors collected informed consent and administered the eight GLE multiple-choice questions as either a scannable bubble sheet form or using a secure learning management system. Students were also provided a link to the pre-course IAI by the instructor. The pre-course IAI was used to collect all student demographics making it particularly important that all enrolled students completed the survey. The inward-facing data collection tool allowed the instructor to upload a roster of student identifiers. The tool also helped the instructor to monitor the percent complete for the online IAI and identify any students who had not completed the survey.

In addition to the pre-course assessments, instructors submitted ungraded student summative assessments and the post-course assessments. Those artifacts were scanned and uploaded to a common database. In the final week of the course, each instructor also administered the online IAI and the eight GLE multiple-choice questions. The two InTeGrate essay questions (interdisciplinary problem-solving and systems thinking) were also administered at the end of the course as part of a graded assessment. To maintain control of the GLE and essay questions, faculty were asked to administer in a secure environment and to not return questions to students.

Student Data Analyses Processes

As previously stated, the independent analysis of student work by the assessment team was an important source of data for improvement and overall evaluation. A Serckit grading tool was designed as a way for the assessment team to select, view, and score anonymized student data (InTeGrate 2017a). After reviewing and assigning grades to these items, the tools also allowed the assessment team to export spreadsheets of anonymized rows of paired student data by module that included GLE and IAI responses.

Analyses-Informed Module/Course Revisions

Just as the common project assessments were refined in response to data, the community processes for analyzing student work and providing feedback evolved over the course of the project. In order to provide feedback to the materials development teams about the student work, the team at first used the module/course-specific rubrics as a primary means of scoring and providing feedback. For the pilots of the first materials development teams, the assessment team scored samples of *embedded assessments* for each module or course using the criterion-referenced rubric unique to that particular assessment. As a secondary source of information, the assessment team developed a matrix that mapped the embedded assessments by module to the InTeGrate guiding principles. The process highlighted shortcomings in these assessments, and the rubrics developed as part of a module or course. Assessment team members noted where student work lacked the specificity to demonstrate module learning goals but yet would achieve high marks on the associated rubric. Assessment team members worked with materials developers on revisions to include more explicit rubrics for that module/course assessment that aligned to the stated learning goals for the module or course. The assessment team found that the process of using the module/course-specific rubrics did not provide sufficient insight as to whether the assessment demonstrated the learning outcomes of the module or course.

To address the limitation of using the module/course-specific rubrics, the assessment team refined the method for scoring student work and providing feedback for subsequent materials development teams. As previously described, the assessment team devised a matrix where they also scored student assessments by the module learning goals explicitly stated on the module webpages and by the InTeGrate guiding principles. This secondary method proved more useful in giving feedback to materials development teams. Assessment team members provided a report to the materials development teams which summarized how well student work demonstrated each of the module/course goals and included concrete suggestions for improvement. For example, in one such report, the assessment team commented, "We liked that most students adequately grappled with the hydrologic cycle concept and introduced terms in their presentations that showed they understood the fundamentals." The review also gave suggestions for how to get students to go beyond the approach that "data speak for themselves." In another example, assessment team members suggested additional instruction such as an additional in-class exercise as part of the module that helps students understand how to support or defend an argument with data. The report was provided to the materials development teams at the face-to-face meeting. Discussions with the assessment consultant provided further context for the feedback and input into the revision plans.

Analyses Informed Project Evaluation

To investigate the impact of the overall curricula on student learning, paired sets of student data from the common project assessments were used. A full set of paired data included pre- and post-course GLE, pre- and post-course IAI surveys, and the two post-course essays. Student responses to the eight pre-course GLE questions served to characterize the overall baseline geoscience knowledge. Student responses to the two post-course essays demonstrated post-course abilities related to interdisciplinary problem-solving and systems thinking. Scores of student essays were compared and discussed for inter-rater reliability with a final score determined for each essay. A subsample of already scored essays was included in the sampling frame of subsequent essay scoring to be used for inter-rater reliability for the project.

A sample of 2023 paired GLE pre-instruction and post-instruction responses from materials development pilot courses was used to investigate geoscience literacy gains. From this sample, students demonstrated the equivalent of a 1 point gain (out of 12 point total) or a 10% normalized gain, irrespective of the pre-instruction score. The lowest quartile of pre-instruction scores exhibited the highest gains as compared to the highest quartile which appeared to have a ceiling effect (Gilbert et al. 2016). Analysis compared student responses in courses taught with InTeGrate materials to courses where no InTeGrate materials were used. Initial analysis found significant gains when comparing treatment population to initial control. Further analyses with additional treatment and control data are being completed.

Approximately 2100 paired pre-post responses from the IAI were used to characterize student attitudes about the environment across the nation and changes in those attitudes across InTeGrate-informed instruction. Comparison of responses from InTeGrate enactments versus non-InTeGrate enactments revealed a small but meaningful InTeGrate effect (Kastens and Mara 2017). Subdividing the data by students' stated reason for taking the course showed that most of the change across instruction detected by the IAI is occurring among students who were taking the course to satisfy general education or distribution requirements (Kastens and Mara 2018). Students who stated that they were taking the course for their major or for their career were already close to ceiling on several IAI items pre-instruction. When the IAI sample was divided into future teachers versus non-teachers, the teachers were found to be more influenced by family and friends in making decisions about sustainability behaviors and more committed to incorporating knowledge about the Earth and environment into their professional careers (Egger et al. 2017). When the IAI sample was divided into underrepresented minorities (URMs) versus non-URMs, the URMs were found to equal or exceed their non-URM peers on their degree of concern for environmental issues and their motivation to take action to create a more environmentally sustainable society (Kastens and Mara 2016).

Essay questions do not lend themselves to a pre-post assessment strategy, because of the test-retest risk for memorable questions. To provide a project-wide measure of students' ability to contribute to solving environmental problems, Gilbert et al. (2017) developed a model in which pre-instruction GLE scores were used to predict essay scores. The model was calibrated with data from enactments taught without InTeGrate materials and then used to test whether student essays from InTeGrate enactments were stronger than predicted. For systems thinking, the InTeGrate student essays were much stronger than predicted, and for interdisciplinary problem-solving, the InTeGrate student essays were slightly stronger. These data provided some indication that the project goals of increasing students' systems thinking and interdisciplinary problem-solving were being met.

Analyses Informed Professional Development and Assessment Revision

Meta-analysis from the materials design rubric identified common shortcomings in the materials, such as weakness in developing student metacognition (Steer et al. this volume). Analyses from student work revealed additional areas where materials and the standards for measuring the materials could be bolstered. In particular, the community process for developing the systems thinking essay prompt identified systems thinking as a common project need.

Student essay responses to the interdisciplinary and systems thinking essays were independently scored by at least two raters using the essay rubrics included in the prompts given to students (Table 4). For each round of scoring, a subsample of both types of essays was scored and discussed by the assessment team to ensure uniform interpretation of the rubric. In the first student work collected for the systems thinking essay prompt, the assessment team independently scored a stratified (by course) random sample of student responses across courses (125 of 362 student responses). An analysis revealed that the majority of the student responses did not demonstrate systems thinking (34% received 0 points and 31% received only 1 of 4 possible points). There was very little evidence of student learning related to systems thinking present in these responses to differentiate learning. In particular, almost no student discussed anything about rates of change. Because the essay prompt was a newly developed question prompt, it was difficult to discern whether the discrepancy rested in a weak essay question or if the curricular materials insufficiently covered systems concepts.

To better assess student learning in this area, the systems thinking essay prompt and rubric was iteratively revised and tested. To test the different iterations of the essay prompt, expert responses were collected from geoscience faculty, student work was collected from a range of courses taught by faculty involved in InTeGrate, and responses from students enrolled in courses taught by assessment team members. The additional testing, analyses of student data, and revisions ensured that the final prompt discriminated learning and that it was possible for students to achieve full marks (InTeGrate 2018b). However, the subsequent analysis of student responses with pilot modules continued to highlight systems thinking as a common curricular challenge. The project responded to this need in several ways. First, the assessment team provided concrete suggestions for revising the recently piloted curricula. Second, project leadership identified that helping faculty better teach systems thinking was a professional development need for the community. The lessons learned from the student work supplied examples where additional professional development was added with web pages (InTeGrate 2018g) and webinars co-created with assessment team members (InTeGrate 2015). Assessment team members reviewed the webinar design and used its lessons to inform the checkpoint reviews for materials in development. Finally, project leadership initiated work on a new InTeGrate module centered on this foundational skill (Gilbert et al. 2016).

Findings from various analyses of IAI student data also influenced InTeGrate activities. Early evidence showed that student attitudes for some IAI items were changing more across instruction for students from URM groups more than non-URM students. Specifically, URM students were more likely to report that they could envision themselves helping to solve environmental problems through personal action and less likely to envision professional actions. These findings informed the work of the InTeGrate HBCU working group whose mission is “to promote Geoscience on HBCU Campuses and in the communities that they serve” (see InTeGrate 2018e).

Lessons Learned and Implementation

In order to assess and improve upon the InTeGrate materials and program approaches, the InTeGrate community approach to assessment aimed to establish curricular quality standards and to develop strong assessments. By departing from a more top-down approach to assessment, the project gained other outcomes in capacity building and co-constructed enduring products. The community approach allowed the project to work toward both goals simultaneously, key to meeting the demands of a finite schedule using the distributed expertise that resides across the community. This developmental evaluation approach allowed the project to iteratively improve toward common goals.

The process spawned feedback and flows of information that allowed for changes in one part of the assessment system to promote positive changes in other parts of the system (Kastens and Manduca 2017). For example, the materials development rubric identified an early need to bolster instruction in systems thinking. This need leads to the development of the systems thinking essay prompt for measuring student learning, professional development offerings related to systems thinking instruction, and an InTeGrate module focused on systems thinking. In addition, using a distributed community process helped to build evaluation capacity (Labin et al. 2012; Preskill and Boyle 2008) and evaluation mindset throughout the nationwide geoscience education community, including the assessment team, research team, IP faculty, and materials developers. The implementation program descriptions and materials instructor stories about faculty use of InTeGrate materials (InTeGrate 2014, 2017b) characterize how this mindset is evidenced in the community. Instructor stories describe how faculty who used the materials were motivated to focus on continuous improvement in their teaching to address changing student populations or to assess student learning in new ways, and implementation program web pages showcase how program approaches were improved, how success was measured, and in some cases how programs were scaled more broadly on campus.

Organizational learning theory distinguishes between single-loop and double-loop learning models. In the single-loop model, decision-making and problem-solving occur in a more tightly controlled environment where less stakeholder input is sought. Single-loop models depend on leaders for energy and order. In contrast, with double-loop learning models, participants are empowered to engage in the problem-solving. Community members draw from those most knowledgeable or competent to participate in problem-solving, and effort is made to build decision-making networks (Argyris 1976). In double-loop learning, community members reflect on both the outcome from problem-solving and also the process of problem-solving and its influence on themselves as a member of the community (Blaschke 2012).

The InTeGrate assessment community approach more closely resembled the double-loop organizational learning model. The project sought to build on the expertise of the community and engage the community in evaluative thinking and reflection related to assessment and the processes surrounding assessment. From the outset, reflection on processes and the role of engagement in the community were critical to the functioning and success of the community assessment approach. One example of this type of critical reflection occurred in the first year of the project as both the assessment team members and the materials developers reflected on the intended role of the assessment team members in working with teams through the checkpoint process. The position title, *assessment consultant*, was initially used to describe the assessment member assigned to a materials development team. However, the expectations for the consultant and how this role was enacted varied across the community. For example, some materials development teams expected that a *consultant* would provide feedback more frequently than detailed by the checkpoint process. The external evaluation team was instrumental in shedding light on this issue through the faculty reflection forms and annual interviews. The reflections from materials developers and assessment team members fostered discussions which led to clearer expectations for the processes and roles across the community. The assessment team role became a critical component in building a community of practice that promoted enhanced awareness of evidence-based curricular design and assessment as well as improving the quality of InTeGrate materials.

Developing project-wide student learning assessment instruments was the second primary role for the assessment team. The team initially put great energy into revising and providing context for the full set of GLE questions. However, the assessment team came to realize that the GLE uptake was less of a focus for the project. The project required more energy to be applied to ensuring high-quality curricula and meaningful student data to inform such curricula. Through development of the systems thinking essay prompt, the project gathered insights into the sticking points for students learning this critical skill and the challenges faculty face in teaching. By shifting the focus from the end outcome being instrument development to what could be learned from and through development, more nuanced understandings emerged, which in turn helped materials developers to better understand systems thinking and how to measure it in their curriculum. The instruments, whether it be the systems thinking essay prompt or GLE, are enduring products co-constructed by the project, as are the processes and professional development resources, such as the curriculum checkpoint process or website resources for systems thinking. By allowing the assessment team to shift its focus, new insights and resources emerged.

Although InTeGrate found success with the community-based, iterative approach to assessment, the difficulties of this approach should not be underestimated. The community approach to assessment for InTeGrate built upon an existing geoscience education community of practice (Kastens and Manduca 2018). A community in a less mature state may not have embraced this approach as readily or gained as much from the process in return. Significant investments of time by staff at SERC were required to coach the materials development teams through the IRB process, develop the technical tools for anonymizing and analyzing the student products, and process and curate the vast quantity of student products of varied formats. Even though staff diligently encouraged all participating instructors to deploy and submit all assessments, there were still gaps in the data. Project duration and budget constraints imposed additional limitations on the assessment program. Developing and refining the assessments iteratively across the project lifespan (rather than having sequential development, testing, and deployment phases), resulted in a data set that is not uniform across the project. Most of the student outcome data was collected during pilot tests of the materials.

Most importantly, the community approach was well suited to the guiding principles of the project. The high-level goals of InTeGrate for students included that students should value multiple perspectives in problem-solving, make use of data in decision-making, and leverage systems thinking. By adopting these same principles for the materials development and assessment processes, the project modeled the habits of interdisciplinary and inter-institutional collaboration, shared decision-making, and iterative cycles of testing and refinement that our students will need for addressing the grand challenges of our future.

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Appendix: The Geoscience Literacy Exam: 8 Question Instrument (GLE Common-8)

Literacy addressed	Question
Earth science literacy Natural hazards pose risks to humans	1. Natural hazards can be put into two major categories. Some natural hazards can be made worse by humans; others are largely independent of human activities. Select the natural hazard least likely to be affected by human activity (a) Forest fires (b) Tsunami (c) Landslides (d) Coastal erosion
Earth science literacy Earth is continuously changing	2. Which of the following geologic processes are most likely caused by the interactions between the tectonic plates at their boundaries? Select all that apply (a) Earthquakes (b) Continental glaciation (c) Floods (d) Volcanic eruptions (e) Mountains
Ocean literacy The ocean supports a great diversity of life and ecosystems	3. Which of the following statements about the distribution of life in the oceans is most correct? (a) Life is more abundant and diverse in some parts of the ocean than in others (b) Life is abundant and diverse throughout the ocean (c) Life is less abundant and diverse in the oceans than it is on land
Ocean literacy The ocean and humans are inextricably interconnected	4. Which of the following ways do humans affect oceans? Select all that apply (a) Humans alter ocean ecosystems through fishing (b) Humans alter shorelines through development (c) Humans mine mid-ocean ridges (d) Humans change overall ocean composition by desalination (e) Humans alter tidal cycles
Atmospheric literacy Earth's atmosphere continuously interacts with other components of the Earth System	5. Which of the following processes primarily involves the atmosphere and the biosphere? (a) The formation of limestone (b) The photosynthetic cycle (c) The hydrological cycle
	6. Which of the following processes are sources of carbon to the atmosphere? Select all that apply (a) Plant decay (b) Limestone formation (c) Cattle ranching (d) Fossil fuel use

Literacy addressed	Question
Climate literacy Our understanding of the climate system is improved through observations, theoretical studies, and modeling	7. There are several climate models used to research future change. Which climate modeling statement about twenty-first-century temperature change projections is most accurate? (a) Climate model projections do not agree on future likely outcomes (b) Climate model projections show similar trends for future outcomes (c) Climate model projections show the same results for future outcomes
	8. The first reasonably accurate mercury thermometers were invented in 1724, almost 300 years ago. What kinds of processes and/or data are used by scientists to determine temperatures more than 10,000 years in the past? Select all that apply (a) Written records (b) Ice cores (c) Tree rings (d) Sedimentary layers (e) Oxygen isotopes

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Part II
Earth and Sustainability Across the Curriculum

Implementing and Assessing InTeGrate Critical Zone Science Materials in an Undergraduate Geoscience Program

Ashlee Dere, Carol Engelmann, Timothy White, Adam Wymore, Adam Hoffman, James Washburne, and Martha Conklin

Abstract The Interdisciplinary Teaching about Earth Science for a Sustainable Future (InTeGrate) course "Critical Zone Science" (CZS) teaches undergraduate students about the services and resources provided by the critical zone (CZ), Earth's terrestrial layer that extends from the top of vegetation to unweathered bedrock. The course was developed through the InTeGrate program, which aims to improve undergraduate geosciences education by teaching earth science within the context of societal grand challenges. CZ science provides a valuable transdisciplinary framework through which students learn the nature and methods of geosciences and

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apply systems thinking as they investigate grand challenges facing society. Using a CZ approach to learn about Earth systems and the services provided by the CZ has the potential to deeply engage students and develop skills necessary to consider how we can achieve environmental sustainability. While teaching the CZS course, instructors employ active learning pedagogical practices using authentic data and current research from the National Science Foundation CZ Observatory program. The CZS course was piloted across a range of institutions and most recently at the University of Nebraska Omaha (UNO), a large, 4-year public and primarily nonresidential campus. Here we present a case study of implementing the course into UNO's undergraduate curriculum, including strategies and challenges of delivering the course, and describe additional attempts to assess course outcomes, including a new summative assessment tool. Assessment data from pilot courses and the most recent UNO course offering show that students leave the course with a high interest level in earth science and sustainability and the ability to apply complex thinking skills, but additional assessment tools are needed to more effectively assess the ways in which these materials impact student learning and critical thinking skills.

Keywords Critical zone · Transdisciplinary undergraduate education · Active learning · Systems thinking · Case study

Introduction

Implementing and assessing Interdisciplinary Teaching about Earth Science for a Sustainable Future (InTeGrate) materials in undergraduate geosciences curriculum moves undergraduate geosciences education forward by improving both teaching and learning as the instructor engages students in active learning and other best practices. Students in the InTeGrate course, "Critical Zone Science" (CZS) (White et al. 2017a), learn to examine the services and resources provided by Earth's terrestrial layer, the critical zone (CZ), or the zone where the atmosphere, biosphere, hydrosphere, and lithosphere intersect (Fig. 1) (Brantley et al. 2007). To fully study such a complex system requires numerous scientific disciplines, including, but not limited to, geology, soil science, biology, ecology, geochemistry, geomorphology, hydrology, and atmospheric science. The CZ sustains terrestrial life and provides many services such as filtering water, buffering atmospheric gases, and supporting agriculture (Field et al. 2015; White et al. 2015). Changes in CZ structure and function have recently accelerated due to human activities, threatening the sustainability of life's support system (Hooke et al. 2012; Banwart et al. 2013).

The CZS course focuses on the CZ system while teaching students to apply scientific thinking through working with CZ data to understand environmental sustainability (Zoback 2001). In-depth discussion of the course development, modules, and piloting process can be found in White et al. (2017b). In this paper we focus on outcomes from a more recent CZS course offering, including strategies and challenges for course implementation, as well as additional efforts to assess course outcomes, especially related to more complex critical and systems thinking skills.

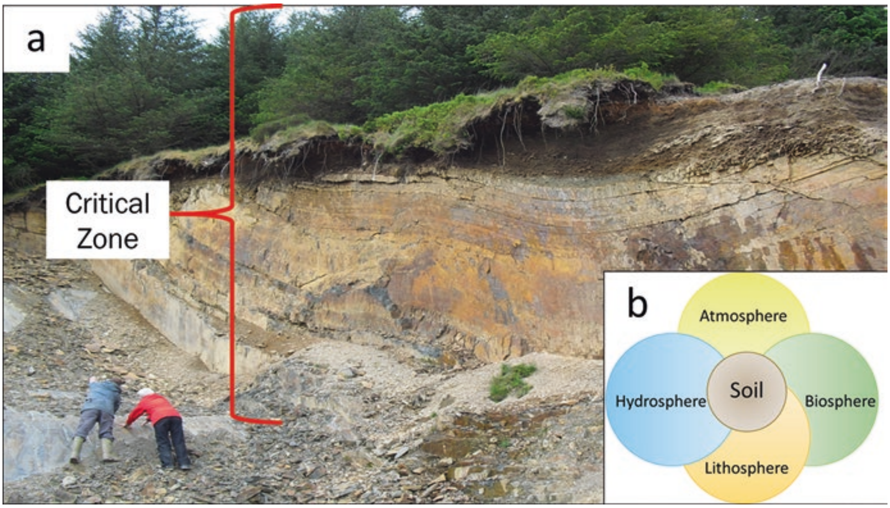

Fig. 1 (**a**) Example of a cross section of the critical zone in Plynlimon, Wales, extending from the vegetation canopy to groundwater below the Earth's surface. (**b**) A conceptual diagram of how Earth's spheres intersect within the critical zone, with soil serving as an interface between all spheres. Figure from White et al. (2017a)

The InTeGrate CZS Course

The CZS course highlights the dynamic nature of science while using a systems approach to investigate CZ structure and function and how humans depend on, interact with, and alter the CZ. An emphasis on the use of scientific data supports development of student's analytical and critical thinking. The published CZS course serves as an example of a challenging semester-long course where students engage in learning activities to explore the scientific principles and realities of CZ science, a large, ongoing scientific research endeavor. All CZS materials are published and available through the InTeGrate (White et al. 2017a). The CZS course uses data and literature generated from the NSF-funded Critical Zone Observatory (CZO) program and emphasizes a systems approach to explore the nature and methods of geoscience while addressing geoscience-related grand challenges facing society. The CZS course follows the five key InTeGrate program guiding principles: (1) connecting to the geoscience-related grand challenges facing societies, (2) developing students' ability to address interdisciplinary problems, (3) improving students' geoscientific thinking skills, (4) making use of authentic and credible geoscience data, and (5) fostering systems thinking (Steer et al. 2018). All CZS course modules contribute to the overall goal of students developing CZ content knowledge and a solid understanding of how the complex coupled processes within the CZ support and influence life. The specific learning objectives of the CZS course state that students will be able to:

1. Identify grand challenges that face humanity and societies, the way in which humans depend upon and alter the CZ, and the potential role for CZ science to offer solutions for these challenges (connected to InTeGrate Guiding principles: 1–5).
2. Use and interpret multiple lines of data to explain CZ processes (connected to InTeGrate Guiding principles: 3–5).
3. Evaluate how CZ structure influences CZ processes and services (connected to InTeGrate Guiding principles: 3–5).
4. Analyze how water, carbon, nutrients, and energy flow through the CZ and drive CZ processes (connected to InTeGrate Guiding principles: 3–5).

The CZS course employs a structure whereby the students work through seven modules throughout the semester. The initial two modules of the CZS course provide a framework to help students understand CZ science and the CZO network. CZ Background (Module 1) covers the definition of the CZ and CZ science, the overall state of the CZ, and the spatial and temporal scales over which the CZ is studied. In addition, students consider why CZ science is a transdisciplinary and international field, how researchers use environmental gradients to study the CZ, and some of the outstanding research questions in CZ science. In Methods of CZ Science (Module 2), fundamental CZ approaches and concepts are explored in the context of current datasets that can be used to study CZ processes at specific sites. The activities of the first two modules culminate with an introduction to basic concepts of system modeling, research methods, and infrastructure and research design.

The bulk of the course (Modules 3–6) delves more deeply into transdisciplinary CZ science and the data available from existing CZOs. Architecture and Evolution (Module 3) emphasizes the importance of considering the depth of the CZ and how the CZ changes on geologic timescales. Here, the lithosphere is presented as the solid framework onto which CZ processes develop and evolve. Land-Atmosphere Exchange (Module 4) analyzes how energy and carbon flow through the CZ and drive many CZ processes. The use of such data in CZ models and how to apply concepts of energy and mass transfer through different environments are explored using multiple datasets. Water Transfer through the CZ (Module 5) employs a systems approach to consider water transfers within the CZ at multiple scales, especially scaling up from point measurements to catchment scales and using water balances to inform resource allocation. Geochemistry and Biogeochemistry (Module 6) examines the integrated roles of biology, chemistry, and geology within the CZ through activities focused on eutrophication and nutrient inputs and transformations to understand the central role of biogeochemistry in CZ processes, function, and services.

The course culminates in a module on Humans in the CZ (Module 7), investigating the interactions between natural processes and human activities within the CZ that influence how humans live in the CZ and depend on it for resources—largely focused on water management and agricultural impacts. For example, activities in Unit 7.1: Model My Watershed direct students to use an online modeling interface to explore ways in which human environments alter watershed hydrologic fluxes and how best management practices can be used to offset some of the consequences of a built or managed environment. In Unit 7.2: Agricultural Impacts, students explore ways that various agricultural practices influence the CZ using soil carbon data from an agricultural and forested site and through readings and discussions of the Dust Bowl. Finally, in Unit 7.3: Panel Review, students participate in a mock panel review of peer-written proposals for a new CZO to evaluate and critically discuss the merits of proposals with respect to CZ science and the potential to solve grand challenges. This final activity builds on the capstone project spanning the semester, where students use systems thinking to write and assess research proposals focused on CZ research and applications to grand challenges.

The CZS curriculum development team included CZ scientists and educators with diverse scientific expertise from across the country and was supported by the Science Education Resource Center (SERC) and their NSF-funded InTeGrate program (Kastens and Manduca 2017). To guarantee the course is of high quality and replicable, all original CZS course material was piloted in a wide range of educational settings, from a small private liberal arts college to large tier-one public research universities, major and non-major courses, undergraduate- and graduate-level courses, online and face-to-face, and small- and medium-sized classes. Following the pilot process, each module was refined using both course assessment data and external peer reviews prior to online publication. We anticipate the material will evolve as more individuals adapt the course for their institution and locally relevant grand challenges, which are currently chronicled as instructor stories on the InTeGrate website (InTeGrate 2018a). Assessment of the CZS course is ongoing as new and better assessment tools that precisely target student learning objectives are developed, tested, and refined.

Pedagogical Strengths of the CZS Course

Throughout the CZS course, active learning strategies guide teaching and learning. Active learning strategies facilitated in the curriculum are group and peer-to-peer discussions, data and worksheets, modeling activities, collaborative writing, and student presentations of scientific literature (Fig. 2) (Grabinger and Dunlap 1995; Freeman et al. 2014). Students also engage in active learning through the use of Excel spreadsheets (Microsoft, Redmond, WA) to integrate and visualize CZO data. This strategy builds data analysis skills and contributes to student-directed learning (Kober 2015). Although the CZ data are messy at times and the boundaries between systems can be difficult to define, the course builds so that students can fully appreciate the complexities of such a transdisciplinary effort. Students learn to locate datasets and deal with missing data when working with authentic data. Many of the datasets and examples used in the CZS course can be tailored to students choosing a location they want to research, thus engaging the student more deeply in place-based learning while addressing real-world problems (Gosselin et al. 2016). The CZO network also presents the opportunity for teachers and students to participate

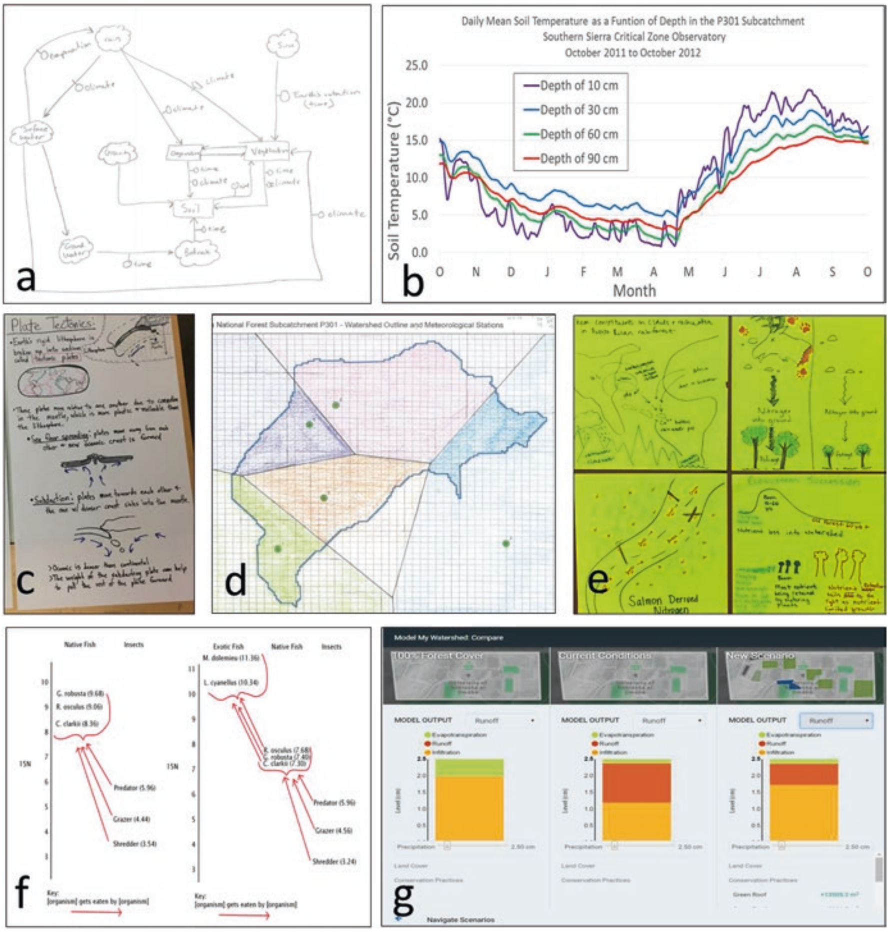

Fig. 2 Examples of student products generated from CZS activities: (**a**) sketching systems diagrams in Module 1; (**b**) plotting CZO data in Module 2; (**c**) reviewing basic geology concepts through peer instruction in Module 3; (**d**) interpolating point data to watershed scales in Module 5; (**e**) illustrating and presenting main ideas from the literature in Module 6; (**f**) plotting isotope data to infer changes in food webs in Module 6; (**g**) using Model My Watershed® to explore how best management practices influence runoff in Module 7

in a field trip to a CZO. Arranging for a CZO field trip is encouraged because it can enhance student connections between CZ concepts and research practice in a place-based context. Although only nine CZOs are currently funded by NSF in the United States, many other field locations self-identify as CZOs and are using a CZ approach to study their sites (see CZEN 2018 for locations and descriptions of CZOs).

Methods

Case Study: Implementing the CZS Course at UNO

The CZS course has been successfully taught twice at the University of Nebraska Omaha (UNO), once in fall 2015 as part of the initial InTeGrate pilot testing and then again in spring 2017. The initial course offering at UNO included 14 students, taught over 2 75-min sessions per week, while the second included 12 students, taught in 1 150-min session per week. The spring 2017 UNO CZS class also had the opportunity to travel to the Intensively Managed Landscapes (IML) CZO in Eastern Iowa. Students camped overnight in a county park and then spent the day visiting several locations within the CZO and assisting with both sample collection and instrument installation (Fig. 3).

UNO is a large (12,536 undergraduates enrolled in fall 2016), 4-year public and primarily nonresidential campus with a student population including 45% first generation, 31% minority students, and 88% from Nebraska (Office of Institutional Effectiveness, UNO 2016). The Department of Geography and Geology at UNO is

Fig. 3 Photos of UNO CZS students visiting and collecting data on a field trip to the Intensively Managed Landscapes Critical Zone Observatory (IML-CZO) in Eastern Iowa. The overnight field trip exposed students to current research and instrumentation, and students helped CZ researchers collect water samples and install instrumentation

a relatively small department similar to many others across the nation both in size and in its interdisciplinary nature. The department includes 4 geology and 6 geography faculty members with approximately 35 undergraduates in geology, 40 in geography, and 30 in environmental studies. In addition, there are approximately 25 geography master's students (full and part time) of the 3,091 total graduate students on the campus (Office of Institutional Effectiveness UNO 2016). The CZS course fulfills upper-level degree requirements for UNO students pursuing undergraduate degrees or minors in geology, geography, or environmental studies as well as MA degrees in geography. At UNO, prerequisites for the CZS course include one introductory physical geology or physical geography course and at least one course in chemistry or physics. Students are encouraged to enroll in the course later in their academic career to have more fundamental courses completed, but in these two offerings, the range of students was sophomore to graduate level with a large range in geosciences backgrounds. This afforded a unique cross section of disciplinary backgrounds and experiences that were leveraged through group discussions to enhance the curriculum.

Future CZS course offerings at UNO are planned for every odd spring semester. Planned changes for future course offerings include a 2-h lab section in addition to two 75-min lecture periods, worth four total credit hours, to provide additional contact hours to complete CZS activities. The course will continue to be offered in a computer lab where all students can work at their own desktop computer. The computer lab also includes a conference table to facilitate student discussions and a dry-erase wall where students can synthesize and illustrate concepts. Such a setup works well to facilitate the broad range of activities in the CZS course for 12–14 students each semester; larger class sizes will certainly be more challenging to accommodate with computers and group workspace.

Assessing CZS Course Impact

A variety of assessment tools support the continuous refinement of the CZS materials and provide data about the impact the CZS course has on student learning and critical thinking skills. The initial CZS course underwent major refinement based on assessments administered during course development and the initial piloting process. The initial CZS course assessment data were collected using both materials administered across all InTeGrate program projects and tools aimed at understanding specifically how CZS materials help student learning and critical thinking skills.

InTeGrate Program-Wide Assessments

As part of the InTeGrate program, the CZS materials were piloted across seven institutions and assessed using three instruments created and validated to assess student attitudes and content knowledge across all of the InTeGrate program projects. The InTeGrate Attitudinal Instrument (IAI) measured student's attitudes and behaviors related to sustainability (Kastens 2016; InTeGrate 2018b). The General Literacy in Earth Science (GLE) measured general earth science knowledge in categories related to earth science, climate, and atmosphere (Iverson et al. 2018; InTeGrate 2018c). Two open-ended essay questions assessed InTeGrate's guiding principles 1 and 5 and targeted the student's ability to articulate their understanding of systems and grand challenges facing humanity (InTeGrate 2018d). The first essay question asked students to identify a global challenge facing society and describe how science can help inform decision-making related to that challenge. The second asked students to provide an example of a real-world system and describe its parts, including an explanation of how parts of the system interact. Answers were scored on a four-point yes or no scale, where students received one point if, for example, they correctly state and describe a grand challenge, and zero points if not. Every student in the CZS pilot groups completed the same pre- and post-material IAI and GLE assessments; the open-ended essay questions were only administered post-course.

Specific CZS Course Assessments

The CZS team hypothesized that better assessment tools could more accurately measure the ways in which student learning and thinking changed after experiencing the CZS curriculum and how students apply complex concepts. In an effort to probe deeper into changes in student critical thinking skills connected to learning from the CZS course, three additional essay questions were developed that attempted to probe student learning related to InTeGrate guiding principle 3 and CZS learning objectives 2–4. One asked students to define the critical zone and its location. The second provided a cartoon sketch of an alpine critical zone and asked students to provide evidence from the image that allows them to infer which direction is north (image available at CZO 2018). From the same cartoon, students were also asked to identify instrumentation and describe the environmental variables measured.

The summative assessment for the CZS course (implemented during the initial pilot process) required students to produce an original ten-page scholarly paper on a grand challenge facing humanity while addressing issues relating to CZ resource sustainability, CZ stability, and/or human quality of life, health, and safety. The paper aimed to assess InTeGrate guiding principles 1–5 and evolved over the course of the semester, beginning with the selection of an approved topic in the second week, an outline due 1 month into the course, a 2-min/two-slide presentation 2 months into the course, and the final paper due at the end of the course along with a 10-min class presentation. Student papers were assessed using a rubric that evaluated the following: purpose, content, layout/organization, research objective/hypothesis, tone, grammar/spelling/writing mechanics, length/spacing/fonts, reference quality, and visuals, rating each category as exemplary, good, acceptable, or unacceptable (adapted from Kansas State University 2017; available online with CZS course materials).

The new CZS course summative assessment (tested during the most recent UNO course offering) requires students to respond to a mock request for proposals (RFP) from the National Science Foundation (NSF): the students are told that $5,000,000 is available to fund a brand new CZO that would generate new knowledge to help address a grand challenge facing humanity. Students are tasked with creating a research proposal for the new CZO. Each research proposal should identify research questions that the new CZO will investigate, describe experimental design and methods to answer those questions, and articulate how the new knowledge would both fill a gap in our basic understanding of the CZ and help address grand challenges (Cole et al. 2013). Once the students complete their written proposals, the next step is for them to undergo peer review and then discuss as a panel which proposals deserve funding (Guilford 2001). The same rubric previously described was modified to explicitly address the new objectives of the proposal. For example, an exemplary research proposal would describe and characterize how interactions among the Earth's spheres support and influence life, how the proposed CZO is uniquely poised to answer scientific questions, and how well the proposal indicates the societal value of the proposed CZO (rubric also available online with CZS course materials).

Results and Discussion

InTeGrate CZS Pilot Assessment Results

The InTeGrate Attitudinal Instrument (IAI) assessment measured little or no change in attitudes when assessing the students that participated in the initial multi-institution CZS pilot courses (Fig. 4). The IAI results showed that overall, students started and ended the course with a high interest in earth science and with concerns about sustainability (White et al. 2017b). Students enrolled in the CZS course reported a higher desire for a sustainable society compared to InTeGrate-wide assessments (Fig. 4), and it is significant to note that close to 100% percent of the students think what they learned will help them solve environmental issues (White et al. 2017b).

The General Literacy in Earth Science (GLE) results came from 29 students across all the multi-institution pilot courses and showed little change in student learning with respect to the GLE questions (Table 1). Again, these results are not surprising given that most students were upper-level undergraduate students having already fulfilled the prerequisites and successfully completed some foundational geoscience courses prior to enrolling in the CZS course (White et al. 2017b). The more recent CZS offering at the University of Nebraska Omaha (UNO) in spring 2017 showed the same outcomes as the pilot studies (Table 1).

The InTeGrate open-ended short essay assessment questions showed that in both pre- and post-course, students could identify a grand challenge facing society, but

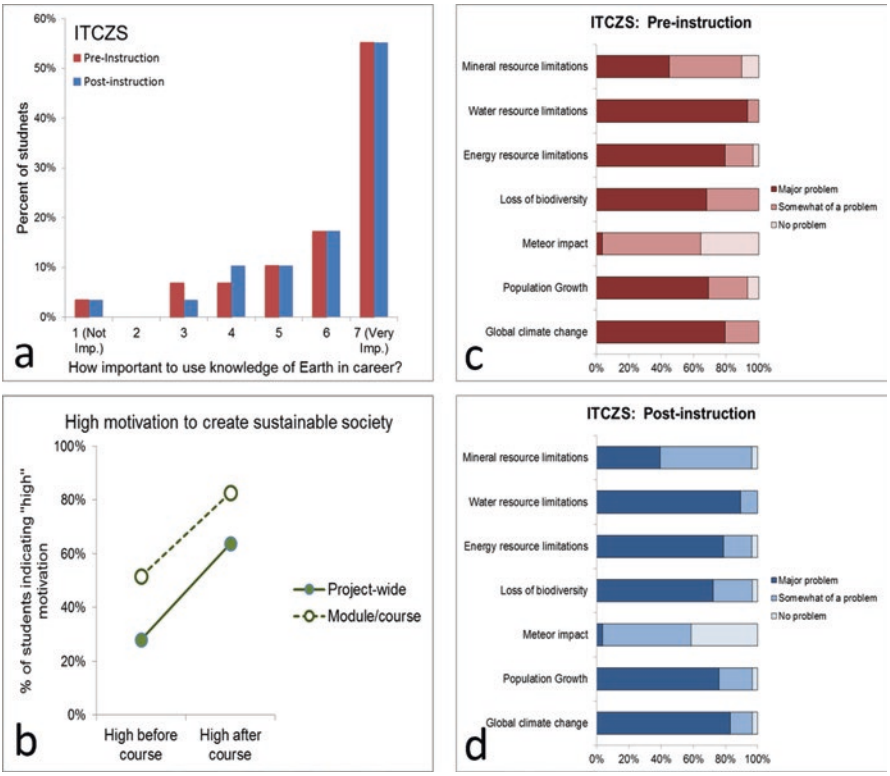

Fig. 4 Student pre- and post-course "Introduction to Critical Zone Science" (ITCZS) responses ($n = 29$) to various questions in the InTeGrate Attitudinal Assessment, including (**a**) the importance of using Earth knowledge in a career, (**b**) motivation to create a sustainable society (compared to InTeGrate-wide responses, $n = 1125$), and (**c–d**) level of student concern about various environmental problems. Overall, students started the course with a high interest in earth science and concerns about sustainability

both pre- and post-course responses lacked clear connections of the grand challenge to CZ science (Table 2). In general, pre-course responses only generically discussed a grand challenge, while post-course responses included more detail about the grand challenge. However, only 25% of students post-course both identified a grand challenge and linked CZ science to addressing that challenge. The most common topics included climate change and water resource availability (33% each for pre- and post-course responses) and soil resources (~20% pre- and post-course); other topics included mineral resources, energy, air pollution, and sea-level rise. Pre-course, only 20% of students could both define and describe an example of a system, whereas 60% provided generic examples that did not clearly articulate how parts of the system were connected and 20% provided examples that included incorrect science. Post-course, 50% of students could describe a system and its components, while 33% provided generic examples, and 17% of responses included incorrect science.

Table 1 Pre- and post-assessment General Earth Science Literacy (GLE) results from all pilot courses ($n = 29$) (White et al. 2017b) and a more recent offering at UNO in spring 2017 ($n = 12$)

Question subject	All pilot courses ($n = 30$)		UNO spring 2017 ($n = 12$)	
	Answered correctly (%)		Answered correctly (%)	
	Pre-course	Post-course	Pre-course	Post-course
Natural hazard	97	89	–	–
Tectonic plates	60	70	–	–
Life in oceans	60	63	–	–
Human and oceans	40	30	–	–
Atmosphere and biosphere	47	56	58	83
Carbon sources	33	44	67	58
Climate modeling	93	93	92	100
Climate measurements	10	36	17	58

Only GLE questions deemed most relevant to the CZS course were again used in the spring 2017 UNO course offering, but data trends are similar to results from the pilot study, and only minor gains on a question focused on climate measurements were observed

Table 2 Pre- and post-assessment essay question results from UNO CZS course

Question subject	UNO fall 2015 ($n = 12$)		UNO spring 2017 ($n = 12$)	
	Answered correctly (%)		Answered correctly (%)	
	Pre-course	Post-course	Pre-course	Post-course
InTeGrate essay questions				
CZ science *and* grand challenges	13	25	17	75
Systems	20	50	33	88
Additional essay questions				
CZ definition and location	–	–	25	92
Environmental measurements	–	–	50	92
Inferring CZ processes	–	–	33	50

In the fall 2015 UNO CZS course offering, students produced papers covering grand challenges such as desertification, heavy metals in the environment, climate change impacts on snowpack, and soil loss. The results indicated most papers were well-written and clearly articulated a grand challenge, but it did not assess how well students could apply CZ concepts and skills gained from completing the CZS course.

UNO Case Study: Results and Student Feedback

UNO student feedback helped to identify both strengths and weaknesses in the CZS learning experience. The open-ended responses from the two UNO CZS offerings included many assertions that the most valuable outcomes of the course enhanced systems and critical thinking skills (Table 3). Specifically, several students reported that they found the CZS material to be important, mentally stimulating, and a valuable course for developing scientific reading, writing, and analytical skills. Many geoscience courses in the undergraduate curriculum require some interdisciplinary thinking, but the CZS course appears to fill a gap in the current curriculum by focusing on a systems approach and incorporating many facets of the earth sciences. While learning to work with real science data is a strength of the course, some students self-reported that working with Excel and large datasets was particularly challenging, and for some, reading scientific literature was a struggle. This outcome is likely not unique to this university or subset of students and thus should be considered in future course offerings at any institution. Thus, we recommend explicitly reviewing basic Excel skills such as data formatting, calculations, and plotting with students in Module 2 prior to using any CZ datasets. Although it is likely useful to expose students to the real frustrations and challenges of working with incomplete and large datasets, the significant cost in time for both students and instructors may warrant providing students with either a subset of data or a CZ dataset the instructor has downloaded and formatted to help students practice working with data.

The first time the CZS was taught, several students expressed concern over high-workload volumes. These workload concerns were addressed during the InTeGrate revision process between the first and second UNO CZS offerings, and looking toward future course offerings, the addition of a lab section to the lectures should provide more class time to accommodate basic skill or knowledge gaps and help students complete activities in class. However, the active learning focus of the course is still demanding of both student and instructor time compared to a traditional lecture course. Time is required up front for the instructor to become familiar with the content; activities using real datasets may require troubleshooting on the part of the instructor and student; and grading time is higher than a course with less active learning. Students were also required to spend more time outside class reading literature and completing activities, a considerable challenge for many students who work outside of school. On the other hand, the materials are well organized and, as with most new courses, required considerably less time to prepare for the second offering. Many activity answer keys are available, and the group nature of many activities means that students can help each other. For example, although some students made light use of office hours, more often they helped each other complete activities outside of class. In the second UNO offering, a part-time graduate teaching assistant who had previously taken the course helped considerably with grading and fielding student questions both in and out of class. Additional options for reducing grading load include having students self-assess some assignments or use peer review to provide feedback.

The students reported that the field trip experience was one of the highlights of the course, enabling them to connect what they had learned in the classroom with CZ science in practice (Table 3). Furthermore, several students reported that they appreciated the opportunity to be part of a larger scientific endeavor, even for just a few hours. Following the course, several students also elected to engage in their own CZ-related research, citing the interest that was sparked during the field trip. Students did not receive credit for attending the field trip, yet all but one student

Table 3 Open-ended responses to UNO post-semester CZS course evaluations (n = 21 students, although not all students responded to open-ended questions)

Which characteristics of this course were most valuable to your learning experience?	
Fall 2015	I think it's good material that needs to be taught to generate a new generation of scientists to tackle new problems
	Very in-depth assignments. Use of various sciences and areas of knowledge helped me to tie in every-day life to the class as well as using work experience to explain answers and concepts. Very mentally stimulating. Critical thinking skills are much better after taking this course
	Diverse coverage of interrelated topics and systems
	Open and independent research methods nurtured
	The mixed methods and multiple formats for learning the information are great
Spring 2017	Active learning style that emphasizes critical thinking and applying the skills you have learned to solve problems
	Working with the class helped to form ideas, and being able to talk about what was understood versus not was very helpful
	Overall great course. Important subject matter. I thought the group paper was a good idea. The field trip was a good way to see CZ science in operation and was a valuable learning experience
	I found the assigned readings to be highly valuable. Not only were they enlightening for the subject material, but reading them also provided practice in efficiently reading scientific papers and extracting the information from them that had the most usefulness for whatever purpose we were reading them for
	I found the final project to be a valuable experience; both the act of researching for it and the creation of the proposal itself really enhanced my understanding of CZO science and the kind of thought that goes into it
	I learned a lot from this course and I was/continue to be excited about the materials and topics
Which characteristics of this course are most important to improve upon?	
Fall 2015	I feel like there was too much readings assigned, so I had to skim over it to get it all done instead, if there was less I could have dived into it more and felt like I had time to get more out of it
	Various math skills are expected of the students and are poorly explained in the assignments. In order to fully understand the concepts covered thoroughly, this course needs to be a two-semester class in my opinion. Out of class workload is way too high for one semester
	Depth of topics was sometimes too shallow, giving an understanding largely already gained in past courses
	If there is any way to cut just 1/8 of the readings out, it would help move the course along
	The assignments are a LOT more in depth than I had planned for
	Moving the course to a "once-a-week" format would help to make more efficient use of time, especially since the class is very activity based

(continued)

Table 3 (continued)

Spring 2017	Data hunting and organizing were difficult and consistently took the most time to complete assignments
	Course moved a little too quickly and is hard to keep up
	I think adding a lab to this course will help a lot. It would also be helpful to have more assigned readings (and more textbooks than research papers, but those are good too) to orient students to the material. I liked the class discussions and wish there were more of those. I think the pattern of reading something before class and then discussing it in class is good
	I am not sure about the emphasis put on graphing in Excel and working with large datasets…. I think this is important, but we spend a lot of time on it at the expense of learning critical zone concepts. More direct help with graphing would be beneficial
	Some assignments were highly frustrating, as I did not feel that what I was learning from them was worth the amount of time or effort that they required. In some cases this was because they took a lot of time and effort; in other cases this was because I did not feel like I was learning very much from them
	The time slot for the class did not really leave enough time to get a good grasp of some of the materials. I think as we talked about in class, that switching to 2 days a week and a lab would be a better platform to deliver this course

with a conflict attended the weekend trip. The enthusiastic attendance perhaps points to the level of importance students placed on the experience and learning about the CZ, even though many have full-time jobs, families, and other personal commitments.

Although anecdotal, these UNO student comments suggest that at a minimum, students perceive they have gained important systems and critical thinking skills. Direct measurements of this gain were more difficult to obtain with the available assessment tools, but we see these anecdotal results, in conjunction with the preliminary assessment work described below, as an opportunity to develop more targeted tools to help quantify and understand how and why such gains are happening when students engage with the CZS material.

Discussion of Assessment Challenges and Solutions

Overall, the InTeGrate AI and GLE assessment data indicated that the CZS course materials did not change student's attitudes or mastery of basic earth science concepts. These results are not entirely surprising given that most students had already selected geology or environmental science as a major, indicative of their interest in earth science and intent to pursue a career in this field. The InTeGrate open-ended essay question assessment showed that students accurately identified grand challenges in both pre- and post-course, but very few clearly articulated how science could help solve the grand challenge, even post-course (Table 2). While the open-ended essay questions initially assessed all the multi-institution pilot courses, the questions were administered post-course only. The UNO 2015 pilot, however, administered the essay questions both pre- and post-course, with little change in outcomes, again demonstrating that students entered the course with an awareness and interest in environmental issues. In fact, student responses focused on similar issues both pre- and post-course, and post-course response topics aligned with the student's choice of research paper topic. InTeGrate program-wide analysis of student responses to this essay question showed that students in control groups focused on climate change, whereas students completing InTeGrate materials discussed a wider variety of grand challenges focused on InTeGrate topics (Caulkins et al. 2014). With respect to the systems thinking essay questions, students in the 2015 UNO pilot showed modest gains post-course (Table 2), which prompted us to emphasize incorporating systems more explicitly in the CZS course during the revision process.

These results were encouraging, but a question remained as to whether this outcome is directly connected to taking the CZS course. Designing and implementing high-quality assessment protocols that accurately measure the impact of a course is an ongoing challenge. Assessment results from the multi-institution CZS pilot testing generally showed that the initial assessment tools were insufficient for measuring changes in student learning as a result of the course, so new assessment protocols and tools tailored more specifically to the CZS course, and the five InTeGrate guiding principles were developed and tested through the 2017 UNO pilot of the CZS course.

In the 2017 UNO offering, we again administered the InTeGrate open-ended essay questions both pre- and post-course to more accurately measure changes in student thinking. The UNO 2017 student pretests showed that 33% of students could articulate what a system is and how components of the system interact. Upon completion of the CZS course, 92% of students could define a system, and 83% could successfully illustrate the components of an example system. Similarly, few students pre-course (17%) could identify a grand challenge facing humanity *and* articulate how science could help address that challenge. Following the course, 75% of students could connect a way in which CZ science could help address a grand challenge. Thus, implementing this assessment tool pre- and post-CZS course improved assessment of the effectiveness of the CZS materials. Although the results represent only one institution and one semester ($n = 12$), pre- and post-course assessment tools that incorporate questions targeting a students' understanding of systems thinking and how to apply CZ science concepts to grand challenges can provide more useful data as to how to affect change in learning and ultimately thinking.

Another assessment challenge that presented itself was that, although the UNO pre-/post-essay question results suggest that students did make gains in understanding complex systems, a wide range of student understanding was evident. For example, in response to the essay prompt to describe a system and how its parts interact, two students answered correctly but showed vastly different levels of understanding. One student provided an example of a bathtub as a system, which was almost an exact reproduction of an example from the systems unit in Module 1 (Fig. 5a), whereas another student drew a complex environmental system, including fluxes and reservoirs, and indicated that the drawing was a simplified representation of reality (Fig. 5b). The latter student demonstrated a deeper understanding of systems and how they are relevant to CZ science, but this difference was not easily distinguished from the previous systems example because both illustrations correctly showed a system. The initial post-assessment essay answers for the CZS course were scored on a four-point yes or no scale, where both students in this example would receive similar scores given that they both provided an example of a system. In assessing the responses in such a binary manner, change in student understanding was measured without capturing the extent of change or the reality that some students demonstrate a deeper understanding than others.

Three additional open-ended essay questions were administered pre- and post-course at UNO in 2017 (n = 12). The results suggest that in addition to gains in understanding systems and how to apply CZ science to grand challenges, students gained the ability to accurately define the CZ, infer CZ processes and provide evi-

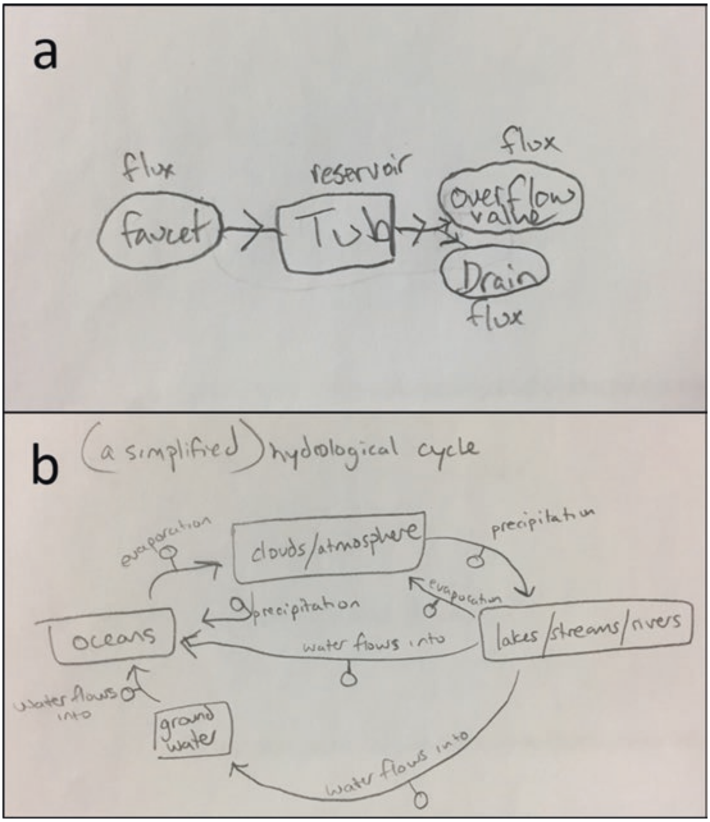

Fig. 5 Examples from the UNO 2017 CZS course offering of post-course responses to a prompt asking students to provide an example of a system and its parts. Although both students correctly illustrate a system, the diagram in panel (**b**) demonstrates a deeper understanding of systems and their complexity than the diagram in panel (**a**)

dence to support their conclusions, and identify environmental measurements to study the CZ (Table 2). Not all students were able to make the connection between environmental observations and process, but 50% of the students could do so post-CZS course compared to 30% pre-CZS course. Although not yet rigorously tested for reliability and validity, the new essay questions have generated additional assessment data that provides a first step toward looking deeper into student understandings; they are part of the ongoing development process of reliable and valid assessment tools tailored to probing systems thinking skills.

The original summative assessment tool assessed whether or not a student could write a research paper, but did not clearly assess whether or not the students met the learning goals of the CZS course. Having students produce an original research paper initially seemed appropriate because it is a common capstone project for many undergraduate courses. Following the pilot testing of the CZS course, the development team recognized a tool was needed that was more closely aligned with the expected student outcomes. The development team chose to design a new capstone project to serve as the summative assessment that aligns with an "authentic complex Earth and environmental systems" conceptual framework (Scherer et al. 2017): students are asked to think and act like scientists, apply their understanding of CZ science, and articulate how CZ science can help address environmental and sustainability issues. This new summative assessment protocol affords students an opportunity to create and critically evaluate proposals and specifically assess student learning aligned with InTeGrate guiding principles 1–5. The panel review activity also provides an opportunity for students to justify their opinions and consider alternative viewpoints in a context that replicates an activity commonly experienced by CZ scientists (Holder et al. 2017).

The new CZS course summative assessment protocol was piloted in spring 2017 at UNO, with students divided into groups of three and tasked with generating a proposal collaboratively. The assignment was structured so that the students had deliverables due in a timely manner. Twenty minutes of in-class time was frequently allocated for students to meet in their groups to discuss plans for the proposal and how to divide the research and writing tasks. The groups received feedback on an outline they submitted mid-semester, and the instructor provided guidance and feedback throughout the semester. Students were introduced to how proposals are peer-reviewed following NSF guidelines and taught how they would participate in a panel review of proposals.

The four UNO student groups proposed new CZOs in Alaska, Iceland, Utah, and the Sand Hills, Nebraska, to address issues related to climate change and managing water resources. After debating the merits and potential benefits of each site to address grand challenges, students ultimately voted to fund the Sand Hills CZO followed by the Alaska CZO. A word cloud generated from all four proposals highlights some of the themes contained within the proposals, including a focus on climate, water, systems, data, and fluxes, among others (Fig. 6). In addition, two of the four proposals used currently available CZO data to support the need for their proposed CZO. All student proposals scored either exemplary or good with respect to purpose, content, and research objective/hypothesis categories of the rubric, dem-

Fig. 6 Word cloud generated from the new CZS summative assessment protocol administered during the spring 2017 UNO CZS course offering highlighting major themes of the student-proposed research. The summative assessment required students to work in groups of 3–4 students to collaboratively write a research proposal for a new Critical Zone Observatory

onstrating the ability for students to apply CZ concepts and systems thinking they learned in the CZS course to identify gaps in the current CZO network and justify a new CZO location. In effect, this new summative assessment is also an example of a “Make a Decision or Recommendation” curriculum design pattern, where students are acting as scientists to make a decision addressing a realistic scenario (Kastens and Krumhansl 2017).

The UNO pilot of this new CZS course summative assessment provided valuable assessment data, both through rubric assessment and student feedback (Table 3). The summative assessment more clearly demonstrates student ability to apply and synthesize CZ concepts and systems thinking and align with the five guiding principles of the InTeGrate program. Furthermore, the opportunity for students to participate in an activity modeled after actual scientific endeavors appears to have both engaged students and enhanced learning (Holder et al. 2017; Scherer et al. 2017). Although the development team had concerns that completing the task as a group might mean not all members contribute similarly, the students self-reported that this was an aspect they found valuable because CZ science is by nature a collaborative effort and working as a group more closely represented reality (Table 3). Providing in-class time seemed key to successful group proposals because students found they could ask questions of the instructor and each other. Class time encouraged them to touch base with each other frequently to keep all group members on task. The students suggested that submitting more frequent drafts for feedback in the future would be particularly helpful for them to know where to focus their efforts. The summative assessment will continue to evolve as it undergoes additional reliability and validity testing.

Conclusions

The "Critical Zone Science" (CZS) curriculum, developed by a team of CZ scientists through the InTeGrate program, provides an effective framework to improve undergraduate geoscience teaching and learning while introducing students to the new transdisciplinary field of CZ science. The curriculum employs leading pedagogical practices to help students learn the foundational concepts of CZ science in order to think about complex systems through the use of authentic datasets and current research. Assessment of the CZS course shows students find it challenging but well balanced, relying on current science and data to help them appreciate the complexities and excitement of a transdisciplinary effort. The course was piloted at multiple institutions, peer-reviewed, revised, and offered most recently at the University of Nebraska Omaha (UNO), where the course is now integrated into the undergraduate geoscience curriculum. Assessment data reveal that students leave the course having gained complex thinking skills that will allow them to address grand challenges and sustainability issues in society. The newly developed summative assessment protocol appears to be a promising way to measure student gains in using systems thinking skills as a result of CZS materials. Assessment of the CZS course will continue to progress as new and better assessment tools that precisely target student learning objectives are developed, tested, and refined.

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Interdisciplinary and Topical in the Science Classroom: Regulating Carbon Emissions to Mitigate Climate Change

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Abstract In this chapter we introduce our module *Regulating Carbon Emissions to Mitigate Climate Change*, in which students learn about the geoscientific analysis that has produced our understanding of the grand challenge of global climate change and then explore how that scientific analysis informs economic analysis and political decision-making in the United States. The module includes 4+ weeks of activity-based instruction within seven units that may be implemented in part or in whole. As with all InTeGrate-developed materials, this curriculum was piloted at three separate institutions and underwent revision both before and after the pilot. Highlights of the module are summarized and include a mix of pedagogical techniques including a climate-economics modeling, a role-playing game, and a unique format of summative writing assignment. Student attitudinal data was encouraging: almost all of the students surveyed stated that they became more engaged and aware of environmental issues after instruction.

Keywords Carbon · Climate · Economics · Emissions · Policy

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Introduction

Climate change is a grand challenge that behooves interdisciplinary understanding and political action. Decades of scientific data analysis and modeling have definitively shown that anthropogenic emissions of carbon dioxide and other greenhouse gases are changing our environment (e.g., IPCC 2013). Research by scientists and economists shows that while averting climate change will be costly, the cost of *not* undertaking aggressive and timely policy action will likely be much higher (Stern 2008; Moore et al. 2017). Despite this widespread consensus among scientists and economists, political leaders have been slow to respond to warnings from the academic community and enact policies that will decrease greenhouse gas (GHG) emissions. Compelled by the supreme court ruling in Massachusetts vs. EPA (2007), the EPA issued the Clean Power Plan (CPP) in June 2014 with the aim of reducing GHG emissions from the US power sector 30% by 2030 (Federal Register 2015). However, at the time of writing, President Trump has begun the withdrawal process from the Paris Climate Agreement (Trump 2017), and the CPP is under review by the EPA (US EPA 2017). While these developments will exacerbate the dynamics of the unfolding carbon pollution crisis, they also present a unique and timely opportunity to teach students about climate change, interdisciplinary problem-solving, and the complex web of real-world systems thinking.

In traditional science courses, students learn about climate change, societal issues, and proposed solutions from the perspective of their single discipline, if such topics are discussed at all. Instructors interested in interdisciplinary teaching and problem-solving may find themselves limited by their narrow expertise and uncomfortable teaching about topics far outside their research focus. Our InTeGrate module, *Regulating Carbon Emissions to Mitigate Climate Change* (Smyth et al. 2017), is designed to give both students and instructors a multidimensional perspective on these topics. The module includes 4+ weeks of instruction within seven units that may be implemented in part or in whole. With the exception of the first two units, virtually all of the material in the module is outside the typical earth science curriculum and is suitable for all student levels. We piloted these materials at three different undergraduate institutions and in classrooms including an introductory non-major course and 200-level major courses in political and climate science. In this chapter, we highlight some of the most unique aspects of this integrative curriculum, review how the pedagogical techniques that we use in the module are in line with the InTeGrate guiding principles, review results from student attitudinal data, discuss the piloting process, and make suggestions for instructors who wish to use some or all of this curriculum in their own classroom.

Module Description

In this section we give a general overview of the module, highlight a few unique activities and assignments, and discuss how our curriculum supports the five InTeGrate guiding principles. As part of the InTeGrate process, these materials, underwent several rounds of review, both internal and external, and were formally piloted and revised before final publication (for more details, see Steer et al. this volume).

The module is divided into seven units, and instructors should allow for at least 4 weeks in a typical college classroom to complete it in its entirety. Following instruction, we expect that students will achieve the following overall learning objectives (From Smyth et al. 2017):

- Connect the causes, effects, and potential solutions to climate change in a socio-environmental system analysis.
- Run a global climate-economy model, and interpret the output in terms of the social cost of carbon pollution.
- Argue for policy action to curb climate change based on sound scientific and economic reasoning.

Figure 1 shows a concept map that summarizes the flow of the module. This concept map is built with the students over the course of a few 5–10-min sessions aimed at reinforcing both systems thinking and metacognition. The geophysical process circle is material covered by Units 1 and 2. In these units, students discuss the impacts of anthropogenic climate change as outlined in the National Climate Assessment (NCA 2014) and then dig into climate science with activities demonstrating the greenhouse effect and how climate forcings (e.g., GHG emissions) trigger feedbacks (e.g., ice-albedo feedback) within the climate system. Activities in these units include a demonstration of albedo and equilibrium, a gallery walk (Kolodner 2004), guided discussions, and small-group work. In Unit 3, climate science and economics are integrated through the use of a climate-economy model that runs through a user-friendly web interface (webDICE, 2010). With the model, students work in small groups to reinforce climate sensitivity lessons from Unit 2 and develop the idea that there are calculable and costly damages caused by climate change, called the social cost of carbon pollution. This leads to the discussion of the legal doctrine of "common but differentiated responsibil-

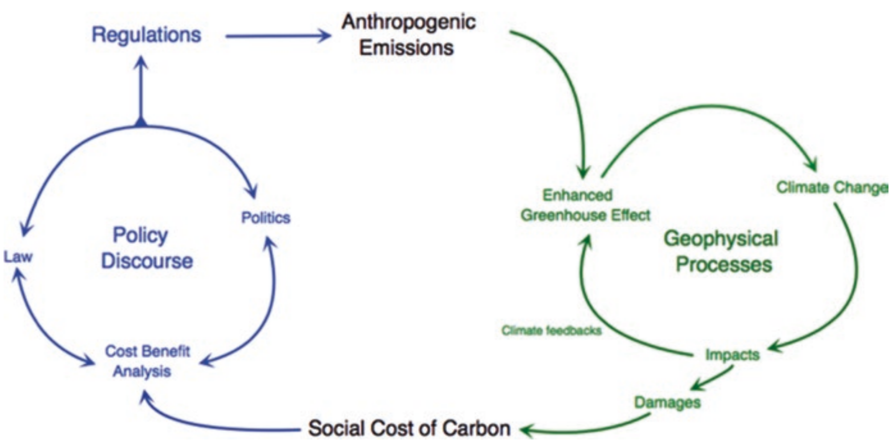

Fig. 1 Concept map that summarizes module flow and is built through in-class discussion. From Smyth et al. (2017)

ity" for climate change and analysis of regulatory policy options in Units 4 and 5 as shown in the Policy Discourse circle of Fig. 1. In these units, students conduct a variety of activities including think-pair-share (Lyman 1987), SWOT analysis (Professional Learning Board 2018), small-group work, and a T-chart to discover that taking substantial action now to abate carbon pollution is less costly than following a business-as-usual emission trajectory. Unit 6 is the Carbon Emissions Game, a climate change-specific application of Corrigan's *Pollution Game* (2011), where students compare and contrast (1) command and control, (2) cap and trade, and (3) carbon tax as regulatory options to reduce carbon emissions. Unit 7 promotes interdisciplinary synthesis and reflection with a return to the climate literacy assessment taken at the start of the module and a systems thinking exercise that leads students to a summative writing assignment.

In Table 1 we include a comprehensive list of the learning objectives, featured activities, and pedagogies for all seven units. For full details of the module, including instructor pages, student pages, suggestions for adoption in the classroom, grading rubrics, PowerPoint files, answer sheets, and printable activity sheets, the reader is referred to the InTeGrate website (Smyth et al. 2017).

Pedagogy and Activity Highlights

This module addresses all of the InTeGrate guiding principles (see Steer et al. this volume) through a wide range of activities. For reference, the five guiding principles and abbreviations are:

1. Connect geoscience-related grand challenges facing societies (GP1).
2. Develop students' ability to address interdisciplinary problems (GP2).
3. Improve students' geoscientific thinking skills (GP3).
4. Make use of authentic and credible geoscience data (GP4).
5. Foster systems thinking (GP5).

In this section, we highlight three innovative activities and discuss how they address the five guiding principles. The first activity utilizes a web-based version of the widely used Dynamic Integrated Climate-Economy model (webDICE 2010), the second is an in-class game to demonstrate the differences in regulatory options for pollution reduction, and the third is a persuasive Op-Ed writing assignment to argue for the regulation of carbon emissions in the United States.

Web-Based Dynamic Integrated Climate Economy (webDICE) Modeling (Unit 3)

In our experience, students struggle to interpret and understand the output of models. In Unit 3, we tackle this problem through the use of webDICE, a parameterized and web-based version of the widely used DICE integrated assessment model

Table 1 Summary of the time required, learning objectives, featured activities/pedagogies, and guiding principles addressed for all seven units

Unit	Learning objectives (from Smyth et al. 2017)	Featured activities/pedagogies (*with references to InTeGrate guiding principles in parentheses*)
Unit 1: Evidence and Impacts of Climate Change Time: 75 min	– Summarize the cause and evidence for anthropogenic climate change. – Describe some of the impacts of climate change on people and the environment.	– Complete introductory climate literacy assessment prior to instruction. – Grand challenge of climate change guided discussion (*GP1*, *GP3*). – Gallery walk to summarize key observations (*GP1*, *GP3*) (Kolodner 2004). – Begin to construct module system map (*GP5*).
Unit 2: Climate Forcings Time: 75+ min	– Utilize systems thinking to examine how emissions and feedbacks within the climate system influence global equilibrium temperature.	– Define forcing, feedback, & equilibrium with demo (*GP3*). – Draw feedback loops in small groups (*GP3*, *GP5*). – Discuss frozen lake photo to emphasize systems thinking and role of uncertainty (*GP3*, *GP5*).
Unit 3: Dynamic Integrated Climate Economy (DICE) Modeling Time: 95+ min	– Differentiate between climate sensitivity and future emissions as distinct sources of uncertainty in our projections of future climate change. – Quantify the social costs of climate change with a global Dynamic Integrated Climate Economy-Model.	– webDICE in small groups to distinguish between two types of uncertainty: future emissions and climate sensitivity (*GP2*, *GP3*, *GP4*). – webDICE in small groups to examine the importance of the social cost of carbon (*GP2*, *GP3*, *GP4*). – Continue to construct the module system map (*GP2*, *GP5*).
Unit 4: Toward Climate Change Policy in the United States Time: 75–90+ min	– Summarize the meaning of "social cost of carbon" and provide detailed examples of climate impacts that impose social costs worldwide. – Elaborate on the concept of "common but differentiated responsibility" and characterize the challenge presented by global climate change through this framework.	– Review social cost of carbon with guided discussion and T-Chart (*GP1*, *GP2*, *GP5*). – Introduce common but differentiated responsibility with guided discussion (*GP1*). – Introduce supreme court case (Mass v. EPA 2007), requiring regulation of carbon pollution, with guided discussion and think-pair-share (Lyman 1987) (*GP2*).

(continued)

Table 1 (continued)

Unit	Learning objectives (from Smyth et al. 2017)	Featured activities/pedagogies (*with references to InTeGrate guiding principles in parentheses*)
Unit 5: Abating Carbon Emissions Time: 75+ min	– Evaluate the effectiveness of the Clean Power Plan at addressing the United States' responsibility for global climate change. – Explain why and how costs and benefits of carbon abatement are calculated by economists. – Calculate the efficient level of global carbon abatement and the price of carbon emissions that can help achieve that target.	– SWOT (strengths, weaknesses, opportunities, and threats, see Professional Learning Board 2018) analysis for the Clean Power Plan (*GP3*). – Introduce cost-benefit analysis (CBA) and complete CBA assignment in small groups or as homework (*GP3*).
Unit 6: Carbon Emissions Game Time: 90+ min	– Compare and contrast commonly discussed policy options for mitigating carbon pollution.	– Carbon pollution regulation game occupies the entire unit (*GP2*, *GP5*).
Unit 7: Climate Change from the Socio-environmental Systems Perspective Time: 60+ min	– Communicate accurately about the challenge of climate change. – Describe natural, social, and economic impacts of climate change. – Argue for strong policy to regulate carbon emissions to curb climate change.	– Metacognition reflection: return to the climate literacy assessments complete 3-min free write to reflect (*GP5*). – Complete the final version of the module's system map (*GP1*, *GP2*, *GP5*). – Introduce/discuss the RAFT writing summative assignment (*GP1*, *GP2*, *GP3*, *GP4*, *GP5*) (Senn et al. 2013).

(webDICE 2010), to make predictions about future climate and economic outcomes. The model runs in seconds on a computer, tablet, or even a smartphone, yet it is a research-caliber model utilized in a range of peer-reviewed publications (e.g., Moyer et al. 2014) (GP4). Students complete two separate activities in small groups. In one activity, students produce Fig. 2 as they explore the effect of high/medium estimates of the harms (i.e., costs) done by climate change impacts. They are then asked the following question:

> What source of uncertainty (climate sensitivity or harms) has a greater impact on the costs of damages to our environment?

Through the modeling exercise, students come to the conclusion that our uncertainty in climate sensitivity (i.e., the scientific uncertainty) is small compared to the uncertainty in how changes in climate will manifest as harmful and expensive outcomes. In the other activity, students discover that the uncertainty in climate sensitivity (i.e., the scientific uncertainty) is less than the uncertainty in our future emissions. In other words, future warming depends on actions and decisions made during our lifetime, and we should not be paralyzed by a lack of scientific understanding. These exercises are inherently interdisciplinary (GP2): students must

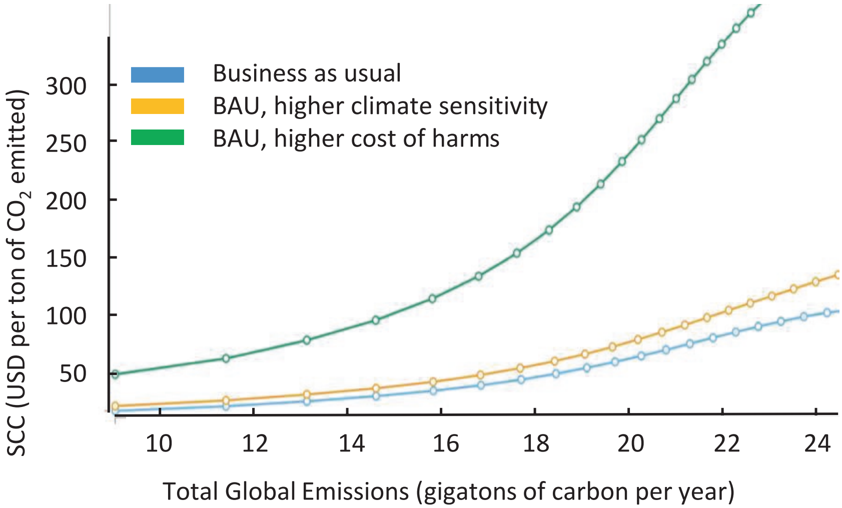

Fig. 2 Sample webDICE model output, from webDICE (2010). The y-axis shows the Social Cost of Carbon, in US dollars per ton of CO_2 emissions. A question to students based on this result is: What uncertainty has a greater impact on the costs of damages to our environment—climate sensitivity or harms?

speculate on climate science, economics, and even global policy as they struggle to interpret their results. Students also exercise good geoscientific habits of mind (GP3) and systems thinking (GP5) as they grapple with the very real role that uncertainty plays in the predictions they make about our future. How do interactions between Earth, economic, and political systems give rise to uncertain forecasts? Does uncertainty mean that we know nothing and should do nothing? Or does it play a vital role in how we should interpret any scientific result? Misunderstanding of the uncertainty in climate change projections by the general public is a long-standing issue for the scientific community (e.g., Collins and Nerlich 2015, Budescu et al. 2009), and these activities emphasize this important geoscientific habit of mind.

Carbon Emissions Game (Unit 6)

Another highlight of the module is presented in Unit 6, with a carbon pollution-specific application of the "Pollution Game" (Corrigan 2011). In this role-playing game, students are divided into three groups: Ace Energy, Deuce Energy, and the Regulator (i.e., the EPA), as they maneuver the regulatory options available for carbon pollution mitigation. Ace and Deuce are utility companies that each emit 15 million tons of carbon pollution a year, and the regulator has decided that these emissions must be reduced by a factor of 3. Ace and Deuce each have three different technologies that they can use to abate their emissions. Each technology has a different abatement cost (i.e., cost to reduce the utility's carbon pollution) and abatement potential (i.e., millions of tons of carbon pollution that can be eliminated through the technology). The object of the game is for Ace and Deuce to determine the "optimal abatement," i.e., the optimal balance between carbon pollution reduction and costs while learning about the strengths and weaknesses of the three different policy options.

The game is completed in three rounds, and Fig. 3 diagrams the game from the perspective of Deuce Energy. In the first round, Ace and Deuce must reduce their emissions by a technology that the regulator chooses. However, without allowing the free market to make the most cost-effective decision, this "command and control" approach is both costly and inhibits innovation. In the second round, the regulator sets the price of a carbon tax based on limited information that they receive from the utilities, and the utilities must determine their costs and optimal abatement. In the final round, the regulator sets an emission cap and issues or auctions permits. The utilities determine their optimal carbon abatement and negotiate the cost to buy or trade permits. The game is a lively exposure to the real world: utilities keep their proprietary abatement costs secret in an effort to save money, while the regulators are forced to make policy decisions based on the incomplete information that they

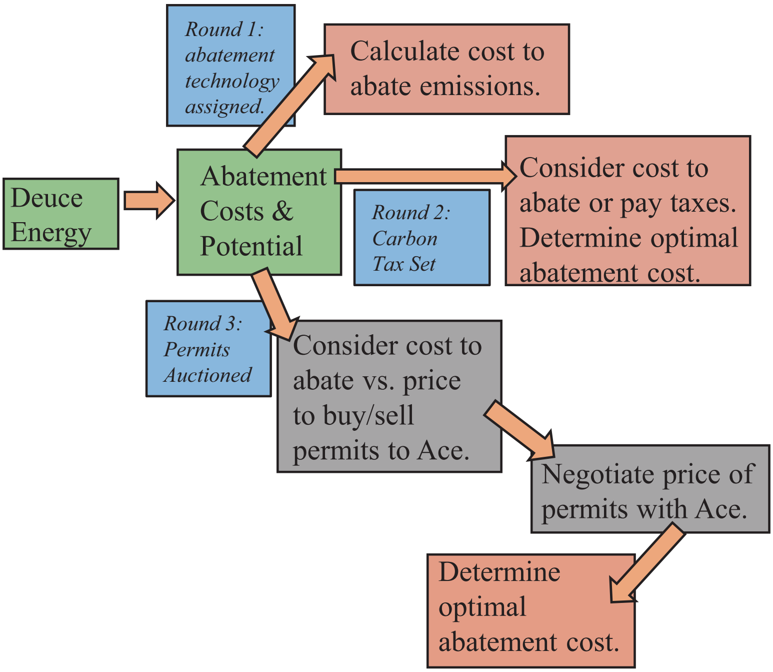

Fig. 3 Visualization of the Carbon Emissions Game from one group (Deuce Energy) perspective. In each round students calculate the total cost of the amount of abatement that is optimal from a cost perspective. From Penny et al. (2016)

receive from the utilities. We think that the carbon game, together with the cost-benefit analysis that precedes it in Unit 5, is a suitable alternative to the Carbon Mitigation Initiative: Stabilization Wedges activity (Hotinski 2018) that has been widely implemented in the classroom. Students learn to appreciate the complexity of the problem, applying interdisciplinary (GP2) and systems thinking (GP5) to understand the costs associated with reducing our future emissions, the costs (in damage to the world, measured in dollars) associated with a business as usual scenario, and the difficulty in implementing climate policy in a political environment that is often dysfunctional and irrational.

Climate Change from the Socio-environmental Systems Perspective (Unit 7)

A summative assignment asks students to write an Op-Ed piece to persuasively argue for a carbon pollution mitigation strategy in the United States. To promote synthesis of the interdisciplinary module, this assignment asks students to (from Smyth et al. 2017):

- Communicate accurately about the challenge of climate change.
- Describe natural, social, and economic impacts of climate change.
- Argue for strong policy to regulate carbon emissions to curb climate change.

The assignment utilizes a RAFT (role, audience, format, topic; Senn et al. (2013)) format, where the role is the area of expertise assumed by the student, the audience is newspaper readers, the format is Op-Ed Opinion Piece, and the topic is regulating carbon emissions. While the Format and Topic are the same for all students, the Role and Audience are assigned at the instructor's discression. For example, one student may write an article for the Washington Post (Audience) as a lobbyist for the West Virginia Coal Association (Role), while another student may write for a local student newspaper (Audience) as the leader of an indigenous community in Alaska (Role). We recommend that instructors select roles that reflect the learning goals for the course in which the module is taught. This assignment trains students to consider different perspectives, appreciate the complex dynamics surrounding climate change policy, and research a diversity of scenarios and audiences. The successful paper draws from topics throughout the module: scientific consensus on the grand challenge of climate change (GP1); webDICE model output (GP4); natural and economic impacts of carbon emissions (GP3); systems thinking connections between carbon emissions, damages, and regulation (GP2, GP5); and potential methods of carbon pollution regulation. We have found that students appreciate the opportunity to get creative with their roles, and an added benefit is that grading this assignment is never dry and repetitive!

Description of Module Pilots and Student Demographic Data

This module was piloted in spring 2016 at three different undergraduate institutions in New York State. Anonymous student survey demographic data was collected from a total of 33 students across the three pilots. Of these 33 students, 31 had already declared a major, and the most populous majors were arts (10), environmental sciences/studies (9), business (4), and social sciences (4). Most (25 of 33) were enrolled in the course as either a general education or major/minor requirement. The students were largely traditional college students: all but two were between 18 and 21 years old, with 9 freshmen, 12 sophomores, 9 juniors, and 3 seniors.

The first pilot occurred at The Sage Colleges, which is a small liberal arts college comprised of two campuses with a combined ~1500 students. The course is a 100-level offering called "Energy and the Environment" that meets general education science requirements and is populated by mostly art, business, and social science majors who take it as one of their only quantitative or scientific classes. This class has previously been lecture-centered and covers topics such as fossil fuels, environmental impacts of fossil fuels, alternative energies such as nuclear and renewables, and climate change. This module was completed in its entirety over 4 weeks at the end of the semester, and it replaced previous lectures on climate change.

The second pilot took place at Vassar College, a liberal arts college with ~2600 students. "Killing Fog: Coal, Energy and Pollution" was a separate 6-week intensive course at the intermediate level for environmental studies, international studies, and sociology majors. Building on the science, economics and politics of coal usage, and its impact on the United States and globally, the course explored coal's role in defining the Anthropocene and finally studied social movements against coal and fossil fuels. Throughout, the course concentrated on the understanding and communication of risk and the connections between scientific knowledge and public policy-making, in order to examine the terms of civic responsibility. The course integrated many components of the module throughout. The first two sections, concerning anthropogenic climate change and the social cost of carbon, set the foundation for the discussion on carbon emission policies in the United States and in the world.

The third pilot took place at SUNY-Plattsburgh, a 4-year public comprehensive college with ~5400 undergraduate enrollments. Environment and Society is a 200-level introductory course in environmental science and studies. The course examined the environmental challenges in water, air, biodiversity, climate, energy, population, waste, and consumption and explored how societal structures integrated into politics, economics, science, and the media influence collective understanding of environmental issues. The implementation of the module focused on the integrative and compounding effects of society on regulating carbon emissions. Following the module, in order to reinforce the embedded lessons, the assigned reading covered many of the same issues on a global scale and thus embedded the US response to climate change in an international context.

Overview of Student Attitudinal Surveys

Anonymous attitudinal surveys were administered both immediately before and after module completion concerning student attitudes about environmental issues. These surveys were administered to all students in all InTeGrate modules and are intended to gauge the overall success of the module in generating student interest in a broad range of environmental science-related topics. See Iverson et al. (this volume) for a complete listing of the attitudinal survey questions and discussion of the design of the questions. Only 13 students from our pilot completed both the pre- and post-pilot surveys; however, even with this small dataset, there are few notable observations.

A clear success of the module is that students became more engaged and aware of environmental issues. For example, when asked the question,

> As you consider employment after graduation, how important is it to you to work in an organization committed to environmentally sustainable practices (independent of the field)? Examples of environmentally sustainable practices would include minimizing energy and water use in the workplace,

student's responses rose from 4.69 to 5.23 (on a scale of 1–7), and only one of the 13 students gave a lower ranking after module instruction. Similar results (rise from 4.38 to 4.85 on a scale 1–7) were given in response to the similar question:

> As you consider career directions after graduation, how important is it to you to do work in which you use your knowledge of the earth and environment?

Students were also asked to indicate how frequently they engaged in certain sustainable or consumption-reducing activities in the past week. Responses to this question were varied and didn't show any robust results; however, when students were asked a follow-up question,

> When you engage in behaviors such as those listed in the previous question, what factors or sources of information influence your decision to do so?,

the three most popular responses were climate change (10 of 13), this class (9 of 13), and pollution (9 of 13). In the module, we repeatedly use the terminology "carbon pollution" in lieu of the more common "carbon emissions," so selection of pollution is likely tied to this terminology. Finally, all but two students answered yes to the question:

> As you think about your future, can you envision using what you have learned in this course to help society overcome problems of environmental degradation, natural resources limitations, or other environmental issues?

Follow-up explanations to this question mentioned a willingness to talk with others about environmental issues, leading through example (like not purchasing bottled water, installing solar panels, purchasing fuel efficient/electric cars, etc.), being wary of biased media coverage, using artwork to convey ideas, working in sustainable design, and environmental activism. One student wrote: "I think that the more nuanced understanding of modeling and policy-making surrounding climate change that I've received from this course will leave me better equipped to navigate these areas and find more realistic solutions in my professional life."

Despite these successes, there are a couple of limitations. For example, there was very little change in the response to the question:

> Please indicate your level of concern about each of the following potential developments on the Earth. Focus on the impact on your region in your lifetime.

Before (after) the module, 4(3) students listed climate change as "somewhat of a problem," and 9(10) listed it as a "major problem." We would have liked to see more of a change. In addition, while we were pleased to see that 4 of 13 students reported that motivation "to take action in their personal and professional lives to create a more environmentally sustainable society" rose from low to high over the course of the module, there were also 5 of 13 who reported low motivation both before and after the module.

Post-Pilot Modifications and Suggestions for Adopting These Materials

We made several modifications to the module after piloting, some motivated by our own experiences and others requested after a post-pilot review. Here, we discuss changes that we made after the pilot to address the module's weaknesses as well as tips for instructors considering adopting all or portions of the module.

All three instructors struggled to cover the material in the allotted time. To address this, after the pilot, we eliminated and consolidated a few activities that weren't as well aligned with the module's overall learning objectives and included more realistic time allotments in the activity descriptions. Still, the module takes a considerable amount of time to complete, and we don't recommend rushing through. A better solution for those with limited time is to skip some units altogether. Students also struggled to understand webDICE and models in general. In the final version of the module, we reduced the number of modeling activities from three to two, consolidated the assignments so that all of the modeling occurs in one unit (it was previously spread out over two), allotted more time for model discussion, and included some supplementary reading. Still, modeling is a complex topic, and more than the 95 min we have allotted will be required for deeper understanding. Next, we all struggled to present on topics far outside our areas of expertise. A strong suggestion to instructors adopting these materials is to spend adequate time preparing. The language of environmental economics might not come naturally to a scientist, for example. In addition, we found that some students struggled with the format of the summative Op-Ed writing assignment because they were unfamiliar with what an Op-Ed is and/or they were confused by the RAFT format and/or they were new to grading rubrics like the one we have supplied. Our experience with this assignment was overwhelmingly positive; however, instructors should take extra time out to make sure that everyone understands their responsibilities and how they will be graded.

Finally, reviews and our own experience showed that students were not developing systems thinking skills adequately throughout the module, and we made several modifications to address this. The concept map (Fig. 1) was added as a way to foster systems thinking discussion throughout. In Unit 7, students now return to the concept map, revisit a climate literacy assessment that they took prior to module instruction, and complete a system thinking exercise relevant to the summative Op-Ed writing assignment. We also reorganized the module into seven units. During the pilot, we delivered material by discipline in three units (science, economics, policy in consecutive units), but we determined that students needed some policy context to motivate the economic analysis. The new organization better connects the social cost of carbon and abatement costs to policy concepts and allows for more opportunities for disciplinary integration and systems thinking.

Summary

We have described a replicable, 4+ week interdisciplinary module where students first learn about the geoscientific analysis that has produced our understanding of the grand challenge of global climate change and then explore how that scientific analysis informs economic analysis and political decision-making. Rather than replicating disciplinary silos where students learn partial solutions to societal issues from a single perspective only, this integrated module creates a dynamic learning laboratory where students experience a mix of pedagogical techniques from physical and social science disciplines. Developing meaningful, viable solutions to the climate challenge necessitates a multifaceted and comprehensive approach.

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Tackling the Wicked Problem of Global Food Security: Engaging Undergraduates Through ArcGIS Online

Rebecca Boger, Russanne D. Low, and Amy E. Potter

Abstract Food security is one of the most pressing issues facing our planet. With this in mind, three professors from different disciplinary backgrounds, cultural geography, geosciences, and science education, created a 3-week module, *The Wicked Problem of Global Food Security*, collaboratively through the InTeGrate project. The interdisciplinary module has six 90 min units, is designed for introductory courses for non-geoscience majors, and can be used in online and face-to-face venues. In the first three units, students learn about Earth system science and explore factors that cause food insecurity (including climate, socioeconomic, and physical) through readings, lectures, and geospatial analysis using ArcGIS Online (AGO). The module culminates in the last three units (4, 5, and 6) with a small research project on food security in three localities: urban New York City, rural Nebraska, and developing islands in the Caribbean. AGO web maps with environmental and social datasets were created for each locality that students used in their final projects. The module was piloted in three courses: (1) an online introductory environmental science course, (2) an introductory course in urban sustainability, and (3) an introductory course in world region geography. Students were given pre- and post-course surveys to assess habits, academic and career interests, and possible impacts the materials may have had on the students. Students showed slightly increased awareness of environmental concerns and changing personal habits that promote

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sustainability. Many students commented on how much they enjoyed the module and were pleased at the ease-of-use of AGO.

Keywords Food security · Wicked problem · ArcGIS Online

Introduction

Food security is one of the great "wicked" problems of the twenty-first century (Dentoni et al. 2012). Due to the size, scale, and complex interconnections of wicked problems, they are difficult if not impossible to completely solve (Ritchie 2013). Centered on the premise "that all people at all times have access (including physical, social and economic) to sufficient, safe and nutritious food necessary to lead active and healthy lives" (FAO 2009, quoted in McDonald 2010, p. 2), food security is exacerbated by globalization, population growth, and climate change (McDonald 2010). Understanding the complexity of food insecurity and potential solutions requires a grasp of social, political, cultural, and environmental factors as well as access to diverse data sources and perspectives (Lund and Sinton 2007). Godfrey and others argue for the need to break "down barriers between fields" and navigate a "complex landscape of production, environmental, and social justice outcomes" (Godfrey et al. 2010, p. 418). In order to educate and empower our students to address this wicked problem, we have designed "The Wicked Problem of Global Food Security" (Boger et al. 2016) utilizing systems thinking and ArcGIS Online (an online mapping technology).[1] We find the use of ArcGIS Online to be of particular importance in our design of these educational materials. Sinton and Bednarz (2007, p. 23) write, "Problem solving involves arranging and modifying the variables until a satisfactory solution, or understanding, emerges. Maps, mapping, and GIS facilitate and support the steps of multidimensional, critical, and spatial thinking and problem solving."

This module includes six 90-min units for independent or sequential implementation. Only the culminating three units require that students synthesize knowledge from previous units to examine food security issues through a regional case study. Our goal is to describe the pilot of Wicked Problem of Global Food Security and evidence for its impact on student learning and engagement. We discuss alignment of the fact sheet materials and associated student work with InTeGrate guiding principles. We also discuss key revisions to the module that improved alignment with guiding principles and offer lessons learned for adapting or using this set of educational resources.

[1] A GIS (geographic information system) is a tool that combines information to a linked location on a map (Sinton and Lund 2007). GIS software can be used to visualize, question, analyze, and interpret data to understand relationships, patterns, and trends.

Module Description

The module, *Tackling the Wicked Problem of Global Food Security* (Boger et al. 2016), was part of the larger InTeGrate project that worked to develop educational materials for students that combined an understanding of Earth systems with key societal issues. The module, developed by the authors of this chapter, was designed for three institutional settings and was centered on the premise that students would accomplish three learning goals:

- Students will be able to use systems thinking to evaluate and assess food insecurity in a location by analyzing authentic geospatial and socioeconomic data.
- Students will be able to identify components, processes, and fluxes of Earth system science and apply these concepts in a location and assess the role the Earth system plays in the food system and contributes to food insecurity.
- Students will be able to propose plans to promote food security in a locality that include an understanding of the present-day food vulnerability, the interaction of human and natural systems, and impacts of climate change.

The materials were designed for introductory courses for non-geoscience courses and include a unit on Earth system science and other units where Earth system concepts are elaborated and applied. The module applies place-based pedagogy when students examine food security in three different regions (Caribbean, New York City, and Nebraska) using authentic and credible geoscience as well as datasets that are explored through GIS.

A variety of pedagogical approaches were employed throughout this module including flipped classroom, jigsaws, gallery walk, and project-based learning. The definitions we use for the pedagogic modalities employed in this module are listed in Table 1.

The unit topics, learning goals, and activities during the pilot period are summarized in Table 2. The module, including all instructor and student resources are open access and freely available online (Boger et al. 2016). Each of the Units 1–3 are structured explorations that can be used as stand-alone activities to meet their respective content and technology learning goals, whereas Units 4–6 provide the structure for the problem-based learning activity that results in an authentic assessment for the module. The module was piloted in three institutions of high education in three different courses (see Pilot Setting section below). While the overall course learning goals and objectives varied among the three pilot settings, the *Wicked Problem of Global Food Security* module learning goals were the same for the three courses, and all six units were implemented in the order listed in Table 2.

Unit 1 serves as the foundational introductory lesson that allows students to progress through the remaining units by defining food security and discussing the major factors contributing to food insecurity today (climate change, population growth, economic downturns, and change in global food consumption/wealth). Utilizing ArcGIS Online, students explore the global food system using a case study of the multiple geographic origins of a chocolate bar found in their local supermarket to describe its components.

Table 1 Pedagogic modalities employed in this module

Authentic Inquiry: An instructional approach that begins with the learner's interest and experience and enables the application of scientific reasoning skills
Authentic Assessment: A form of assessment that requires students to exercise real-world skills and knowledge when demonstrating learning outcomes
Flipped Classroom: An instructional strategy that moves active learning engagement into the social setting of the classroom and moves the more traditional lecture-type instruction to independent learning settings
Gallery Walk: Students are assigned to teams and rotate from one station to another, completing tasks and answering questions at each station
Jigsaw Strategy: Class is divided into teams, and each team completes a separate but related assignment. New groups are then created with one representative from each team, who brings her expertise on the past assignment to the new group. Individuals brought together then collaborate on a challenge that requires the expertise of each original group
Place-Based Instruction: Learning activities are situated in an environment familiar to the student, such as their neighborhood or community, strengthening the connection of the student with the disciplinary content that is the focus of the lesson
Project-Based Learning: An authentic learning approach where students build skills and knowledge as they solve a complex problem or challenge over an extended period of time

Table 2 Overview of units piloted in *The Wicked Problem of Global Food Security*, including learning goals and key activities for each of the six units (modified from Boger et al. 2016)

Unit	Learning goals	Key activities
Unit 1: Introduction to Global Food Security	1. Define food security 2. List the major causes of food (in)security 3. Describe the three components of malnutrition 4. Describe and illustrate the components of the global food system 5. Be able to create a simple map using ArcGIS Online	1. Pre-class homework/reading/quiz assignment where students are able to define and explain key concepts of this unit, i.e., food security, malnutrition, and global food network 2. Pre-class activity where student familiarize themselves with ArcGIS Online (AGO) 3. Class discussion of independent observations of food security 4. Create a map tracing the commodity of chocolate through the global food system considering the multiple factors involved
Unit 2: Systems Thinking and the Wicked Problem of Global Food Security	1. Describe the major components of the Earth system 2. Identify the parts of a system: flux, reservoirs, residence time, cycles, and feedback loop 3. Apply systems thinking to wicked problems like global food security 4. Create a diagram that identifies connections between the Earth system and the global food system	1. Completion of a pre-class reading describing the global food security as a "wicked problem" 2. Creation of a system diagram identifying parts of the Earth system and how they are connected to any one of the socioeconomic, geopolitical, and cultural factors that result in food insecurity 3. Group work chart and gallery walk conceptualizing the global food system 4. Written exit assignment describing any one aspect of the global food system how it is linked to other parts of the global food system, including both the human and Earth system aspects

(continued)

Table 2 (continued)

Unit	Learning goals	Key activities
Unit 3: Climate Change and Food Security	1. Describe how the broad features of the global distribution of climate zones are the result of uneven heating of the Earth's surface by the Sun 2. Describe the climatic conditions required for cocoa production, and identify regions on the globe where these conditions are found, using the Köppen Climate Classification System 3. Create a time-aware map application using ArcGIS Online to explore the projected impacts of climate change on cocoa production in Africa 4. Assess the past, present, and future impact of cocoa production on West African landscapes through analysis of map data and its impact on local food security	1. Completion of a pre-class climate system tutorial introduction to the climate system 2. Creation of a time-aware map web service showing biomes using the Köppen Climate Classification System, and determine what changes are projected that will impact the suitable production regions for cacao in West Africa
Unit 4: Case Study Group Work-Problem Identification	1. Brainstorm solution(s) to the wicked problem of food security using spatial tools 2. Synthesize multiple datasets and types of background material 3. Describe the various factors that influence food security in three different regional contexts	1. Completion of background readings on a region 2. Teams will then identify what aspect of food insecurity they would like to specifically explore in their analysis in the context of their community/regional plan
Unit 5: Case Study Group Work-Spatial Data Investigation	4. Make connections between the Earth system and cultural, economic, and political processes to understand the wicked problem of food security	1. Examination of food security using datasets in ArcGIS Online. 2. Creation of an action plan for a food insecurity issue teams have identified for their region
Unit 6: Regional Case Study Community Action Plans	5. Communicate findings via authentic assessment activity	1. Create a PowerPoint detailing food security context and solutions for an assigned region 2. Participate in a gallery walk and showcase their different regional solutions as articulated through a PowerPoint 3. Write a reflective essay describing the similarity and differences of food security in three regions

Unit 2 begins by contextualizing food security as an example of a wicked problem and then presents systems thinking as a way to identify complex problems and explore solutions, using the Earth system as an example. After a short class discussion that introduces concepts of sustainability and ecosystem services as they relate to food production, students are divided into groups and are asked to create their own system diagram of the global food system, using the organizational system concepts they examined as homework and the introduction activities of Unit 1.

Unit 3 students return to the theme of cocoa production introduced in Unit 1 by identifying climatic conditions conducive for cacao production around the world, especially West Africa where the majority of cacao is grown. They build a GIS application that displays biomes based on the Köppen Climate Classification System (Köppen 1900), a system that uses monthly temperature and precipitation to define boundaries between different climate types around the world. The system has been extensively employed as a conceptual tool in climate change research (Chen and Chen 2013). Upon identifying the regions in West Africa suitable for cacao production, they then explore how the range and extent of these regions are subject to change under different climate change scenarios.

Using a jigsaw model, each group of students uses a web application in ArcGIS Online to create a time-aware map sequence to evaluate changes in climate projected by one of the four emission storylines developed by the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Nakicenovic et al. 2000). Each emission scenario presents a unique story line based on assumed adjustments to population demographics, technological developments, and economic growth over time, with climate change consequences. Students then compare the projected climate outcomes of each of the four scenarios in specified cocoa production regions. This activity enables students to discover through data analysis and map visualizations the decisive role of societal decision-making in the future food security, using the case study of cocoa production as an example.

Units 4, 5, and 6 provide the opportunity for students to delve into a greater examination of food security at a regional level in small teams selecting one of the following locations: Caribbean, New York City, or Nebraska. In addition, there are materials provided to the instructor so that she can create other location activities to support place-based instruction. Unit 4 materials are designed to provide a place-based overview for students to prepare them for the summative assessment in Unit 6. Unit 5 allows students to delve more into an examination of food security using ArcGIS Online, with the intentions that students utilize their maps from ArcGIS Online within their action plan.

The module culminates with Unit 6, a summative assignment where students design a community-based action plan in a PowerPoint presentation. They are asked to utilize a variety of data sources addressing food insecurity in one of the three regional locations to showcase their mastery of all previous units. Students are expected to utilize components of all other previous units (1–5) by including (1) information from assigned readings and additional outside research, (2) a description of a system and a model that connects the Earth system to the global food system utilizing system terminology, (3) two maps they create based on the analyses of the ArcGIS Online activity, (4) discussion of the factors influencing food security in their region, and (5) two proposed solutions. These expectations were articulated in the rubric provided to students with the details of the summative assignment. During the pilot, the six units were employed in sequence; however, Units 1 through 3 can stand alone.

Traditional Versus Online Delivery

The module was adapted for use in an asynchronous online course and modified in several ways to accommodate the online, asynchronous modality of delivery. To keep the module structure parallel to the rest of the course, two units were bundled to comprise a week's assignments. The final module included 3 weeks of classwork; 1 week devoted to research and project development, followed by peer review; and an additional 4 days (during exam week) for incorporating feedback into the final product. Students conducted the group work in a variety of ways, including Skype sessions and face to face meetings. The gallery walks were interpreted in the online environment as an assignment with prompts to review and comment on the presentations posted on the class space by other groups.

A key feature of a successful online learning experience is a course design where participants are highly motivated to contribute to group discussions. For each unit, students were asked to compare the observations and outcomes of their investigations with that of teams examining other regions in the discussion board, so they needed to rely on each other's work to craft their weekly reflections. One of the most successful elements of this course was how its structure encouraged, promoted, and facilitated discussion and collaboration among class participants. Because the participants knew that their outputs for each of the assigned activities in the module potentially could be integrated into their final project, they were highly motivated to complete all the assignments in the module.

Pilot Setting

Table 3 provides a synopsis of some of the key characteristics of the three institutions and the respective courses where the module was piloted. All are public institutions and vary in size. They are located in three different regions in the United States—highly urban New York City in the northeast, rural Nebraska in the west north central, and the suburban Savannah, Georgia, in the southeast. Ninety percent of the students in the pilot identified themselves as non-Hispanic, 73% as white, and 11% as black. Forty percent of the students were in their second year of college. The remaining students were evenly divided between first, third, and fourth years (20% each). The majority of students enrolled in each institution are from the states in which the universities are located.

Table 3 Overview of the institutions of where the module was piloted

Institution	Type	Diversity[a]	Department	Venue	Enrollment	Course type
University of Nebraska, Lincoln	R1 rural land grant public university; ~26,000 students	77% white	School of Natural Resources	Online	22	200-level non-major course, science systems: environment and sustainability
Brooklyn College, CUNY	Urban public institution; ~17,800 students	26% white	Interdisciplinary program in urban sustainability	Face to face	15	Introductory course in urban sustainability
Armstrong State University	4-year public university; ~7000 students	57% white	History	Face to face	48 (2 classes of 24)	Introductory course in world region geography

Combining the demographics for all courses, there were slightly more female students (56%)
[a]Sources of demographic data: (http://www.brooklyn.cuny.edu/web/abo_misc/171120_Enrollment_Snapshot_Fall_2017.pdf), (https://www.collegefactual.com/colleges/university-of-nebraska-lincoln/student-life/diversity/), (https://www.armstrong.edu/about/quick-facts)

Armstrong State University is a 4-year public university in the University System of Georgia. The module was piloted in two introductory courses of world region geography (Geog 1100) with 24 students each. The students in the course were completing the global perspectives general education requirement, which included exploration of the themes of globalization, population geography, and agriculture as played out in major world regions. The module aligned with the themes discussed throughout the class and served as a final 3-week capstone allowing students to focus on the problem of food security in the context of a regional case study.

Brooklyn College is a highly diverse, urban public institution that is part of the City University of New York (CUNY) network of 2-year, 4-year, and graduate colleges that in total enrolls over 500,000 students. At Brooklyn College, the module was piloted in an introductory course for a new interdisciplinary program in urban sustainability (SUST 1001). This course is co-taught by professors in sociology, earth and environmental sciences, and economics and is structured by thematic modules (e.g., transportation, housing, water and air) taught over the course of the semester with perspectives from the three disciplines. Food is one of the themes taught. For this course, the instructor followed the materials as they were designed. It was taught at the end of the semester and presented sustainability themes touched on in other thematic modules earlier in the semester. The AGO presentation served as culmination of the themes for the new module as well as incorporating concepts taught in other themes. It served as a summative assessment not only for the module but for the entire course.

University of Nebraska, Lincoln (UNL), is a land grant public university with an enrollment of about 26,000 undergraduate and graduate students. The module was embedded in a team-taught introductory environmental science course offered by UNL's School of Natural Resources online, 200-level course, Envr201, science systems: environment and sustainability. The course emphasizes the importance of personal ethics, social responsibility, and sustainable practices as linkages between the environment and society and is designated as one of the UNL's Achievement-Centered Education (ACE) general education courses approved for enrollment by all undergraduate colleges at the university (ACE 2018). These courses are built on student learning outcomes that answer the fundamental question "What should all undergraduate students—irrespective of their majors and career aspirations—know or be able to do upon graduation?". The module was used in the last 4 weeks of the semester as a structured capstone project, an activity that is especially useful for lower division students who have little experience in completing a research project that requires collection and analysis of original data.

Connections to Integrate Guiding Principles

The InTeGrate program stimulates interdisciplinary teaching about the Earth for a sustainable future through the creation and dissemination of educational resources that can be used by undergraduate faculty (InTeGrate 2017a). Our module development team was composed of undergraduate faculty members with specializations in GIS, Earth systems, and cultural geography.

As all modules developed through the InTeGrate program, the *Wicked Problem of Global Food Security* module was designed to:

- Address one or more Earth-related grand challenges facing society.
- Connect geoscience to grand challenges facing society.
- Develop students' ability to address interdisciplinary problems.
- Improve student understanding of the nature and methods of geoscience and developing geoscientific habits of mind.
- Make use of authentic and credible geoscience data.
- Foster systems thinking.

Our food security module focus is the grand challenge of "Zero Hunger," one of the United Nations Sustainable Development Goals (UNDP 2016a). Whereas there is currently enough food to feed the world, it is not distributed in such a way that all obtain the food they need. By its very nature, understanding food security requires systems thinking. The food system from production to harvesting, packaging, distribution, cooking, consumption, waste, etc. is a system itself, which involves economics, politics, and cultural considerations of social systems as well as weather/climate, soils, geology, fuel, and microbial communities, among other factors within natural systems. While a single module cannot address all of these numerous dimensions of food security, it introduces learners to its complexity and has them think about how climate, Earth systems, and societal data all play crucial roles in its understanding. In this way, students examine the interactions within and among systems through the lens of geoscientists as well as social scientists. As we face rapid changes in climate, technology, and society, there needs to be a profound change in the global food production and distribution system in order to feed an additional two billion people by 2050 (UNDP 2016b).

As the title of our module indicates, food security is characterized as a wicked problem and thus meets the requirements of a problem-based learning (PBL) challenge: a complex, open-ended, real-world problem that lends itself to student exploration. As a mode of authentic inquiry (Chinn and Malhotra 2002), PBL pedagogies promote creativity, critical thinking skills, and problem-solving abilities in students. PBL also lends itself to exploration of topics by small teams of students and fosters social and communication skills in participants. Furthermore, place-based approaches help motivate students by leveraging and strengthening their connection to their own community (Adams 2013; Boger et al. 2014; Kudryavtsev et al. 2012).

Process of Course Development

Material developed through the InTeGrate program follows a carefully planned process that includes several team checkpoints, face-to-face team and cohort meetings, and internal and external product reviews. Our team was assigned an InTeGrate leader and evaluator who guided us through the process and answered our questions as needed. Our team held telecons every 2 weeks or as needed over the course of 2 years and kept in communication with each other through email correspondence.

The team members have diverse backgrounds and expertise that span the natural and social sciences including cultural geography, science education, climate change, geospatial, and geosciences. There were varying levels of previous collaborations from none to several. As well, there were varying levels of exposure to and application of the flipped classroom model using classroom techniques such as concept mapping, jigsaw, interactive lectures, and cooperative learning. The InTeGrate model had us design our module and individual units using backward design (Wiggins and McTighe 2005). As part of the development process, our mentors provided feedback on how well the units addressed goals and objectives using backward design and how well our formative and summative assessments measured student work.

The process was rewarding, though time consuming and at times frustrating. The six units were divided equally among us. We worked independently on our assigned tasks that we shared for review. As we drafted, shared, and revised sections, there were several iterations including modifications of the overall module and individual unit goals. The required checkpoints and monetary incentives kept us more or less on track given our busy, and often conflicting, schedules. The end product is a cohesive scaffolded set of six units. While the module can be taught as is, it is designed to be robust and flexible on the types of courses where it can be taught and how it can be taught.

The module was taught in three different contexts. At UNL the course was taught as part of an online course that emphasizes Earth systems content in the School of Natural Resources, while at Armstrong State, it was taught in a traditional face-to-face format in the History Department, arts and humanities. At Brooklyn College, the course was taught in an interdisciplinary program that includes departments in the School of Natural and Behavioral Sciences, School of Humanities and Social Sciences, and School of Business. As with Armstrong State, students at Brooklyn met twice a week in a traditional face-to-face venue. In the UNL online course, students used web conferencing software to meet with their teams, and kinesthetic activities such as gallery walks were emulated in online discussion boards. Whether online or face to face, the courses employed the same activities, data explorations, assessments, and rubrics. The breadth of university and course contexts allowed us to test the materials and later revise in order to make the module robust and flexible.

GIS as a Pedagogical Tool

GIS and more broadly geospatial technologies (GPS, remote sensing, and GIS) have been rapidly evolving over the past few decades and are now commonplace in everyday life. Smartphones are universally equipped with GPS capabilities, and many apps leverage Google maps. As users, we move from one app to another fairly quickly and quickly learn how to navigate new apps because of intuitive interfaces, standardized features, and visual displays. Spatial thinking is rapidly becoming a core skill for everyday life in the twenty-first century.

The National Research Council (NRC 2006) stresses the importance of spatial thinking and its usefulness in many academic disciplines and everyday problem-solving activities. Spatial thinking is defined as “the knowledge, skills, and habits of mind to use concepts of space, tools of representation (such as maps), and processes of reasoning to structure problems, find answers, and express solutions to these problems” (Sinton and Bednarz 2007, p. 28). GIS has become an important tool for geospatial visualization and analyses. It is an essential tool in geography, and many other disciplines. The primary products are maps, and maps provide the venue to represent these spatial relationships. By bringing datasets together, students learn how to detect spatial relationships such as containment, proximity, and adjacency. GIS can be used to generate or test hypotheses from visual examinations or geo-statistical analyses that reveal patterns. In this way, students can explore spatial relationships and possible causal interactions (Bearman et al. 2016).

However, perhaps as great as its importance in the promotion of spatial thinking is the ability of GIS to promote systems thinking and interdisciplinary approaches:

> There is a growing awareness of the value of spatial or geographic thinking to multidimensional critical thinking and problem solving. Inquiry-based education is a defining paradigm of college-level instruction in the United States today… In every one of these situations, the 'solution' involves a spatial or geographic understanding of why things are the way they are, how they got to be that way, and what would have to be different to change the results. (Sinton and Bednarz 2007, p. 23)

GIS is not commonly employed as an analytical tool in introductory courses, and it is only recently that analytically powerful GIS capabilities could be accessed by novice users without having to take a prerequisite GIS course. ArcGIS Online's (AGO's) simplified visual interface and intuitive navigation have drastically decreased the learning curve required to use GIS in the classroom. ArcGIS Online (AGO) has now become a tool that allows students to learn the mechanics of how to use the tool quickly, and as a result, students can be simultaneously introduced to GIS while also acquiring in-depth knowledge about the topic of global food security. More broadly, GIS is now a tool amenable to use in any course where the spatial analysis of data can support learning outcomes. Because AGO is web-based, students no longer have to be in a college computer lab to use the software; they can access the tools from their home computer. AGO can be accessed by users with a free public account, although the full capabilities of the software are accessed through a paid subscription or organizational account through the college or university.

In this module, AGO is used extensively, first as guided exercises to learn how to use the technology and then to explore spatial relationships of the food system using chocolate as a hook for engagement. For our introductory lesson, we adapted an AGO exercise, ArcGIS Online Five by Five (ArcGIS 2018),[2] which takes about 30 min to complete. By the end, students know how to move around the interface (e.g., zoom in and out, pan, change base maps, rearrange the order of the layers), create a new map, search and add new data layers, and symbolize the features displayed. ESRI's Living Atlas of the World allows students to search and explore high-quality datasets that can be easily integrated with other datasets in AGO.

The very first experiences with using ArcGIS Online can often be daunting to students, but the fun factor built into the "Story of my Chocolate Bar" activity lowered the anxiety level. The unit leveraged a familiar everyday food item and used it as an entrée to not only geospatial analysis tools but also to many aspects of the global food system—from sustainable production to fair trade to the use of slaves in producing luxury goods to the decision-making processes that cause agriculturists to produce cash crops for export in lieu of food crops that would be consumed locally. By identifying the social context of chocolate production beforehand, it was relatively easy for participants to cognitively link Earth system science and its relevance to social issues throughout the course.

Students then conduct their individual and team explorations of food security in different regions using AGO combined with other sources of information students

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[2] For educators interested in learning AGO and employing AGO in their classrooms, ESRI provides no cost instructional support (see https://esri.app.box.com/v/agoskillbuilder).

identify. Students thus examined how components of systems interact with other systems, for example, how cocoa production in West Africa may be impacted by climate change, which then impacts the cost and availability of chocolate bars in the United States. Figures 1, 2, and 3 highlight examples of the AGO activities.

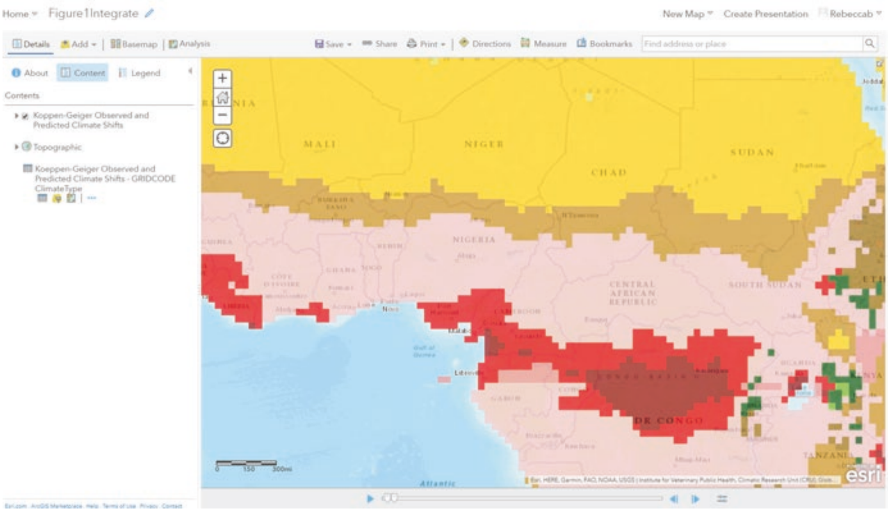

Fig. 1 Screenshot showing the Köppen-Geiger Observed and Predicted Climate Shifts (IPCC) data layer in AGO. Students select one of the IPCC scenarios (A1, A2, B1, or B2) to see how the climate changes through time. The scroll bar at the bottom shows the time period being displayed

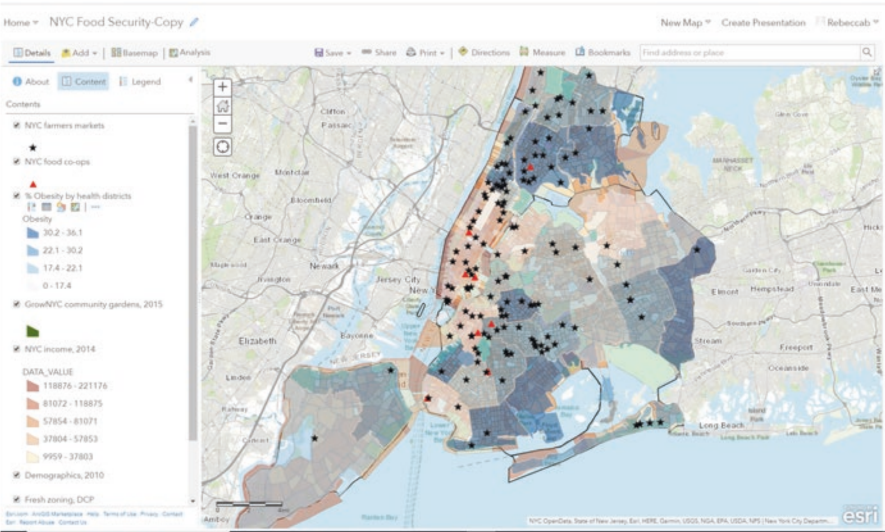

Fig. 2 Screenshot of AGO datasets for New York City activity. Students can work with these layers, examine the tables of data associated with the layers, and perform spatial analyses

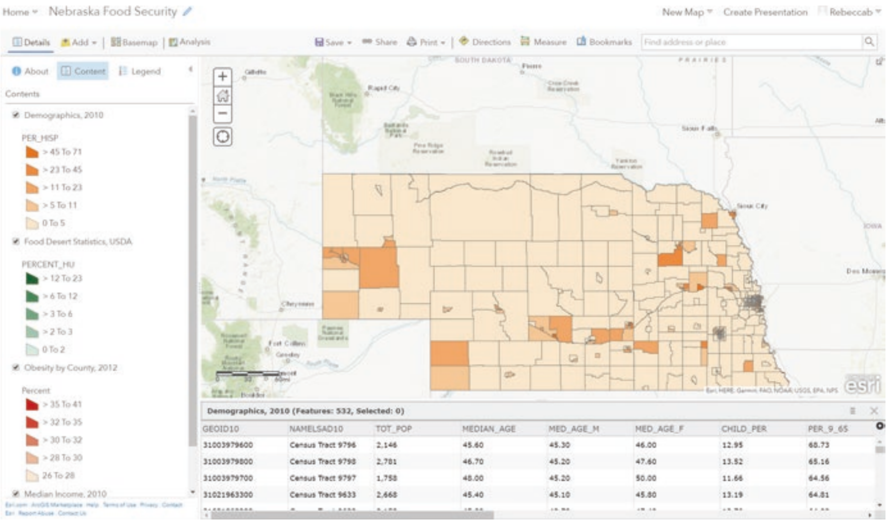

Fig. 3 Screenshot of AGO datasets for Nebraska activity. Students can work with these layers, examine the tables of data associated with the layers, and perform spatial analyses

Assessment

As part of the InTeGrate pilot testing process for the module, students were given pre-course and post-course surveys (InTeGrate 2017b). These questions were designed to assess habits, academic and career interests, and possible impacts the materials may have had on the students. In addition, a Geoscience Literacy Exam (GLE) was administered by SERC to assess students' understanding of geoscience concepts and systems thinking. Initial analysis revealed little differences among the students at the three locations. Results shown here are the combined totals for all three institutions. Unfortunately, there were no post-course surveys for the 22 students who took the online course. This reduced the number of students to compare pre-course and post-course surveys.

For the habit question, students indicated a fair amount of sustainability activities coming into the courses, and little change was seen in the post-course survey responses. Their habits included turning off water while brushing teeth, using cold water for laundry, recycling, and turning off lights. Pooled together, the majority of students do not use public transportation; however, those students located in an urban college do. There was a slight increase in the post-course responses indicating that they talk more about ways that humans impact the environment as well as refrain more from purchasing goods in order to reduce impact to the environment.

Student response to career interests showed little change in the post-course survey, other than fewer students who selected the "unknown" category. This may suggest that students felt better informed about what the various professions entailed and, so, were more confident in selecting the options provided. Thirty-four percent took the course for personal interest followed by 30% for general education of distribution requirement. Twenty percent each took the course as a major requirement or because it could be helpful in his/her career. There was little change in their intended majors.

For the question "As you consider career directions after graduation, how important is it to you to do work in which you use your knowledge of the Earth and environment?", students were asked to select a value from 1 to 7 with 1 indicating not important and 7 very important. The average value of 4.6 was the same for the pre- and post-course surveys. For a similar question that asked about the importance of the environmentally sustainable practices of the workplace, the average values showed a slight increase of 4.6–4.9 before and after the course.

Students' concern about environmental problems (global climate change, population growth, loss of biodiversity, and limitations in energy, water, and minerals) were above 83% for both pre-course and post-course surveys and showed little observable difference. The post-course survey had two additional questions where students were asked to choose a graph that depicts their level of interest or motivation before and after taking the module. For the question on whether the module increased their interest in choosing earth and environmental science as a career, the majority, 68%, said that it did not, while 31% said their interest was increased. More than half (54%) said that the module did not affect their motivation to take action to create a more environmentally sustainable society, while 42% said that their motivation was increased.

The GLE assessment instrument (InTeGrate 2016) contains eight questions (Table 4) derived from four geoscience literacy documents covering earth science, ocean science, atmospheric science, and climate science. The questions span a range of geoscience topics including natural hazards, atmosphere, biosphere, and geologic processes and time scales. See Appendix for list of questions. The total scores for the GLE increased from an average total of 6.7–7.7 out of 10. Table 5 shows the results of a paired T-test. Answers to all the questions except questions 1 and 4 showed increases in scores. Questions 1 and 4 ask about natural hazards and human impacts on the oceans. This is not surprising since the module does not discuss these topics. Answers to questions 5 and 6 pre and post showed statistically significant increased understanding with $p < 0.05$. These are the two questions on the test that addressed content covered in the module, specifically processes involving the biosphere and atmosphere.

Table 4 The eight questions from the Geoscience Literacy Exam used for all modules (from Iverson et al. 2018, this volume; for complete GLE, see InTeGrate 2016)

Q1	Natural hazards can be put into two major categories. Some natural hazards can be made worse by humans; others are largely independent of human activities. Select the natural hazard least likely to be affected by human activity
Q2	Which of the following geologic processes are most likely caused by the interactions between the tectonic plates at their boundaries?
Q3	Which of the following statements about the distribution of life in the oceans is most correct?
Q4	Which of the following ways do humans affect oceans?
Q5	Which of the following processes primarily involves the atmosphere and the biosphere?
Q6	Which of the following processes are sources of carbon to the atmosphere?
Q7	There are several climate models used to research future change. Which climate modeling statement about twenty-first-century temperature change projections is most accurate?
Q8	The first reasonably accurate mercury thermometers were invented in 1724, almost 300 years ago. What kinds of processes and/or data are used by scientists to determine temperatures more than 10,000 years in the past?

Table 5 Comparison of the pre-course and post-course GLE scores. The questions in orange are ones where the average value increased. The paired T-test results in red are those averages that showed significant differences at $p < 0.05$

	Average pre	SD pre	Average post	SD post	Paired T tests
Q1	0.90	0.303	0.82	0.386	0.484
Q2	1.22	0.584	1.36	0.509	0.196
Q3	0.65	0.481	0.69	0.466	0.496
Q4	1.14	0.540	1.01	0.463	0.243
Q5	0.42	0.497	0.65	0.480	0.026
Q6	0.83	0.717	1.40	0.667	7.78E-05
Q7	0.78	0.415	0.86	0.347	0.228
Q8	0.75	0.600	0.93	0.546	0.196
Total score	6.67	1.743	7.70	1.586334	3.46E-04

Conclusions

There were several goals our team hoped to accomplish through this module. First, participants addressed one of the UN Sustainable Development Goals and were given the opportunity to learn about Earth systems thinking and then apply the system concept to exploration of a societal issue, global food security. Second, because the classes serve lower-division students with limited to no research experience, we wanted to model a process of developing a research project stepwise over the course of 3 weeks. Third, we wanted to expose these students to geospatial technologies and ArcGIS Online, so they would experience the power of the tool and also the power of conducting an original analysis of data when doing research. Finally, we wanted the module to connect Earth system concepts with a socially relevant issue, i.e., global food security. All these goals were met by the module.

One of the most successful design elements of this course is how the units led students to apply systems thinking and develop a progressively more focused, specific original research question that they could explore using spatial data. While most of our lower division students had prepared research papers for other classes, most had never been afforded the opportunity to carefully develop a research question over a protracted time period or conduct original research using primary data. Several student teams indicated that they felt that their research had important outcomes, and this was evident when they invoked their own project outcomes as support of findings obtained in the final projects of the other teams. In student evaluations, one student said that she felt the module prepared her for developing research projects for future coursework in other subjects.

The gallery walks where student teams presented their research allowed students to examine similarities among the food systems operating in the three regions. As one student said about what she observed between Caribbean and Nebraska:

> I will admit, I did not think these two regions could have anything in common at all, but after going to the Gallery Walk… Nebraska, while they are a huge exporter, they have very few local grocery stores, farmers markets, and shops, but instead have a surplus of chains. While the Caribbean does not have a large amount of chains, they do import from those companies that supply, instead of buying locally grown products. The obesity rate in Nebraska was also similar to Jamaica's adult obesity rate for the same reasons-unhealthy, unnutritional foods. The main different between these two regions is that Nebraska is a huge exporter and the CARICOM countries are huge importers.

The importance of Earth system science to the societal issue of global food security was obvious to all the students by the end of the courses. Many commented that they were excited to see how helpful and user-friendly ArcGIS Online is and that they planned to take a future GIS course because they saw how they could employ these new skills in coursework in their home departments. The instructors noted that systems thinking was evident in student products. The opportunity for students to generate their own data for their final product proved motivating, and the students worked diligently on their projects.

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Using Ecosystem Services to Engage Students in Public Dialogue About Water Resources

Edward Barbanell, Meghann Jarchow, and John Ritter

Abstract Stormwater management under a changing climate will need to address more frequent and more intense extreme rainfall events. One way to mitigate the costs associated with stormwater runoff is to take advantage of ecosystem services already provided by the natural environment or mimicked through low-impact development practices. We developed a 3-week InTeGrate module, *An Ecosystem Services Approach to Water Resources*, to enable students to evaluate the impact of urban development on ecosystem services and stormwater runoff. In the module, authentic data (aerial imagery, rainfall and runoff data, the EPA's National Stormwater Calculator) are used to connect classroom knowledge to real-world problems. Modeling exercises are employed to engage students in actual or hypothetical campus- and community-based land-use decisions. The module was piloted in three different types of universities, programs, and courses. Student attitudes in all three environments were measurably changed by their participation in the module: interest in sustainability, intention to declare a related major, the importance of using knowledge gained from the course in their future careers, and the importance that the organization for which they worked was committed to sustainable practices all increased. Notably, students indicating that they were motivated to "take action in their personal and professional lives to create a more environmentally sustainable society" increased from 48% to more than 90%, and almost a quarter of the students became more interested in pursuing a career in earth or environmental sciences by the end of the courses.

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Introduction

Stormwater management under a changing climate will need to address more frequent and more intense extreme rainfall events. Rainfall amounts in the most extreme events have increased across the United States, from a minimum of 5% in the southwest to as much as 71% in the northeast (Melillo et al. 2014). Following extreme rainfall from Hurricane Harvey, van Oldenborgh et al. (2017) demonstrated that human-caused global warming has made extreme rainfall events, defined as the annual maximum 3-day precipitation amount, on the US Gulf Coast three times more likely and 15 percent more intense. Urbanized areas are especially vulnerable to extreme rainfall because land use associated with urban development affects flooding in many ways, including higher peak discharge and more rapid time-to-peak discharge (Konrad 2003). Concerns associated with stormwater management are among the most frequently cited by urban centers in response to changes in timing and quantity of extreme rainfall events (Carmin et al. 2012). Existing infrastructure is undersized, and future infrastructure in developing areas will need to account for not only increases in stormwater resulting from urbanization but also from climate change. One way to mitigate these costs is to take advantage of ecosystem services.

Ecosystem services are "the benefits human populations derive, directly or indirectly, from ecosystem functions" (Costanza et al. 1997). Ecosystem services are typically divided into four groups depending on the service role they play: supporting, regulating, provisioning, and cultural services (Millennium Ecosystem Assessment 2005) . The ability of ecosystems to moderate extreme rainfall events is an example of a regulating service. Soil absorbs rainfall, and the amount it retains becomes soil moisture. The excess flows on or through the soil and becomes stormwater, or infiltrates more deeply as groundwater, returning to the stream as baseflow. In contrast, much of the urban environment is covered by impervious surfaces, which converts much more rainfall directly into stormwater. The change in storage capacity associated with the land-use change results in lost ecosystem services that have historically been replaced by an engineered drainage network and series of detention or retention basins. We have traditionally viewed ecosystem services such as stormwater regulation as free, but Costanza et al. (2014) have valued them at $125 trillion per year. They estimate that the loss in ecosystem services between 1997 and 2011 due to land development alone amounted to $20.2 trillion per year (Costanza et al. 2014). Recognizing and maintaining ecosystem services already provided by natural areas in urban areas (Bolund and Hunhammar 1999) and introducing low-impact development practices—such as rain gardens, green roofs, porous pavement, and biofiltration—when development does occur, both provide sustainable solutions to stormwater issues.

As part of the InTeGrate project, we developed a 3-week instructional module, *An Ecosystem Services Approach to Water Resources* (hereafter *An Ecosystem Services Approach*; Barbanell et al. 2016), based on the impact that urban development has on the ecosystem services provided by natural soils. It provides students with (1) a conceptual framework, the hydrologic cycle, from which to understand the impact of development on stormwater backed by (2) an empirical framework using authentic data on rainfall-runoff relationships in undeveloped and developed watersheds and (3) a versatile toolkit for modelling the impact of land-use decisions on stormwater generation, including exploring different low-impact development (LID) practices to mitigate it.

The modeling exercises that form the basis for the final section in the module can be used to engage students in actual campus- and community-based land-use decisions (e.g., planning commissions, zoning board changes) but can be easily manipulated to simulate hypothetical or "what-if" scenarios of land-use changes as well. Exercises like this incorporate several high-impact practices, including collaborative assignments and community-based learning (Kuh 2008), and are increasingly being used by colleges and universities as an alternative to national surveys to assess student learning (Kuh et al. 2014).

Module Overview

Proposals to develop natural landscapes—turning them from green spaces and agricultural lands into industrial, commercial, or residential areas—are among the most common issues that come before local governing bodies. College campuses and nearby communities are often the locations for such projects. One of the ecosystem services most clearly affected by such urbanization projects is stormwater regulation: as natural, pervious soils are replaced by impervious surfaces, stormwater runoff increases during intense rainfall events. Such effects on the services provided by the existing landscape need to be recognized, measured, and taken into account when evaluating proposals for land-use change. The two goals of *An Ecosystem Services Approach* module are to introduce students to ecosystem services as a way of thinking about these sorts of land-use changes and to thereby empower them to become informed and active participants in the process of evaluating, discussing, and effecting such changes.

To accomplish this, the module progresses through three major units, each meant to take about a week. These units, their themes, and the transitions between them are illustrated in Fig. 1. In Unit 1, we focus on recognizing ecosystem services and understanding their relation to land use and the hydrologic cycle. In particular, we want students to understand how land usage and its associated ecosystem services can change over time. In Unit 2, we concentrate on modeling changes in land use and their impact on the hydrologic cycle, specifically stormwater runoff. We want students to be able to quantify changes in stormwater runoff associated with development through modeling as well as to recognize and model LID practices to reduce

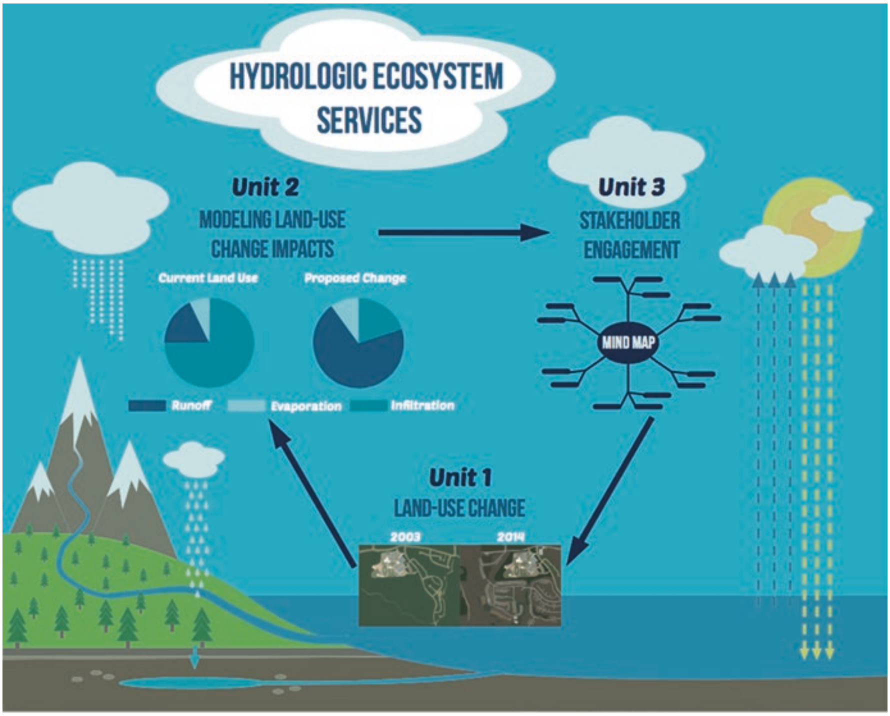

Fig. 1 Conceptual diagram of *An Ecosystem Services Approach* module

this impact. In the last unit, Unit 3, we want students to see these changes through the eyes of particular stakeholders and to be able to articulate the impacts of land-use change on water resources by utilizing an ecosystem services approach. To fully engage students in this process, we lead them through a case study analysis of a proposed land-use change within their own community—on or near their actual campus. They are asked to present a stakeholder position statement to a decision-making body responsible for approving the proposed change. Finally, students reflect on the efficacy and usefulness of an ecosystem services approach for considering land-use change and whether it sufficiently captures the full scope of the ways stakeholders value, use, and otherwise engage with their local landscapes.

The major units of *An Ecosystems Services Approach* are broken into eight separate subunits; most are meant to be completed in a single classroom meeting, with some pre-class preparation by the students. Table 1 lists the learning goals and key activities associated with each of the subunits. To get students to recognize ecosystem services and understand how landscapes and their associated services change over time, we first present them with the United Nations' *Millennium Ecosystem Assessment (MEA)* (2005) definition and categorization of ecosystem services. Students then apply that framework, through an examination of Google Earth satellite images of mixed landscapes (e.g., forest, crop fields, and housing). We also use

Table 1 Overview of module units piloted in *An Ecosystems Services Approach*

Unit	Learning goals	Primary activities
Unit 1.1: Mapping Ecosystem Services	1. Define ecosystems and ecosystem services 2. Identify and classify ecosystem services using satellite imagery 3. Demonstrate the variability of the production of ecosystem services at a particular location over time	• Present and discuss materials—pre-class reading and in-class presentation—on ecosystems and ecosystem services (e.g., UN's *Millennium Ecosystem Assessment*) • Evaluate Google Earth images of a mixed-use landscape, with multiple ecosystem services • Walk through a tutorial of Google Earth, e.g., search and layer panels, tools (ruler), and navigation • Utilize Google Earth's "display historical imagery" to evaluate how a particular landscape and its associated services changed over time
Unit 1.2: Exploring the Hydrologic Cycle	1. Characterize, from a systems perspective, the major components and processes of the hydrologic cycle as they relate to a small watershed 2. Analyze actual rainfall and runoff data, and construct a water balance equation, for a small agricultural watershed 3. Describe the relationship between (a) hydrology, rainfall and runoff data, and (b) watershed characteristics	• Present and discuss materials—pre-class reading and in-class presentation—on the hydrologic cycle and watershed hydrology • Retrieve, examine, and discuss online data for local watershed (e.g., Surf Your Watershed [EPA], Streamer [USGS]) • Construct water balance equation for a small agricultural watershed • Connect watershed characteristics to runoff data using images associated with the watershed's characteristics (e.g., land cover, impermeable surfaces)
Unit. 1.3: Understanding Perturbations to Hydrologic Systems	1. Analyze rainfall and run-off data from two different watersheds, one agricultural and one urban 2. Compare and contrast, both quantitatively and qualitatively, the difference between the two watersheds 3. Evaluate the role of ecosystem services in watershed hydrology and the water balance	• Present and discuss materials—pre-class reading and in-class presentation—on the impacts of urbanization on streamflow • Construct water balance equation for small urban watershed • Examine, using Google Earth images and NLCD land-use classifications, reasons for differences in the two datasets • Discuss the impacts to ecosystem services caused by urbanization and the ways to mitigate/remedy those impacts

(continued)

Table 1 (continued)

Unit	Learning goals	Primary activities
Unit 2.1: Hydrologic Impact of Land-Use Change	1. Model the impact of development on stormwater runoff 2. Compare the relation between rainfall and runoff data from pre- and post-development scenario 3. Assess the role of ecosystem services in regulating the hydrologic cycle	• Present and discuss materials—pre-class reading and in-class presentation—on the effects of urban development on floods • Introduce the EPA's National Stormwater Calculator (SWC) tool • Utilize the SWC to compare the runoff pre- and post-expansion of an existing residential neighborhood • Discuss how urban development effects stormwater runoff
Unit 2.2: Mitigation Using Low-Impact Development (LID) Controls	1. Model different strategies for mitigating the effects of development on stormwater runoff 2. Characterize the ecosystem services replaced by low-impact development (LID) controls	• Utilize the EPA's National Stormwater Calculator to model the effects of different LID controls (e.g. green roofs, infiltration basins, porous pavement) on stormwater runoff • Experiment, in groups, with trying to fully mitigate the effects of neighborhood expansion on stormwater runoff via LIDS in the SWC
Unit 2.3: Modeling Land-Use Change and Mitigation Strategies	1. Appraise the existing ecosystem services of a site being considered for development 2. Create a model to simulate the impact of that development on stormwater runoff 3. Identify and evaluate LID controls to reduce the impact of the development on stormwater runoff	• Present students with a hypothetical development scenario for an existing facility on or near their particular campus • Utilize Google Earth to evaluate the existing ecosystem services of the current scenario • Utilize the SWC to model the pre- and post-development stormwater runoff scenarios • Evaluate LID alternatives via the SWC to the proposed development to reduce the impacts of stormwater runoff

Unit 3.1: Land-Use Change and Stakeholders	1. Assess a proposed land-use change from multiple stakeholders' perspectives 2. Express different stakeholder values in terms of discrete ecosystem services 3. Evaluate the effectiveness of expressing stakeholder values into ecosystem services	• Present pre-class readings and discuss in class how an ecosystem services approach tries to incorporate cultural and aesthetic values in ecosystem services' trade-off calculations • Introduce mind mapping as a tool for identifying the cultural values of a location, place, or landscape • Use mind mapping to identify different stakeholder groups who have an interest in the site, how each group currently utilizes the site, and how the site could be utilized by those groups under various land-use change scenarios • Attempt to fully articulate groups' cultural values into discrete ecosystem services • Reflect on the difficulty of fully capturing cultural values in terms of ecosystem services
Unit 3.2: Presentation and Reflection	1. Develop stakeholder position statements, supported by hydrologic data 2. Present stakeholder position to panel representing a range of stakeholder groups 3. Reflect on an ecosystem approach to land-use change	• Student groups, representing particular stakeholders, prepare PowerPoint presentations • Presentations are made to a panel consisting of (or representing) university personnel responsible for deciding on the proposed land-use change • Complete a series of essay questions reflecting on key elements of the module

Google Earth's "display historical imagery" tool to show how landscapes, and their associated services, can change over time. Focusing in on just the water-related ecosystem service of stormwater control, we then present materials explaining, from a systems perspective, the hydrologic cycle and watershed hydrology. By comparing authentic rainfall and runoff data from two watersheds in Ohio, one mostly green space and agricultural land and the other much more urbanized, and then calculating the water balance equations for each of them, the students are able to evaluate the impacts to ecosystem services caused by urbanization and to begin to discuss ways to mitigate these impacts.

Next, we move onto modeling the impact of development on stormwater runoff and assessing methods to mitigate that impact using LID controls. Here we make extensive use of the EPA's National Stormwater Calculator (SWC) (EPA 2018). This free desktop application estimates the annual amount of rainfall and frequency and amount of runoff based on local soil conditions, land cover, and historic rainfall records, by accessing several national databases that provide soil, topography, rainfall, and evaporation data for any chosen locale. The SWC also allows users to select from several different LID practices (e.g., green roofs, infiltration basins, porous pavement, biofiltration) they would like to use and to see the effects of such controls on runoff. Exercises in Unit 2 are tutorial-based, using a location and hypothetical scenario typical of a planned development and for which a SWC file is available for uniformity in the class. The tutorial approach enables students to use the SWC to (1) model a baseline scenario for the location representing the current condition, then (2) model a proposed development without any LID practices, and finally (3) model the proposed development using LID practices to preserve or mimic ecosystem services as a means of making the proposed development stormwater neutral.

In the last unit, we bring together the skills the students learned in the first two units, and then add in the element of their personal connection to the landscape. In Unit 3.1, students are asked to consider an example of an actual or hypothetical proposed development project on or near their own particular campus. Using a mind-mapping exercise, they identify different stakeholder groups who have an interest in the site and all the various ecosystem services the site provides to those groups (Fig. 2). Unit 3.2 was tailored to take advantage of the locations, resources, and campus plans of our respective universities and the communities in which they reside. Our implementation of Unit 3.2 used both hypothetical and actual scenarios, involving land-use changes on campus, off campus, and at the interface of campus and the surrounding community. In all cases, the modeled scenarios introduced in Unit 3.2 address the impact of development on the stormwater runoff with the goal of making the development stormwater neutral through the use of LID practices.

As an example, the scenario used at Wittenberg by Ritter represented an actual land-use change on campus, the construction of an indoor athletic complex with practice fields, locker rooms, offices, and classrooms (Fig. 3a, b) on a space that was, at the time, dominated by an outdoor, grassed practice field. This figure illustrates the potential use of Google Earth or other available aerial imagery by students in their presentation of the scenario. The SWC allows users to capture a baseline

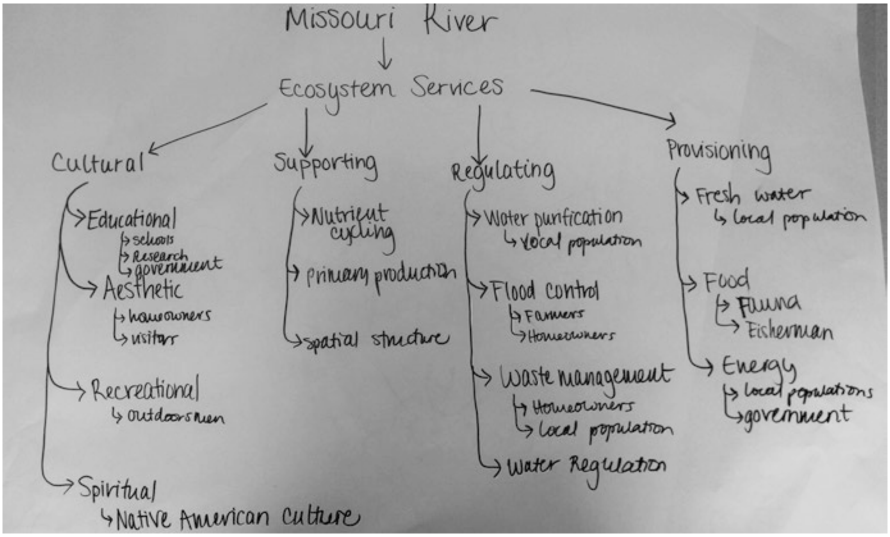

Fig. 2 Mind map created by students in Jarchow's pilot course (Barbanell et al. 2016)

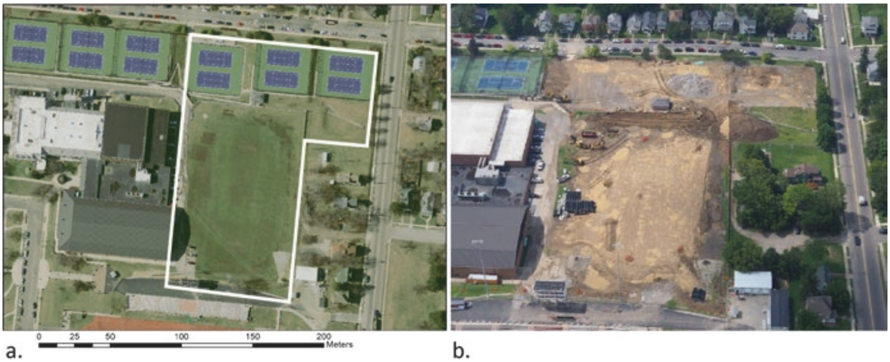

Fig. 3 (**a**) The proposed footprint of a new health, wellness, and athletics (HWA) facility on Wittenberg University's campus. The planned footprint, a total area of 4.8 acres, was originally 65% pervious (i.e., outdoor athletic field) and 35% impervious (i.e., tennis courts). (**b**) The HWA facility, including parking, will increase impervious area to approximately 90% of the total area

condition for comparison to subsequent model runs. The default output from the calculator is a pie diagram illustrating the percent of rainfall occurring as runoff, infiltration, and evaporation. The results for three successive simulations for the Wittenberg scenario are illustrated in Fig. 4. For most students, results presented in this format were easily and effectively understood and then incorporated into their final presentations. Some students explored additional options for reporting their results. Figure 5 is an example used by students during the Wittenberg pilot, build-

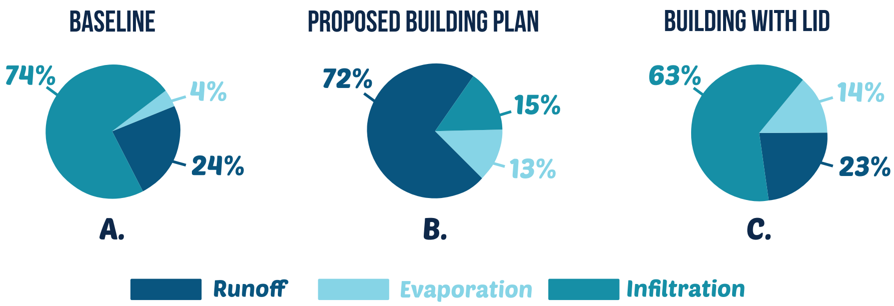

Fig. 4 Results from the EPA's National Stormwater Calculator illustrating percent runoff, infiltration, and evaporation from annual rainfall (37.50 in) for (**a**) the original baseline condition, (**b**) the proposed building plan, and (**c**) the building plan with low-impact development to control increases in runoff from the impervious surfaces

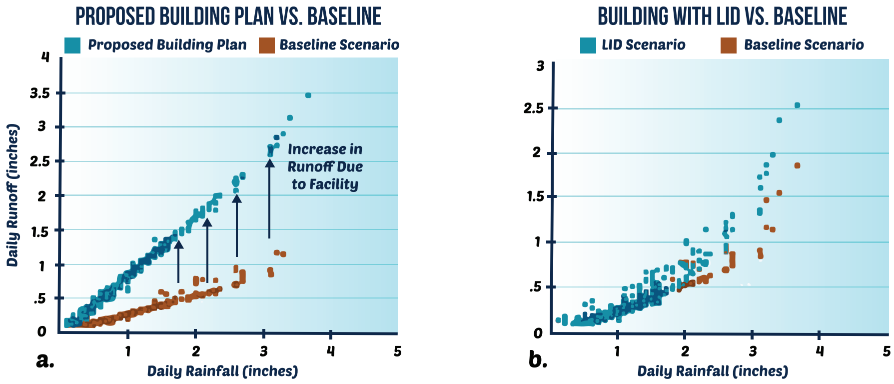

Fig. 5 Results from the EPA's National Stormwater Calculator illustrating the rainfall-runoff relationship for a distribution of rainfall events comparing the original baseline condition with changes in runoff due to (**a**) the proposed building plan and (**b**) the building plan with low-impact development to control increases in runoff from the impervious surfaces

ing on observations made from their analysis of rainfall-runoff data in Units 1.2 and 1.3. With this data in hand, plus the concepts and tools from the first two units, the students were put into presentation groups, representing some of the particular stakeholder groups previously identified (e.g., university administrators, facilities management, research faculty, residential students). Each stakeholder group was asked to put together a position paper, advocating for their own particular vision of how the site should be developed and utilizing hydrologic data from the SWC to support their argument.

Finally, having the students reflect on the value of an ecosystem services approach is an important aspect of the module. This final assignment asks students to define an ecosystem services approach, to identify advantages and disadvantages/limitations of using such an approach, and to evaluate whether they recommended using such an approach for making land-use decisions. This allows students to evaluate whether the concept of ecosystem services is sufficient to capture the full suite of values that different stakeholders may have or whether some values do not translate well into the concept of ecosystem services.

Pilot Settings

The module was piloted in three quite different types of institutions, programs, and courses. Wittenberg, where Ritter teaches, is a private, predominantly undergraduate university for the liberal arts and sciences affiliated with the Evangelical Lutheran Church in America. A leader in providing an active, engaged learning environment defined by excellence in academics, innovation, student success, service, and athletics, it has 1900 full-time students from 37 states and 15 countries, with an average class size of 20 students and a 13:1 student-faculty ratio. The module was piloted by Ritter in an introductory science course (Environmental Geology, GEOL 160) that serves the general education program as a lab science and is taken by science and non-science majors. It is a gateway course to majors in geology and environmental science and a cognate course for biology majors. It is data-driven, using locally available data or data from the US Geologic Survey, state surveys, and other federal and state agencies, to analyze geologic hazards and resources. This module was used to cover water resources in the course with the added context of ecosystem services.

The University of South Dakota (USD) offers undergraduate, graduate, and professional programs and is the only public liberal arts university in the state. USD has a total enrollment of approximately 10,000 students of which 75% are undergraduate students. The sustainability program contains an interdisciplinary, undergraduate major and minor that is housed within the College of Arts and Sciences. Jarchow piloted the module at USD in Sustainability and Science (SUST 203), one of the core, introductory courses for the sustainability major and minor, but it is open to students in any major and has no prerequisites. SUST 203 is a discussion-based course taught using team-based learning. There are four modules in SUST 203: climate change, energy, ecosystem services, and the built environment. *An Ecosystem Services Approach* is used for the ecosystem services module.

The University of Utah is the flagship public research university in Utah, offering over 100 undergraduate degrees, and more than 90 graduate degree programs, to over 30,000 students. Barbanell piloted the module there in environmental ethics (PHIL 3530), an intermediate-level philosophy course that satisfies major requirements for both philosophy and environmental and sustainability studies. The course also fulfills a Humanities general education requirement, so it attracts students from across the academic spectrum, particularly from engineering, the biological sciences, and urban planning. The course surveys various approaches to describing the different ways and reasons why we value "nature." Throughout the course, conceptual analysis is interspersed with examinations of real-world scenarios. Ecosystem services is an emerging area of inquiry for environmental ethicists, and the module was utilized in the last 3 weeks of the course.

The authors piloted the first two units of the module identically, but Unit 3 was tailored to take advantage of the locations, resources, and campus plans of our respective universities and the communities in which they reside. In all three pilots, the modeled scenarios introduced in Unit 3.2 addressed the impact of development on the stormwater runoff with the goal of making the development "water neutral" through the use of LID practices.

At Wittenberg, students modeled the impact of a planned campus facility on stormwater runoff. At the time of the course, the University was planning to convert a 4.8-ac area comprising a grassed practice field and several tennis courts to a health, wellness, and athletic (HWA) facility, including an indoor practice field, with parking. Students modeled changes in runoff, infiltration, and evaporation using the SWC for the building as proposed and with LID controls for comparison with the current, baseline use. They then presented their work to members of the Wittenberg community, including administrators from athletics and advancement. Our implementation of Unit 3.2 utilized both hypothetical and actual scenarios, involving land-use changes on campus, off campus, and at the interface of campus and the surrounding community USD is in Vermillion, SD, which is located on a part of the Missouri River that is a national park—the Missouri National Recreational River. The SUST 203 students modeled a hypothetical scenario of the expansion of an existing housing subdivision along the banks of the Missouri National Recreational River. The scenario involved the conversion of land currently used for annual row-crop production to low-density housing.

The University of Utah is sited on the downslope of an interface between urban and natural hillside areas, and at the time of the course, it was considering acquiring an adjacent site, right on this interface, that was mostly undeveloped. The students modeled a hypothetical scenario of developing the site in such a way that any additional stormwater runoff caused by the redevelopment be mitigated on-site, via LID strategies, so that the development would be "water neutral." Student groups prepared 15 min in-class presentations to invited guests that included students, faculty, and administrators.

Median student age was similar in all three courses at 21 years. Most of the students were self-identified as third or fourth year students: 61% in GEOL 160, 53% in SUST 203, and 56% in PHIL 3530. The gender composition was nearly equal in GEOL 160, whereas SUST 203 had more female students (63%), and PHIL 3530 had more male students (61%).

Module's Alignment with InTeGrate's Pedagogy

There are several pressing global resource challenges associated with water resources. However, the particular challenge of increased stormwater posed by rapid urban development is readily observable, understandable, and explainable to students; it lends itself to fruitful classroom exploration utilizing all five of the InTeGrate project's major themes and teaching strategies: (1) connect geoscience-related grand challenges facing societies, (2) develop students' ability to address interdisciplinary problems, (3) improve students' geoscientific thinking skills, (4) make use of authentic and credible geoscience data, and (5) foster systems thinking (Steer et al. 2018).

Throughout the module, we incorporated a variety of authentic data—satellite images, rainfall and runoff data, and soil and topography information—to connect classroom knowledge to the real world. This connection was further enhanced by utilizing local examples, especially in Unit 3, easily identifiable and relatable to individual students. Using these data, students explored the complexity and the relationships and interactions among components of both individual and interlocking systems, including watershed hydrology and the hydrologic cycle. Observations of changes in the actual landscape over time and association with concomitant changes to runoff data provided opportunities to develop the students' faculties for doing temporal and spatial reasoning. Modeling proposed land-use changes via the SWC allowed students to test hypotheses and alternative scenarios. And by directly inserting students into the process of explaining and advocating for a particular land-use change via the elements of Unit 3, we were able to expose them to the multiple disciplinary perspectives and points-of-view required for making critical decisions in a complex world.

Assessing the Impact of the Courses on Student Attitudes

Students in all three courses were given a survey, which was developed by the InTeGrate project assessment team, at the end of the semester to evaluate whether and how the course within which the *An Ecosystem Services Approach* module was taught changed their attitudes about environmental sustainability and possible careers in earth and environmental sciences. In general, student interest in environmental sustainability was high in all three courses. Approximately 55% of the students in our courses either had or intended to declare majors in sustainability or environmental science/studies (Fig. 6). More than 80% of the students indicated that it was important to them to use their earth and environmental science knowledge in their future careers (Fig. 7), and more than 85% of the students felt that it was important that the organization for which they worked was "committed to environmentally sustainable practices" (Fig. 8).

Our courses appeared to increase the students' interest in creating a more sustainable society through their personal actions and careers. Fewer than half of the students (48%) indicated that they were motivated to "take action in their personal and professional lives to create a more environmentally sustainable society" before the course, and this increased to more than 90% by the end of the course (Fig. 9). This change in motivation was relatively consistent among our three courses. We also found changes among the students in their interests in pursuing a career in earth

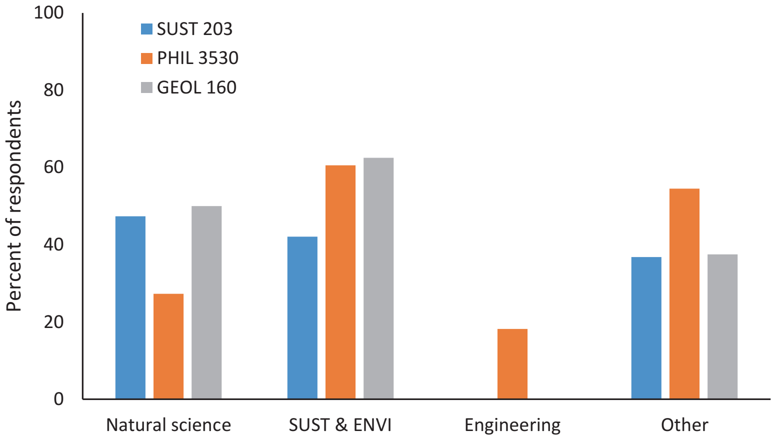

Fig. 6 Percentage of student respondents who indicated at the end of the course that they "will definitely or have chosen" to declare a major in natural science, sustainability or environmental science/studies (SUST & ENVI), engineering or computer science (Engineering), or another field (Other) in SUST 203 ($n = 19$), PHIL 3530 ($n = 33$), and GEOL 160 ($n = 16$). Natural science fields included biology, life sciences, ecology, chemistry, physics, and geosciences. The other fields included arts, business, economics, education, humanities, and social sciences

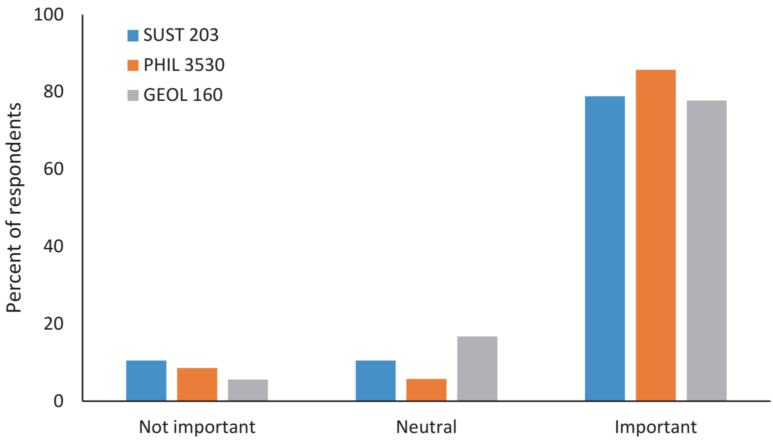

Fig. 7 Percentage of student respondents who indicated at the end of the course that it is not important (scores 1–3 on a 7-point Likert scale), neutral (score 4), or important (scores 5–7) for them to them "to do work in which [they] use their knowledge of the earth and environment" in SUST 203 ($n = 19$), PHIL 3530 ($n = 35$), and GEOL 160 ($n = 18$)

or environmental sciences. Almost a quarter of the students became interested in pursuing a career in earth or environmental sciences after taking our courses: an increase in interest from 64% at the start of the course to 88% at the end of the course (Fig. 10). The amount of change in interest from the beginning to the end of

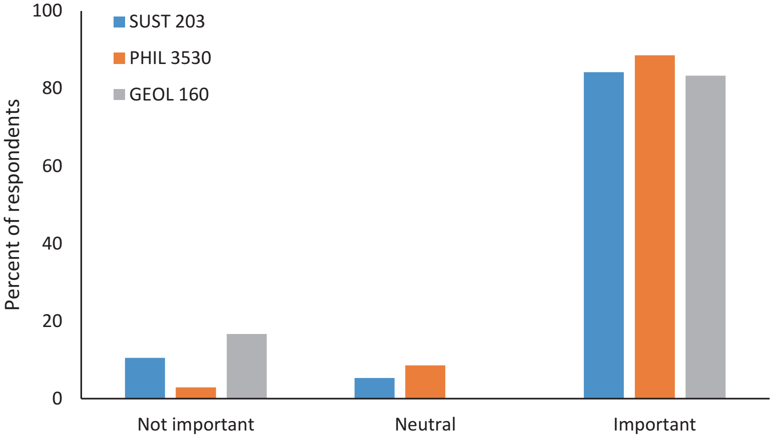

Fig. 8 Percentage of student respondents who indicated at the end of the course that it is not important (scores 1–3 on a 7-point Likert scale), neutral (score 4), or important (scores 5–7) for them to them to "work in an organization committed to environmentally sustainable practices (independent of the field)" in SUST 203 ($n = 19$), PHIL 3530 ($n = 35$), and GEOL 160 ($n = 18$)

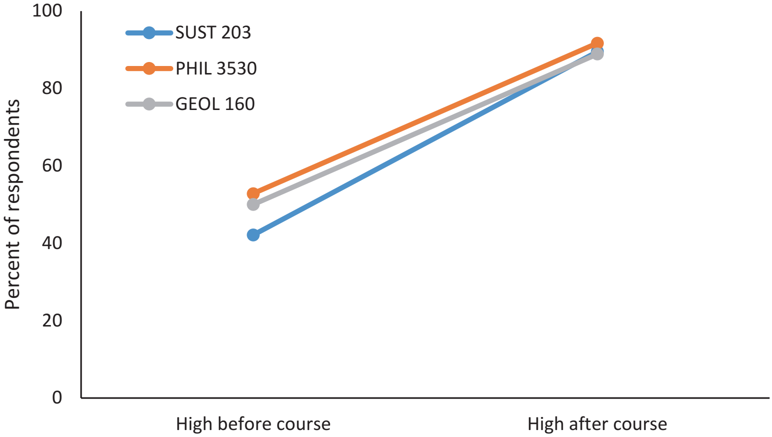

Fig. 9 Percentage of student respondents who indicated at the end of the course that they were "highly motivated" to "take action in their personal and professional lives to create a more environmentally sustainable society" before and after taking SUST 203 ($n = 19$), PHIL 3530 ($n = 36$), and GEOL 160 ($n = 18$)

the course appeared to be lower in SUST 203 than the other two courses, likely because students in SUST 203 had high interests in pursuing a career in earth or environmental sciences at the start of the semester (79% of students).

In response to the question "As you think about your future, can you envision using what you have learned in this course to help society overcome problems of

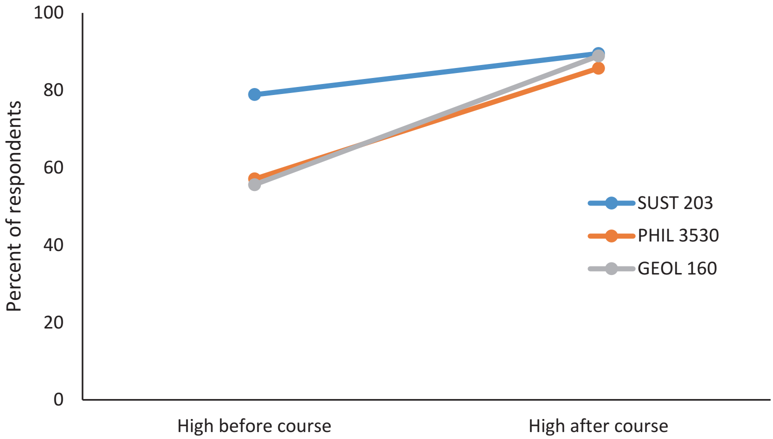

Fig. 10 Percentage of student respondents who indicated at the end of the course that they had a high level of "interest in a career in earth or environmental sciences" before and after taking SUST 203 (n = 19), PHIL 3530 (n = 35), and GEOL 160 (n = 18)

environmental degradation, natural resources limitations, or other environmental issues?", all but one of the students who answered the question selected "yes." Many students described how they would use the information from the courses to change their behaviors and educate other to do the same. For example, one student in SUST 203 wrote, "I can personally make choices daily to reduce [my] environmental impact and teach others what I have learned." Students also described how the courses improved their ability to address issues from multiple perspectives. A student in PHIL 3530 wrote, "If nothing else, this course taught me that the world we live in (and its problems) can be approached in a multitude of different ways. This is important because even the simple recognition of this fact can help different groups, cultures, etc. to work together to help make our world better..." Whereas another PHIL 3530 student highlighted the importance of integrating across academic disciplines "Instead of just viewing things mathematically and scientifically, I can now overcome the issues with a more deep way of thinking..." Students also identified the courses as increasing their critical- and systems-thinking skills. One PHIL 3530 student specifically identified the *An Ecosystem Services Approach* module as potentially influencing her career trajectory: "Before this class I was not very interested in storm drainage or hydrology, now that I am interested I would like to use my civil [engineering] degree to design sustainable water usage."

Conclusions

We felt that the module was successful in our courses, but there were also opportunities for improvement. On the end-of-the-semester course evaluations, students in GEOL 160 commented that "We used many different programs and got to see real data that was online for our local areas." All of the students in GEOL 160 found that the course, primarily through the *An Ecosystem Services Approach* module, "involved students in 'hands on' projects such as research, case studies, or 'real life' activities." The SWC software, however, was not compatible with Apple computers or tablets (Android or Apple), which limited student access to the software. In SUST 203, the students commented about the module that "I liked the content but I wasn't able to use the software on my computer so I felt like I was always behind on homework." The students generally found the software (Google Earth and the SWC) to be useful, but it can be difficult to ensure that all students have access.

We chose to have a place-based focus to the module by developing local scenarios for Unit 3. Using local examples has advantages because it builds on the students' existing knowledge of their campus or city and shows them how they can be active participants within those communities (Gruenewald 2008; Sobel 1996). There are also disadvantages to using a place-based approach. In a review of the module by the InTeGrate project assessment team, it was noted that it was difficult to determine whether the students were able to transfer the knowledge gained about their local communities to more general principles or to a larger geographic scale. One possible adaptation of the module would be to have students compare stormwater concerns among different geographic regions to demonstrate the universal importance of stormwater management, and hydrologic ecosystem services, highlighting how the specific hydrologic concerns differ greatly among regions. One of the strengths of the module is the pairing of ecosystem services and water resources because of their universal applicability but with numerous opportunities to tailor the module to any region.

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Teaching Societal Risk and Resilience Through Systems Analysis of Major Storms

Lisa A. Doner and Patricia Stapleton

Abstract Community resilience increasingly depends on adapting to *uncertain levels of risk* from weather extremes interacting with complex Earth surface processes. Preparation for extreme events, with risk assessment, management, mitigation, and resilience, requires community knowledge of natural hazards, many of which involve the geosphere, while geoscientists need to be aware of the social, political, and economic contexts into which they share data and risk communications. This three-unit, three-week teaching module introduces students to various natural hazards associated with weather and climate extremes, risk assessment for those hazards, and community-based risk mitigation strategies. At the same time, students acquire familiarity and hands-on practice with the vocabulary, data, data visualization, and communication of storm risk that they can carry forward not just in career applications but for practical use as community citizens. Pilot tests of the module at three university settings reveal that students acquire proficiency in many key components but underemphasize communications of the evidence base for their outcomes and proposed resilience strategies. The module is adaptive to many different regions and event types, with multiple activities that involve the use of local events.

Keywords Community · Education · Resilience · Risk · Storms

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Introduction

Extreme storms in any season can have major impacts on communities that lie in their path, as witnessed with the 2017 Hurricanes Harvey, Irma, and Maria and record-breaking low pressure and storm surge, followed by severe cold associated with Winter Storm Grayson. Many climate models predict increased frequency of heavy rains and icing events, freak storms, and severe weather within the continental United States as a result of ongoing climate changes (e.g., Jones et al. 2004). Varying conditions, such as time of year, time of day, tidal conditions, and societal response, can exacerbate the severity of a storm's impact. In particular, a community's ability to plan for and respond to major storm hazards, and to exhibit resilience afterward, depends on its capabilities in risk assessment, emergency management, and preparedness (Comfort et al. 2010; Linnenluecke et al. 2012; IPCC 2012).

Because the global climate system is undergoing rapid changes, preparedness for future risks now also depends on understanding that old paradigms about risk may no longer apply. New risk models must take into account complex and incompletely identified geosystem feedbacks. Community resilience, therefore, increasingly depends on adapting to an *uncertain level of risk* from weather extremes that involve largely complex and largely unknown interactions in Earth surface processes. Community preparation for extreme weather, through all phases (risk assessment, management, mitigation, and resilience), requires knowledge across several disciplines (i.e., Morss et al. 2005; Barros et al. 2014; Leal Filho 2017). Emergency management specialists in particular need to comprehend the processes involved with natural hazards, many of which involve the geosphere. Similarly, public policymakers need to understand natural hazard risks and vulnerabilities in order to appropriately direct their attention and resources. Finally, geoscientists need to be aware of the social, political, and economic contexts into which they share data and risk communications.

To meet this need, a creative team of three instructors, Lisa Doner (Plymouth State University), Lorraine Motola (Metropolitan College of New York), and Patricia Stapleton (Worcester Polytechnic Institute), with the assistance of an InTeGrate materials guide, John Taber, worked from 2014 to 2017 to develop the Major Storms and Community Resilience module (Doner et al. 2017). The module addresses Grand Challenges to Mitigate Risks and Build Resilience from Natural and Human-made Hazards (AGI 2012) and in Disaster Reduction (NSTC 2005), enabling individuals and communities to better assess and manage risks related to major storms, prepare for these extreme weather events, and demonstrate resilience in response to storm impacts. Educators are well-positioned to help train future decision-makers with an interdisciplinary knowledge base that prepares them to assess, manage, and respond effectively to natural hazard risks and to participate in community actions on risk reduction, adaptation, and resiliency planning (e.g., Shaw et al. 2009). This module puts educators on the front line addressing disaster reduction challenges in the next generation of citizens. It was first published on the

SERC course materials portal in fall 2017. Module development included pilot testing on 149 students in four courses at three institutions and in three disciplines: geoscience, public policy, and emergency management. While the module is aimed primarily at students in higher education, portions of it can be easily adapted to professional certification programs and grades 8–12.

Module Summary

The Major Storms and Community Resilience module uses interdisciplinary teaching materials that incorporate scientific knowledge, social and political perspectives, and logistical concerns, as well as illustrate the complex system of human and natural interactions of risk in major storms. It integrates three distinct fields into the coursework and assignments: geoscience, public policy, and emergency management. The materials target three specific learning goals so that students are able to (1) identify and describe weather-related hazards and vulnerabilities for their community, (2) relate historical storm data at the national and local scale in order to draw conclusions about community preparedness and current and future community vulnerabilities, and (3) develop evidence-based strategies and recommendations to mitigate local community vulnerabilities to storms, with specific emphasis on different sectors and/or stakeholders in that community. Although the module's materials focus on the intersection of geoscience, public policy, and emergency management, instructors can implement them in a range of courses, including in earth science, environmental science, and environmental sociology, among others.

The module is comprised of three units: (1) foundational concepts, (2) application of concepts to case studies, and (3) the "town hall" meeting. The module should be implemented in a course over three weeks, with each unit taking a week. The progression of course materials and activities builds particular skill sets and then challenges students to apply them in a series of real-world case studies. Each unit scaffolds on the one before, adding sequential and interactive layers of engagement, knowledge, and skill. Throughout the module, students participate in a range of activities and assignments that develop particular levels of awareness and sensitivity to system skill sets. For example, students use high-profile, extreme weather events as case studies to study storm-related risk and resilience measures and to analyze and apply information sources and data-handling methods. They also conduct their own research on storm preparedness in a chosen region, with a focus on risk assessment, management, and resilience through various investigative, data-rich assignments.

Unit 1 introduces foundational concepts in geoscience, public policy, and emergency management critical to the module's learning objectives. Within this unit, students acquire the vocabulary to communicate and share concepts on systems and risk. They engage in practical exercises on event probability and frequency that underlie the science behind meteorological weather warnings and watches. They write and orally present discoveries on these learned concepts in the context of two government case studies (the state of New Hampshire and the city of New Orleans in Louisiana), as well as for their own community. The first unit's activities include a pre- and post-unit survey on natural hazard risks; an exercise on probability, frequency, and how these concepts relate to natural hazards and risk; an exercise using hazard vulnerability analysis (HVA) and the HVA's findings; and a synthesis analysis of New Orleans' hazard mitigation plan (HMP), which includes students developing their own proposals to improve the HMP in light of the 2005 Hurricane Katrina disaster.

Learning outcomes for Unit 1 include the ability to recognize, define, and communicate geophysical, social, and policy foundational concepts as part of a system of major storm and climate change hazards, hazard mitigation, and community planning. Students achieve initial literacy in weather systems and extreme weather, including hazards, risks, emergency management, strategic planning, and stakeholder communication. These outcomes are achieved by iterative and reinforced use of relevant terms and concepts. These reinforcing actions include determining and using event probabilities and recurrence intervals for natural hazards associated with major storms (i.e., storm surge, inland flooding, icing, and blizzard conditions), identifying storm-related threats to critical infrastructure (i.e., electrical supply, transportation routes, drinking water), and conducting HVA and HMP assessments, followed by crafting policy memoranda and implementation proposals. Pre-unit and post-unit survey comparisons demonstrate these learning outcomes. The activities in Unit 1 also encourage and promote global skills in writing, math, data management, and data visualization in a real-world context.

Unit 2 serves as a bridge between the first and last units in which students apply foundational concepts to case studies. Students also engage in online research and data collection that relate storm hazards to hazard magnification caused by climate change. In this unit, students use two weather case studies that exemplify the multi-seasonal nature of storm hazards: Superstorm Sandy (a hurricane in 2012) and the Storm of the Century (a blizzard in 1993). Unit activities and assignments promote skills in finding, evaluating, and using real-world data as they relate to community preparedness, response, and resilience. These activities include analyses of local HMPs and of storm-related geophysical processes in the context of societal risk. Students learn how to write an effective press release for community preparedness, through a process of drafting, peer review, and revision.

Learning outcomes for Unit 2 include the ability to find and analyze large online datasets (numerical and graphical), critique and enhance existing policy, and communicate to a broad audience from a decision-maker perspective. These outcomes are achieved and assessed through activities that use sea level and storm surge datasets and visualization tools available through the National Oceanographic and Atmospheric Administration's (NOAA) Coastal Resilience Mapping Portal (NOAA 2018) and New York City's Open Data portal (City of New York 2018). Students also revisit and reinforce Unit 1 learning outcomes as they evaluate their local community's HMP in the context of major storm preparedness, risk communication plans, and various stakeholder perspectives. They synthesize this information in order to communicate risk and emergency warnings in a simulated press release to their community.

In Unit 3, students apply Unit 1 and Unit 2 concepts to evaluate multiple stakeholder perspectives of storm vulnerability and hazard mitigation in their local community. They embody roles of community decision-makers who seek to improve the local HMP to reduce stakeholder risk, which they do by presenting and defending recommendations in a simulated town hall-style meeting. These assignments develop students' abilities to work in teams to make and communicate evidence-based decisions and recommendations that mitigate local community and specific stakeholder vulnerabilities to storms and to defend those recommendations in a peer debate.

Learning outcomes for Unit 3 include improved ability to critically think about system dynamics, to express those thoughts in written and oral communications, to use team capacity in handling complex decision-making, and to evaluate the effectiveness of individual team members (using a rubric). The instructor completes outcome assessments by using evaluations of the oral presentation by each team and its team members, in addition to an evaluation of each team's policy position paper. The culmination of Unit 3 in the town hall-style meeting serves as the summative assessment for the Major Storms module.

Connections to the Five Guiding Principles of InTeGrate

Connecting Geoscience to Grand Challenges Facing Society

The module addresses five grand challenges in disaster reduction (National Science and Technology Council 2005), merging education in geo- and societal systems to produce learning outcomes that specifically aim to (a) increase understanding of the natural processes producing hazards, (b) develop hazard mitigation strategies and technologies, (c) recognize and reduce vulnerability of interdependent critical infrastructure, (d) assess disaster resilience using standard methods, and (e) promote risk-wise behavior. The module meets these challenges through its learning activities. Units 1 and 2 increase understanding of the natural processes, with the probability and comparative probabilities of risk exercise and homework on the Storm of Century blizzard and Hurricane Katrina. Multiple activities with HVAs and HMPs provide training on hazard mitigation strategies and technologies. Unit 2's sea level rise, case study, and press release activities promote recognition of vulnerability to critical infrastructure and comparisons of strategies, specifically in New Orleans and New York City, for reducing those risks. Unit 3 reinforces attention to all of the grand challenges and requires participants to assess disaster resilience using local data and to promote risk-wise behavior in two activities, the policy memo and the town hall meeting.

Develop Students' Ability to Address Interdisciplinary Problems

The Major Storms and Community Resilience module brings together perspectives from multiple disciplines on storm safety, hazards, and risks, with the aim of enhancing students' ability to conceptualize interdisciplinary systems related to these grand challenges. The interdisciplinary nature of major storms is highlighted through systems awareness in Units 1–3, with assessment of this awareness in concept maps in Units 1 and 2, identification of stakeholders and vulnerabilities in Unit 2, and application of system knowledge in the culminating activities in Unit 3. This module addresses a long-standing challenge to apply components of scientific thinking and approaches in traditionally non-science-based situations so that they enhance overall outcomes of understanding and awareness.

Improving Students' Geoscientific Thinking Skills and Make Use of Authentic and Credible Geoscience Data

The module focuses on the short- and long-term geologic processes of sediment transport and deposition that influence impacts and outcomes during extreme meteorological events. Various activities, especially in Units 1 and 2, explore the role of sediment in the creation of floodplains, river banks, beaches, and sand dunes. In Unit 2, two case studies illustrate how land topography and elevations of river banks, levies, and coastal dunes interact with storm-related changes in water height to cause inland and/or coastal flooding. For example, the Sea Level Activity uses GIS-based maps of topography data and FEMA flood zones, as well as data on storm surge and projected sea level rise, and places these geoscience elements inside New York City's five boroughs. Students must then evaluate how infrastructure and population density interact with local geology to enhance flood risk and all the system components related to that risk, such as access by emergency responders, flooded utility services, and escape routes (Fig. 1). In addition, the Coastal Erosion Activity engages students with LiDAR data and pre- and post-Superstorm Sandy beach and sand dune elevations. It encourages students to consider how sediment loss affects future flood risk and asks them to determine which response is more feasible, allowing the dunes and beaches to reform naturally or rebuilding them using imported sand. Finally, the Debris Removal Activity looks at sediment flood deposits from two perspectives and compares cleanup costs, with sediments treated as storm waste or as a resource for beach rebuilding.

It is important to note that interdisciplinary problems often require understanding of both science and society, but student and instructor abilities to apply knowledge across those disciplines vary widely. While the module is designed so that the material is accessible to individuals from a wide variety of backgrounds, a significant component of the module is focused on fostering geoscientific thinking

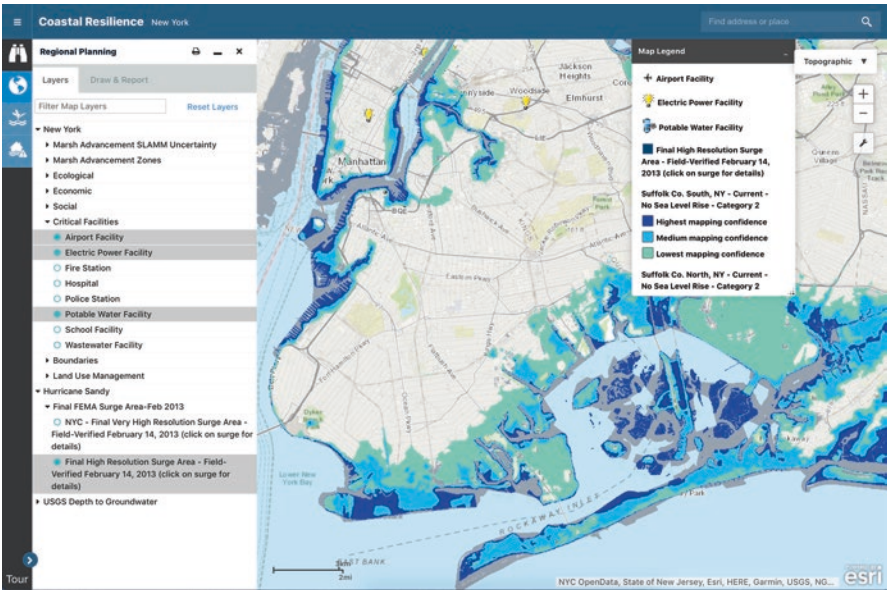

Fig. 1 Example view from the Unit 2 Sea Level Activity, illustrating the use of the Coastal Resilience Tool to map out Superstorm Sandy's storm surge flooding in New York City (light blue) and critical infrastructure (see map legend), based on data from USGS, FEMA, Esri, and Garmin

skills and making use of authentic and credible geoscience data. Our pilot studies indicate that instructors without prior training in geoscience, physical geography, or map visualizations may find the science concepts and exercises easier to implement by partnering with a geoscience instructor. As such, we recommend partnering with science instructors in the General Education program as a way to help non-science majors develop skills that address interdisciplinary problems and scientific habits of mind.

Upon consideration of the roadblocks that our two non-geoscientists encountered during the pilot, we made the Coastal Erosion Activity in Unit 2 an optional assignment, and we reduced the time needed to complete the Sea Level Activity by simplifying the questions. Students had struggled with these map-based activities in the pilot process and were often frustrated when the small screens on their cell phones proved inadequate to access the activity's high-resolution, geospatial imagery. However, these data visualization methods are commonly used by NOAA, FEMA, and the US Geological Survey Hydrologic Service and Emergency Management divisions, making them an important aspect of hazard awareness and risk mitigation. As such, we still encourage instructors to make use of the assignment, if possible, because the effort and time spent mastering the map interface ultimately increased student confidence with online mapping tools, a skill that can be applied to maps of new events such as USGS Emergency Management Event Support for Hurricane Harvey (2018), for example.

Fostering Systems Thinking

Throughout the module, students consider and conceptualize the natural and human systems that come into play during major storms. They learn how these system interactions act to increase or decrease community risk, vulnerability, and resilience and how policy decisions can mitigate or enhance these outcomes. Systems thinking awareness is the primary objective of the first activity in which students sketch out their current perceptions of a major storm system in a concept map. Throughout Unit 1, activities and readings promote an increasingly broader perspective about how major storms interact with topography, river systems, coastal geomorphology, sea level, and, ultimately, climate change. At the same time, activities involving hazard mitigation plans illustrate and guide thinking about human recognition of storm hazards and risks and of decision-making that can reduce loss. In Unit 2, case studies help develop understanding about the wide range of impacts that can arise in single storm events and about the effectiveness of existing mitigation plans. After deep immersion into these case studies, students return to their original storm system concept map and revise it (or redo it), to reflect on their new, and hopefully wider, knowledge. In Unit 3, system awareness is called into action as students create revisions to a hazard mitigation plan as preparation for a future event. They take on the roles of various stakeholders proposing changes that enhance their resilience and reduce their risks, using evidence drawn from past system outcomes.

Module Pedagogy and the Need for Climate Education

The Major Storms and Community Resilience module prepares students across disparate disciplines to develop interdisciplinary skills associated with storm resilience. Active learning pedagogy (Bonwell and Eison 1991; Michael and Modell 2003; Michael 2006) underlies all the module materials, capitalizing on different student knowledge bases for module topics while exposing students to interdisciplinary concepts. The module contains almost no traditional lecture material aside from a suggested introduction to systems thinking and concept map construction. Instead, over three weeks, a series of activities and assignments engage students in research that links together geoscience data and societal need in an interdisciplinary framework (i.e., Egger and Carpi 2013), built upon student knowledge within their own discipline. Active learning techniques used throughout the module's activities and assignments include (but are not limited to) jigsaw (Aronson et al. 1978), peer learning activities (e.g., Topping 2005), think-pair-share activities (Lyman 1981, 1987), and structured debates (e.g., Oros 2007).

The development team considered several factors when selecting active learning as the pedagogical approach for the module, including the general state of climate education in the United States and the stated outcomes of the InTeGrate project. As Kuster and Fox note in their study on climate education in natural and social sciences in the United States, the current generation of young adults "will be faced with difficult decisions on how to best guide local, regional, and national communities in adapting to and mitigating the impacts of climate change" (2017, p. 614). Thus, undergraduate and graduate students will be the "future innovators and leaders of our communities" (Kuster and Fox 2017, p. 621), and "as voters, they are capable of contributing to political and social change in the present," which makes "their understanding of this urgent, socioscientific issue… critical to the future of the global climate" (Huxster et al. 2015, p. 150). Other scholars have already demonstrated that the American public's understanding "has not tracked [with] scientific understanding" of climate change (Weber and Stern 2011, p. 317; Huxster et al. 2015). College students are no different as a demographic subset of the American public (Huxster et al. 2015); research shows that they "have alternative conceptions and fragmented understandings about climate science due to the complexity of the climate change models, and [to] the multidisciplinary content knowledge… needed to be able to understand and articulate the key concepts in climate science" (Versprille et al. 2017, p. 407). This lack of scientific literacy regarding climate is concerning because it can result in a general misunderstanding of the effects and severity of climate change, which can in turn lead to ineffective solutions and "possibly weakened support for governmental initiative" in responding to climate change (Huxster et al. 2015, pp. 162–163).

One approach to solving the lack of convergence between scientific understanding of climate change with the American public's understanding would be to improve science literacy through education. However, studies have shown that while increased scientific literacy can help people grasp the causes and effects of climate change and encourage interest in the issue, public engagement is needed to effect real change and increase public attention to climate change.[1] In this context, public engagement means that "the public needs to actively take part in learning and action on climate change" rather than to passively receive climate change risk communications (Wibeck 2014, p. 391). Wibeck details two types of public engagement: (1) "public participation in climate science and policy processes" and (2) "a personal state of connection with the issues of climate change" (Lorenzoni et al. 2007, as cited in Wibeck 2014, p. 391). She concludes that "there is a need for anyone looking to facilitate learning to [not only] consider the communicative context for climate change education, but also to explore learners' already existing perceptions of climate change" (Wibeck 2014, p. 391).

The results from Huxster et al. (2015) study of undergraduate students' understanding of climate change track with Wibeck (2014) argument. The researchers found that majoring in science and being a member in an environmental group both had significant positive effects on student understanding of climate change. However, of the two variables, the environmental group membership was "a greater indicator of a high Knowledge Score [on the administered survey] than enrollment in a science major" (Huxster et al. 2015, p. 158). Although Huxster et al. found this result to be surprising, they noted that a possible explanation "could be that respon-

[1] For a brief literature review of this "information deficit model," see Wibeck (2014, pp. 390–391).

dents' greater understanding is a function of a higher level of interest and concern for climate change, which is manifested in the respondents' choice of major and environmental group participation" (2015, p. 163). This would support the approach that improved understanding of climate change can be facilitated not only by an improved science literacy curriculum but also by deeper engagement with the topic. Students who make a personal connection to climate change issues should have fewer misconceptions about climate change and thus would be better prepared to address it effectively.

The two major goals of the InTeGrate project are to "develop curricula that [will] dramatically increase Earth literacy of all undergraduate students" and "to increase the number of majors in the geosciences and related fields who are able to work with other scientists, social scientists, business people, and policy makers to develop viable solutions to current and future environmental and resource challenges" (InTeGrate 2017). The first goal clearly aligns with the "information deficit model" approach to improving the public's understanding of climate change: develop and support efforts to increase scientific literacy. And, while not as explicit in its language, the InTeGrate project's second goal focuses on the need for public engagement. InTeGrate emphasizes the importance of connecting "geoscience education to societal challenges" through a community-based and interdisciplinary approach (InTeGrate 2017). The project's leaders recognized that in order to increase scientific literacy and facilitate students making a personal connection to climate change issues, educators must employ interdisciplinary teaching materials that incorporate scientific knowledge, social and political perspectives, and logistical concerns.

As such, the Major Storms and Community Resilience development team set out to meet the InTeGrate project's goals by bringing together the fields of geoscience, public policy, and emergency management. The team designed the materials to foster geoscience literacy of and a personal connection to natural hazard risks—specifically major storms—through the achievement of our three specific learning goals. The team's active learning approach to module development started with assignments using historical cases and primary documents as scaffolding to familiarize students with a range of material and activities. This approach gave students the opportunity to explore both the role of scientific expertise in public policy-making and administrative tasks such as writing hazard mitigation plans and writing press releases. The module then requires that students use their newly developed analytical skills to assess their own community's hazards, risks, and vulnerabilities. The module culminates in the mock "town hall" meeting, which has students role-play as community stakeholders who take part in the hazard mitigation and policy-making processes.

Learning assessment is built into many activities, such as the HVA Activity in Unit 1. For this activity, students complete and submit their homework on HVA and HMPs before the next class meeting. This Just-in-Time-Teaching technique (Novak et al. 1999) allows the instructor to identify areas of concern or low understanding before the class meeting. In another example of assessment in Unit 1, a concept map activity allows the instructor to provide feedback to students in a way that encourages a broader scope of interdisciplinary systems thinking. In Unit 2, a required revision by students of their concept map helps to reveal both areas of increased understanding and areas where students might need additional instructor feedback. The culminating town hall meeting and related Unit 3 assignments emphasize team effort, peer training, and peer evaluation on interdisciplinarity and utilization of systems understanding. In some pilot tests, this final activity clearly transported the class into a higher plane of systems understanding because of the peer interaction, the challenge of a town hall debate, and student "ownership" of decision-making.

Module Assessment

The efficacy of the storms module in meeting broader InTeGrate goals was assessed during pilot tests, using Geoscience Literacy Exams (GLEs), pre- and post-module attitudinal surveys, and summative assessments (Iverson et al. this volume) and reviews by InTeGrate evaluation guides and outside reviewers. In 2016, 89 students who participated in the module pilot tests were evaluated, with 49 in an Introductory Environmental Science course at Plymouth State University, NH; 2 in a Disaster Response and Recovery course at Metropolitan College of New York, NY; and 39 in an American Public Policy course at Worcester Polytechnic Institute, MA. Of these, 89, only 32 fully met the matched pair survey criteria for attitudinal evaluation, and the large majority (27) was in the American Public Policy course.

Of greater importance are the summative assessments, which determine how well students in all the pilot studies for this module demonstrated the targeted learning outcomes of the module. According to these module-based assessments, students learned to identify local weather-related hazards and vulnerabilities, many with a level of sophistication that indicated systems thinking. For example, in the American Public Policy class, students were able to name several more natural hazards, on average, when asked to list as many as they could after completing Unit 1 of the Major Storms module than at the start of the course. In addition, student responses to the request to rank the hazards in priority for state funding and explain why the highest priority hazard was so ranked yielded a higher level of specificity in justifications for funding, as well as more attention to key concepts such as the frequency, probability, severity, intensity, and impact of natural hazards (Table 1).

Unfortunately, student learning fell short of desired outcomes in the use of historical event data as evidence of current and future risks and to promote specific ideas for preparedness. The instructors' intended outcome is for students to cite scientific evidence in their final proposals and in the town hall meeting that defends suggested revisions to their local HMP. Despite strong proposals and debate performances that demonstrated understanding of the social, political, and logistical concerns related to storm hazards and risks across the pilot courses, few students incorporated historical event or other data to support their recommendations. It seems likely that students became caught up in the intense effort of thinking about the interdisciplinarity of their proposals and their roles as decision-makers, such that they failed to recognize the need to justify their proposals with data. It should be noted that individuals in the pilot studies were largely first-year students, presumably less familiar with the data demands of critical thinking. Consequently, the authors responded to this oversight by revising the instructions for the final proposal and

Table 1 Example of pre- and post-Unit 1 survey results of students in an American Public Policy course at Worchester Polytechnic Institute (*n* = 38 students). Note the increased recognition of weather-related hazards and sophistication of funding justification for these hazards after the module training

Overview of pre- and post-Unit 1 natural hazards survey results for American Public Policy

Survey directions:
1. List as many natural hazards as you can think of
2. Mark each hazard as frequent (3), common (2), rare (1), or absent (0) for Worcester, MA. Note: You may have more than one hazard with the same frequency ranking
3. Rank the hazards in priority for state funding: high priority (3), moderate priority (2), low priority (1), and do not fund (0). Note: You can give more than one hazard the same funding priority
4. Explain why the hazards with highest priority for funding (3) were so ranked

	Pre-Unit 1 results	Post-Unit 1 results
Range of natural hazards listed	5–15	8–16
Average of natural hazards listed	8.4	11.6
Most commonly listed, "highest priority for funding" hazards	1. Snow 2. Flood	1. Winter weather events 2. Flood 3. Hurricanes 4. Wind/tornados
Sample justification 1	For highest funding prioritization, I only ranked *snowstorms* as 3. This is due to their *frequency* in MA as well as their *severity*. It is rare to have a year without snow, so monies must be spent on snow removal annually… No other natural disaster, except maybe *coastal flooding*, occurs as frequently and severely as snow storms…	The three hazards ranked for highest funding—*snow emergencies, blizzards, and flooding*—were ranked this way for a couple of reasons: (1) the *frequency* of the hazards. All three happen rather frequently in MA. (2) *Potential effects* of the hazard. Flooding can cause *severe property damage, impact travel, and even death*. Both snow-related hazards have similar effects…
Sample justification 2	*Snowstorms* are very common in Worcester; it was the snowiest city in America in 2013. Therefore, the government needs to *prepare* for as much snow as possible in order to *keep people and infrastructure safe*	Most *frequent and severe* weather conditions—such as *floods, blizzards, severe winter weather, and hurricanes*—necessitate the highest funding to *mitigate the most dangerous conditions* of each hazard. On the other hand, while *tornadoes and thunderstorms* are frequent, they usually do not cause as much damage, and do not need as much pre-planning or funding

town hall meeting to make sure that students understood the importance of using data to support their recommendations (Table 2).

The most significant outcome of the module is the degree that it leads to student success in addressing InTeGrate's guiding principle on interdisciplinary problem-solving. Most students demonstrated improved ability in linking scientific components of a hazard with societal factors and applied these in a systems framework.

Table 2 Instructions for Unit 3's policy memorandum including post-pilot revisions that emphasize the need for data-based evidence (underlined text) supporting proposed actions

Overview of position paper Each team must write a policy memorandum from the perspective of their assigned stakeholder. It should be between five and seven pages long, double spaced. The memo should evaluate your community's hazard mitigation plan *and local data specific to the storm type*, for example, severe winter weather (blizzard, ice storm, etc.), and should have recommendations to improve risk mitigation and resilience
Policy memos must follow the specific structure outlined here
MEMORANDUM TO: [government officials/entities]
From: [team stakeholder name]
Date: --/--/--
Subject: Name of the issue or situation about which you are writing
Problem definition: Describe the issue that you would like to be addressed in the town hall meeting. In this section, you must clearly define the problem and explain why it is a public problem that needs to be addressed at this level of government and how the issue should be framed in terms of risk, hazard, and vulnerability
Background: Describe the causes of this problem, the history of the situation, and any important considerations about the political, social, and economic context that must be known in order to make a decision. *Papers should demonstrate that your team has collected and evaluated relevant weather-related and community data to determine community vulnerabilities and preparedness.* Reminder: Although each team has been assigned a particular stakeholder group, successful proposals will show evidence of a systems thinking approach to major storms.
Key actors: Identify key stakeholders, organizations, and individuals in this situation. What are their interests and views? How much power and influence do they have on this issue and in the risk communication process? How might they contribute to hazard mitigation and community resilience for major storms? Are there groups with particular vulnerability to the hazard? Do they have a voice in the policy-making process?
Recommendations and alternatives: List at least two feasible strategies for improving risk mitigation and community resilience for major storms in your community. What are the pros and cons of each? What steps are required to implement the recommendations you have proposed? What criteria do you propose for evaluation and assessment of your suggested strategies? *Include data/evidence to support your recommendations*
Tables/graphs (optional, not included in page count): Include any tables or graphs that support or illustrate your position
Bibliography (not included in page count): Include a bibliography of your references in assigned citation style. Use at least three news sources and three academic and/or government sources. Excellent papers will include additional sources, indicating a more comprehensive treatment of the issue

Conclusions

Overall, the students who participated in the Major Storms and Community Resilience module clearly met two of the three stated learning goals; they were able to (1) identify and describe weather-related hazards and vulnerabilities for their community and (2) relate historical storm data at the national and local scale in order to draw conclusions about community preparedness and current and future community vulnerabilities. The authors saw mixed results on the third learning goal, which was that students should be able to develop evidence-based strategies and recommendations to mitigate local community vulnerabilities to storms, with specific emphasis on different sectors and/or stakeholders in that community. Students were able to develop strategies and recommendations to mitigate local community vulnerabilities to storms with specific emphasis on different sectors and/or stakeholders in that community when working on activities and assignments in Unit 2, where some data and/or detailed instructions were provided. However, students were less likely to show strong results on their use of evidence in crafting and supporting those strategies and recommendations in Unit 3. Because this issue became apparent during the InTeGrate evaluation of the module pilot, the module authors revised the assignments in Unit 3 to be more explicit in requesting historical data be used in the development of the final proposal for the town hall meeting. The published module now includes specific instructions in the summative assessment—the final HMP proposals and town hall meeting—for students to demonstrate that they have "collected and evaluated relevant weather-related and community data to determine community vulnerabilities and preparedness" (Doner et al. 2017). The authors note that many students experience trouble distinguishing class lecture and other learning materials from "evidence." As such, we also suggest that instructors provide examples of data-based evidence to distinguish it from other forms of information and to allow students to engage in debate over differences in information reliability. Students could then assess whether or not evidence-based data strengthens communication of risk and vulnerability and arguments for change.

Case study materials in the module can be readily updated with more current events, as needed by instructors. The 2017–2018 tropical storm season, for example, provided many new case studies that could be substituted for Hurricane Katrina. To that end, the authors specifically recommend comparing the vulnerabilities and resilience of Houston versus Puerto Rico as case studies. Both of those localities' have a rich prior history of major storm impacts, providing ample opportunities for students to find and engage with historical storm data.

The authors find that the progressive nature of the assignments, which evolve to incorporate the students' own community, and the active learning pedagogical approach in the classroom keep students engaged and directed to achieve the module's learning goals. This intensive use of active learning style can be exhausting for some students, however, especially if introduced into a course that is primarily lecture based. During the pilot testing of this module, students started to weary of the constant pressure to work in class and to complete homework prior to the next class over three, work-intensive weeks. This was particularly problematic for students when the module was implemented during the last 3 weeks of a term because of the competing, high demands from other courses. If this is a concern for implementation, the multi-unit nature of the module allows the unit material to be spread out over a full term. Similarly, instructors might find some activities are a better fit than others for their courses and so may choose to implement the material in several courses over the course of a major. Learning goals, in the latter case, might require more instructor preparation to attain because many concepts will have slipped from student memory. Additionally, some students may only receive fragments of the module material, if they do not take the full sequence of courses in which the materials are implemented.

In summary, the Major Storms and Community Resilience module succeeds on both measures needed to improve climate education in the United States; it improves students' scientific literacy, and it personally engages them in issues related to climate. This module takes hazards that occur within the scope of a student's life, exposes societal vulnerabilities to that hazard that persist despite mitigation efforts, and encourages students to take on leadership roles in changing the system. These actions allow students to become vested in the power of data to reveal community needs and areas for improvement on topics that, while linked to climate change, are less politically charged. In short, students completing the module can acknowledge the destructive power of storm hazards and develop actionable models to reduce those risks, thereby promoting community resilience to climate feedbacks, without directly confronting the challenging politics of climate change.

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"Map Your Hazards!": Assessing Hazards, Vulnerability, and Risk Through an Active Learning-Based Educational Module

Brittany D. Brand, Melissa Schlegel, and Pamela McMullin-Messier

Abstract One of the society's grand challenges is reducing the risk of natural hazard events. To address this concern, we developed the "Map Your Hazards! – Assessing Hazards, Vulnerability, and Risk" module (Brand et al., Map your Hazards. [online] Map your Hazards!. https://serc.carleton.edu/integrate/teaching_materials/map_hazards/index.html. Accessed 27 June 2018, 2014), which provides students with an interactive mechanism to engage in place-based exploration of natural hazards, social vulnerability, risk, and the factors that shape community perception of natural hazards and risk. Students identify and apply credible geologic and social science datasets to identify hazards and social vulnerabilities within their region; collect and evaluate survey data on the knowledge, risk perception, and preparedness within their social networks; and make recommendations based on their findings to potential stakeholders for development of prepared and resilient communities. The interdisciplinary nature of the module allows students to improve their geoscientific thinking skills while fostering systems thinking about the interconnection of hazards, social vulnerability, and risk. The course is designed to be adaptable to any location and can be taught from 100 to 300 levels in Geoscience, Environmental Science, and Social Science courses.

Keywords Natural hazards · Vulnerability · Risk · Resilience · Mapping

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Introduction to Societal Issues and Interdisciplinary Nature of Problem

Reducing the social and economic impact of future natural hazard events is a multidisciplinary problem that requires multidisciplinary solutions. To mitigate the risk of natural hazard events, we must understand the nature of the hazard, which includes the probability, expected area of impact, duration, severity, and immediacy (e.g., Wood 2011). To evaluate risk, we must understand who and what is vulnerable to a future natural hazard event, which includes attributes and assets (e.g., infrastructure, social context, possible economic losses) and capacities for response (Cutter et al. 2003; Shirley et al. 2012; Cutter 2016). Once risk is established, it must be effectively communicated to policy-makers and at-risk populations (Siegrist and Cvetkovich 2000; Wachinger et al. 2013). Finally, to reduce risk, the whole community must work together by taking household and neighborhood action (Patterson et al. 2010).

To address the concern of reducing the risk of natural hazard events with the need for multidisciplinary learning, we developed *Map Your Hazards! – Assessing Hazards, Vulnerability, and Risk* (Brand et al. 2014a). The "Map Your Hazards!" module provides students with an interactive mechanism to engage in place-based exploration of natural hazards, social vulnerability, risk, and factors that shape their communities' perception of natural hazards and risk. The module is multidisciplinary in nature as it allows students to integrate geoscience and social science methodologies to understand societal impacts that result from natural hazards. Students (1) identify and apply credible geologic and social science datasets to identify hazards and social vulnerabilities within their region, (2) collect and evaluate survey data on the knowledge, risk perception, and preparedness within their social networks, and (3) make recommendations, based on the findings of their work, to community stakeholders for continued development of a prepared and resilient community. In summary, students gain insight into how our knowledge and perceptions of the world shape how we interact with it and how we promote and build resilient communities through understanding the relationship between the built environment and natural systems.

Module Summary

"Map Your Hazards!" is a three-unit, place-based module adaptable to location, course type, and course level. Students are divided into groups of 3–4 at the beginning of the module. In Unit 1, Hazards, Vulnerability, and Risk, student groups define their communities, locate the occurrence of local natural hazards (from credible resources provided by the instructor or sought by the students), identify vulnerable populations, and assess relative risk for regions in their communities. In Unit 2, Perception of Hazards, Vulnerability, and Risk, student groups distribute an online survey to peers in their communities and then analyze the data to create and test hypotheses about what factors control their peers' knowledge of natural hazards, perception of risk, and level of preparedness. They also explore survey results to identify factors that may increase vulnerability, such as lack of household preparedness due to lack of knowledge regarding hazards that might affect the region. In Unit 3, Translating the Message, student groups identify stakeholders in their community that would be interested in the findings of Units 1 and 2 and create recommendations to these specific stakeholders for improving community resilience to future hazardous events. Student groups then prepare and deliver a short PowerPoint presentation that communicates their findings to a specific stakeholder (different stakeholders are assigned to each group by the instructor).

All units are appropriate for a range of courses in Geology, Environmental Studies/Sciences, Earth Science, Geography, Psychology, Sociology, and Social Work. Course materials could also be modified to facilitate projects in an introductory GIS course.

The module engages students to consider the idea that there is no such thing as a "natural" disaster, only natural hazards (Comfort et al. 1999). Natural hazards are extreme natural events or processes, whereas disasters are sudden events that cause great damage or loss of life. While disasters often follow natural hazard events, a disaster's severity depends on how much impact a hazard has on society and the environment (Wachinger et al. 2013). The scale of the impact depends on the choices we make, which relates to how we grow our food, where and how we build our homes, what kind of government structure we have, how our financial system works, and even what we teach in schools (Blaikie et al. 2004). Each decision and action potentially makes us more vulnerable to disasters—or more resilient to them.

By vulnerability we mean the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, adapt, and recover. Therefore, to reduce risk and improve community resiliency, individuals, communities, and societies need to take action and prepare for natural hazard events like severe weather, earthquakes, floods, droughts, and tornadoes. Preparedness will reduce the damage and impact caused by natural hazards, decreasing the severity of future disasters (Lovekamp and McMahon 2011; Berkes and Ross 2013).

At the start of the module, students are given a road map and grading scheme that provides a general overview and expectations for each unit. Students also take a formative assessment of their knowledge and understanding of general principles (hazard, vulnerability, risk, and risk perception) that establishes a baseline of knowledge to compare with their post-module summative assessment. Students are also informed about the risk perception survey that they will be analyzing in Unit 2 and asked to distribute the online survey to their social networks to ensure sufficient time for data collection. Some of the class meetings for the module are comprised of lecture and discussion periods, but we recommend holding classes in a computer lab or requiring students to bring laptops to class as students need to have computer access to complete some of the assignments as a group.

Unit 1: Hazards, Vulnerability, and Risk

The learning goal for Unit 1 is for students to identify and describe (1) natural hazards that are possible in their region and (2) vulnerable groups and structures in within the same region. Based on the overlap of hazards and vulnerabilities, students then evaluate the level of risk within specific segments of their region (segments assigned by instructor). Unit 1 is most effective in relatively small classes (<40 students). It can be taught during lecture periods (assuming 3 h of lecture per week) or in a lab setting.

We recommend beginning Unit 1 with a think-pair-share (Lyman 1987) activity that first asks students to think about and write down their pre-module definitions of natural hazard, vulnerability, and risk. Students then discuss their answers with their neighbor, followed by a class discussion. The InTeGrate Unit 1 site provides interactive PowerPoints for discussing these topics in more detail, such as the causes and consequences of natural hazards and definitions for natural hazards, vulnerability, and risk (Brand et al. 2014b).

Students are assigned to groups of 2–4 students. To keep the exercise consistent, efficient, and at the same scale, the instructor divides their region into several smaller mapping areas and provides a different map within the larger region to each of the student groups. For example, the city of Portland, Oregon, might be divided into six 5-by-5-mile mapping areas; in this hypothetical situation, one of the six maps would be given to one of the six student groups taking the course through the Portland State University.

Student groups then apply credible geologic and social science datasets to identify local hazards and vulnerable systems (e.g., schools, hospitals, retirement homes, bridges) within a given mapping area (Fig. 1). If the module is being taught in a lower-division course, the instructor would likely provide the credible sources (e.g., published hazard maps). If the module is being taught in an upper-division course, the instructor may require the students to find the credible resources.

Students are also encouraged to examine social vulnerabilities within their mapping area, such as the percentage of the population below poverty, minority populations, linguistically isolated communities, and individuals over the age of 64, using census block data (Fig. 2). This data can be accessed through the Environmental Protection Agency's Environmental Justice Screening (EJScreen) and Mapping Tool (EPA 2018). This is an excellent source to explore that does not require knowledge of GIS mapping.

For the purpose of our module, we define risk as the overlap of natural hazard zone with a vulnerable system (Wood 2011; Fig. 3). Using this definition, student groups create and justify a risk map for their mapping region, based on the overlap of their natural hazard and vulnerable system maps (Fig. 4). The unit concludes with a discussion of the student groups' maps, including the importance of accuracy, and factors that put some areas at higher risk than others.

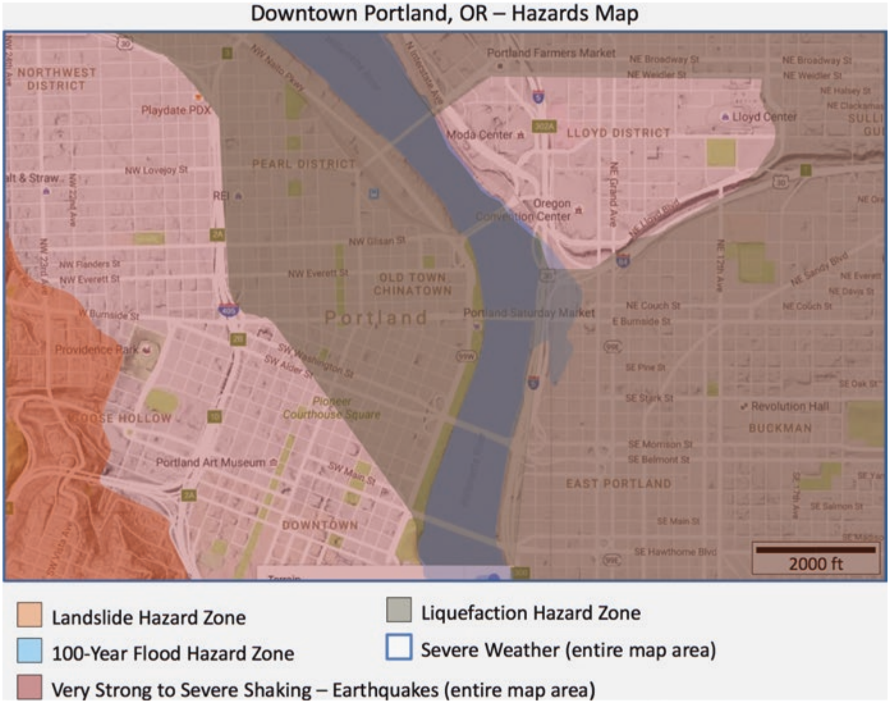

Fig. 1 Example of an all-hazards map for downtown Portland, OR. Hazard regions designated based on the DOGAMI interactive hazards website (DOGAMI 2018)

Unit 2: Perception of Hazards, Vulnerability, and Risk

The learning goal of Unit 2 is for students to collect and analyze relevant social data on individual and community knowledge, risk perception, and preparedness within their local social networks (i.e., friends, family, peers outside of the class). For this purpose, we developed an all-hazards survey that assesses a participants' natural hazard knowledge, risk perception, level of preparedness, and preferred sources of information. Prior to the start of Unit 1, instructors should modify the web-based survey and create a link for students to send to their social networks; instructors can edit or add questions to be more specific to their region. Instructors can access the survey at Brand et al. (2014b). The survey is also available as a modifiable google form, which can be requested from the authors of this article by email.

Instructors copy and rename the survey and then modify the questions to only include hazards relevant to their region. The Google survey tool will automatically populate the results into graphs, facilitating easy download and analysis of the data. If the survey is only being used for classroom purposes and not for research, Institutional Review Board approval should not be necessary. However, we recommend that instructors contact their Institutional Review Board before data collection to be sure institutional protocols are followed.

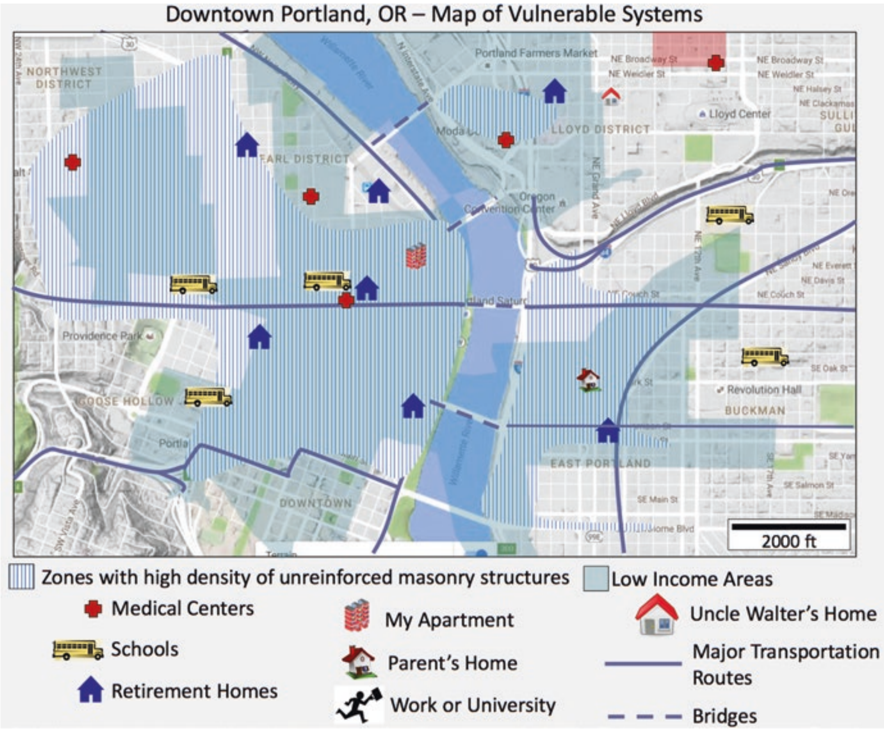

Fig. 2 Map showing vulnerable systems

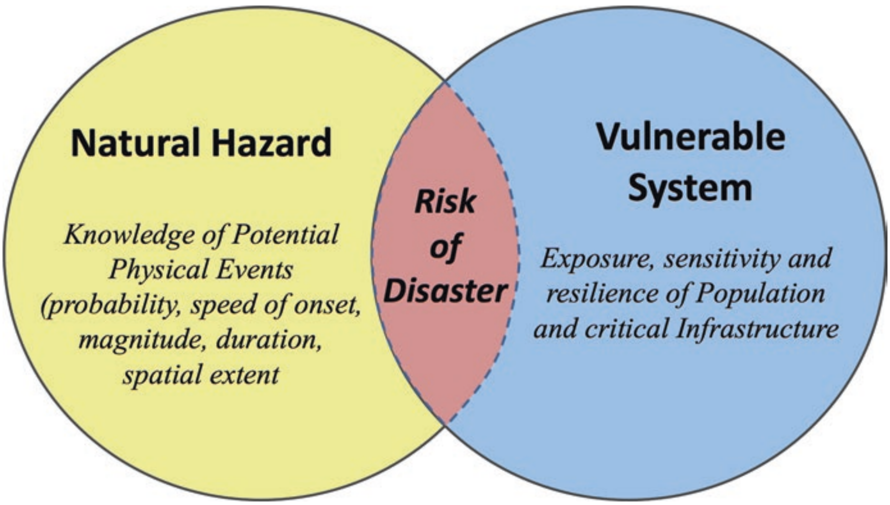

Fig. 3 Diagram illustrating risk of disaster (modified from Wood 2011)

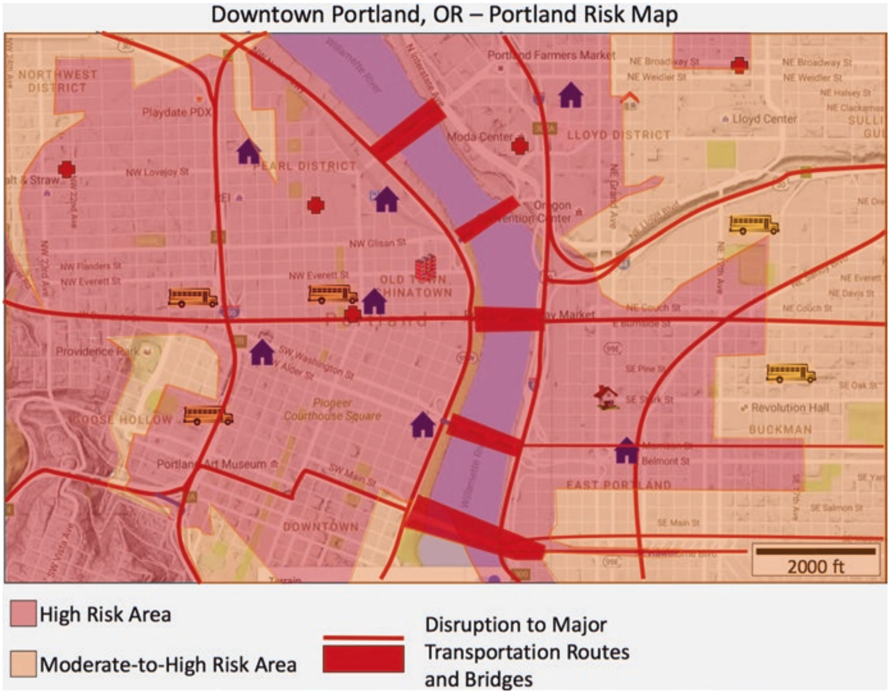

Fig. 4 This map is meant to illustrate the regions at greatest risk based on the overlap of hazard zones and vulnerable systems. Students designate high-, moderate-, and low (if applicable)-risk zones and are required to defend their choices as part of the assignment

Ideally students distribute the survey link via email prior to the start of Unit 1 to provide sufficient time for data collection and compilation by the instructor. Then, prior to starting Unit 2, the instructor creates packets of graphs for each group to analyze based on the collected survey data. Instructions for creating packets can be found at Brand et al. (2014c). Unit 2 is conducted over 3–4 class periods and begins with an introduction and class discussion on risk perception, factors that influence risk perception and preparedness behavior (e.g., knowledge, previous experience, spatial dimension, self-efficacy, socioeconomic pressures), and education strategies to communicate risk and recommended preparedness actions (Brand et al. 2014c). Students then work within their groups to analyze the results of the survey, which evaluates the survey population's state of knowledge, accuracy of risk perception, and level of preparedness for hazards in their community.

Unit 2 is scaffolded to facilitate data analysis. Students first work in small groups to summarize graphs provided by the instructor[1] and designate each graph as

[1] The instructor must compile and organize the data into an Excel spreadsheet and then either use plots provided by google forms or create new plots for the students to analyze. Each student group receives a different set of graphs to read and interpret, guided through a Part A Worksheet (see online module).

addressing knowledge, risk perception, or preparedness (Unit 2 Part A). They are asked to list 1–3 factors that might influence the results of each graph (e.g., age, gender) and provide reasoning for their selection. Next, to demonstrate how to use data to test a hypothesis, the instructor provides each group a unique hypothesis and a graph that allows students to test the hypothesis (e.g., longer residence time in the region results in a more accurate knowledge and level of risk perception). Finally, the instructor leads a discussion aimed to motivate students to engage further with the data. The discussion usually incorporates group presentations with instructor feedback to demonstrate correct graph interpretation, as well as a general conversation (as a class or in smaller groups) of what students think are interesting questions, how to turn the questions into hypotheses, and what graphs might test these hypotheses.

In Unit 2 Part B, the instructor provides student groups with a list of hypotheses or research questions, which students address by creating graphs with relevant data in Excel. Students are also instructed to use the dataset to answer questions regarding where their surveyed population prefers to get their knowledge about local risk from natural hazards and who the surveyed population feels is responsible for their safety. Next, student groups develop their own hypothesis or research question to test with the dataset and create graphs to evaluate and address their hypothesis or question. Finally, based on all findings from Unit 2, students summarize their survey populations' accuracy of knowledge and risk perception, and level of preparedness, while identifying factors that may increase vulnerability, hinder preparedness actions, and put their community at risk.

Unit 3: Translating the Message

The learning goal of Unit 3 is for students to (1) identify stakeholders and stakeholder roles in the community with regard to natural hazard preparedness; (2) develop recommendations to these stakeholders, based on Units 1 and 2 results, for how to reduce the risk of natural hazard events in their community; and (3) communicate the findings of all units to an assigned stakeholder in a short (5–7 min) oral presentation (Brand et al. 2014d). Unit 3 is conducted over 2–3 class periods.

First, students identify potential stakeholders in their community that may be interested in the Units 1 and 2 results (e.g., individuals, social groups, scientists, community planners, emergency managers, policy-makers) through a PowerPoint-mediated discussion (format up to the instructor). Next, with group input, the instructor assigns each student group a different stakeholder, and the students tailor oral presentations toward that specific audience. In their presentations, students present and explain their risk map and a subset of their survey data. Finally, they make recommendations, based on their findings, for how to build a more resilient community. We recommend inviting local emergency managers and/or other pertinent community stakeholders to view the students' presentations, as stakeholder participation and interaction result in a more meaningful experience for the students and community members.

Connection to Five Themes

Connect Geoscience-Related Grand Challenges Facing Societies

One of society’s grand challenges is reducing the risk of natural hazard events by developing resilient communities. Although the severity and probability of hazard events vary greatly from place to place, all students face some type of natural threat; therefore, this grand challenge is relevant to all students who engage in the “Map Your Hazards!” module. Students explore local hazards, risk, and social factors that may increase vulnerability and risk in their surveyed population. More importantly, students identify ways their community could reduce risk to become more resilient to future hazard events. This level of engagement addresses the common problem of student apathy by empowering them to see how they could make a difference in their community.

Develop Students’ Ability to Address Interdisciplinary Problems

Methods and concepts from geoscience, social science, and communication fields are combined in this module to address the interdisciplinary problem of building resilient communities. Students obtain background knowledge in these various fields, learn to apply credible data, and evaluate survey data to identify weaknesses in their community that increase risk to future hazard events. Together, they develop solutions to improve community resilience by (1) identifying stakeholders critical to reducing risk, (2) assessing the importance of communicating with these stakeholders, and (3) recommending ways that each stakeholder could reduce the risk of future hazard events.

Improve Students’ Geoscientific Thinking Skills

The design of our module is to improve students’ geoscientific thinking skills through the *application* of their knowledge of natural hazard events to their current location. Knowledge of natural hazards is presented in the course outside of the module or may be summarized using the “Introduction to Natural Hazards” PowerPoint-mediated discussion contained in the module (Brand et al. 2014b). In order to assess their community’s risk, students must apply their understanding of where and how natural events occur with the probability and possible severity of future events.

Make Use of Authentic and Credible Geoscience Data

The module includes an interactive lecture and class discussion on credible data in Unit 1 (Brand et al. 2014b), emphasizing the importance of using credible data when solving geoscientific problems. To map local hazards and vulnerable systems, students must identify, use, and cite credible geoscience and social science datasets. Upon identifying local natural hazards and social vulnerabilities, students assign levels of risk to areas within their community.

Foster Systems Thinking

Understanding the increased risk of certain natural hazards requires systems thinking, as many social and environmental factors combine to control the impact of a hazard event. In addition, assessing hazards, vulnerability, and risk, and ultimately working toward promoting community resiliency, requires considering variables that are associated with the threat and the social context of the society in which we live, exploring effective messaging techniques for specific stakeholders and seeking to understand human behavior through analysis of perceptions. As such, our module strongly fosters systems thinking as students collect and analyze relevant geoscience data to identify possible natural hazard zones, vulnerability data that helps students assess risk associated with hazard zones, and social data on individual and community knowledge, risk perception, and preparedness within their local social networks.

Instructional Strategies

The foundation of the module is active learning. Active learning is an educational strategy that engages students in activities to enhance their learning experience (e.g., Prince 2004). Active learning is effective because it addresses different learning needs and helps students develop critical thinking skills, while also increasing student confidence and performance through peer-to-peer interactions (Prince 2004; Pappas 2015). Instructional strategies in our module, all aligned with active learning practices, include interactive lectures and class discussions, in class activities, data analysis, and student presentations. Each method engages with and reaches different students in different ways.

In this section we describe aspects of the instructional strategies used, providing specific examples from the three courses in which the module was piloted. At the College of Western Idaho (CWI), the module was piloted in one course, an introductory geology course on natural hazards and environmental geology, and taught in three different times over two semesters. Module materials and activities took place over several weeks in both the classroom and laboratory setting, reaching 49 students. At Central Washington University (CWU), the course was piloted in an upper division Environmental Sociology course. The module was implemented over a 3-week period during the lecture period, reaching 25 students. At Boise State University (BSU), the module was piloted in an upper division, non-major Volcanoes and Society course. The module was implemented over a three-and-a-half-week period during the lecture period, reaching 20 students.

Hazard, Vulnerability, and Risk Mapping: Applying Credible Data

Students first learn about the causes and consequences of natural hazards from a geoscience perspective and the difference between natural hazards and disasters. Student groups then work in class to either use (if instructor provides sources) or identify credible hazard and vulnerability data, map findings for their designated mapping region, create risk maps, and discuss the implications and accuracy of their risk mapping results. Most of these activities are completed in class, where the instructor is present to answer questions and keep students on track.

One interesting issue at BSU was that many student groups were not accurate in where they drew hazard zones on their region maps. Through a class discussion on the importance of accuracy, which included aspects of property value, decisions for zoning and development, and the need to purchase insurance, students gained a better appreciation for both the use of credible data and data presentation accuracy. Student groups revised their maps to present more accurate hazard zones, and many emphasized the need for accuracy in their final presentations.

Interactive Lectures and Class Discussions

Interactive lectures allow students to follow the 5E instructional model, *Engage*, *Explore*, *Explain*, *Extend*, and *Evaluate* (Wyatt et al. 2014). Students are guided, often through the use of our published PowerPoint slides (Brand et al. 2014a), to engage with and explore concepts before receiving an explanation. They ultimately extend their knowledge and evaluate concepts through completing each phase of the module. The "think-pair-share" approach (Lyman 1987) is routinely used to facilitate such discussion between individuals, in small groups, and with the class. An example of an interactive lecture from Unit 1 is when students are first asked to explore definitions for hazards, vulnerability, and risk, followed by an explanation by the instructor. Another example from Unit 1 includes identifying pre-event (anticipatory) and post-event (reactive) mitigation for a natural disaster through an interactive PowerPoint. In our piloted courses, students recognized that even post-event mitigation involves some pre-event preparation. Food, water, and other emergency supplies are distributed after a natural disaster occurs, but distribution is most effective if prepared *before* the event to enable quick deployment. An example from Unit 2 occurs after students receive and answer questions regarding survey data. We discuss their findings in small groups and then as a class (Unit 2 Part A), which prompts them to develop new ideas and hypotheses to test with the data (Unit 2 Part B). All of these examples initiate group and class discussions on the topics.

Data Analysis

Data analysis using a scaffolded approach teaches students how to handle a large dataset, answer questions with the survey data, and develop their own questions to test. Learning through data analysis initially overwhelmed many students. However, the scaffolded approach with guidance from interactive lectures, worksheets, peers, and the instructor allowed most students to become proficient at utilizing the survey data (mostly graphing in Excel).

Student Presentations

In the module, student presentations were targeted toward specific stakeholders and included recommendations for improving community resilience. The goal was to teach students the importance of targeting their presentation to a specific audience while helping them develop oral communication skills. Presentations geared to stakeholders engaged many students, especially when we invited representatives of these stakeholder groups to the presentations. Students observed the impact of their work during the module as invited guests took notes and asked questions. For example, at CWI, one invitee was from wildfire management. His involvement demonstrated real-world impacts of wildfire hazards on the Boise regional community and broadened many students' focus from just a classroom exercise with a grade to actually generating resilient communities using the information synthesized from the module.

At CWU, the instructor invited an expert from the local Red Cross, who discussed the connection between student presentations to her organization's mitigating role in the community. The Red Cross expert also shared their expertise on how social workers respond to disasters. For example, they discussed a personal experience in New York after Hurricane Sandy and stressed how communities pull together after disasters. However, despite recovery and resiliency plans at the government level, the lack of household-level preparedness among the general population hindered effective response. This was a valuable experience for students to be able to ask questions of a stakeholder and understand and apply vulnerability from a different point of view.

At BSU, guest stakeholders included county and university emergency managers. The emergency managers asked numerous questions of each group, specifically regarding the survey data, and expressed how important this data is to their organizations. In fact, one outcome for the county emergency manager was learning that the general public finds the county website too busy to navigate, limiting their ability to identify local natural hazards and ways to prepare for the hazards. As a result, the county overhauled their website, simplifying information and making recommended preparedness actions easier to find.

Summary of Instructional Strategies and Ideas for Adapting to Nationwide Classrooms

The multiple instructional strategies employed in the module, with a solid foundation in active learning, increase the level of students' engagement with the material in all classes (Brand et al. 2014e). The education strategies also provide students with the ability to immerse themselves in important subject matter that often lacks visibility, except in the face of disastrous situations. The module demonstrates to students the importance of integrating social science and geoscience in order to scrutinize the possibilities of how to build better and more resilient communities, directly addressing the need for multidisciplinary learning. In class discussion, students in all courses reported that the involvement of community stakeholders made the module experience more meaningful than just completing another class project. Many students also reported a motivation to take personal preparedness actions to reduce their risk for future natural hazard events and check hazard maps before renting or buying property in the future. In their reflections, students also expressed an empowerment to make a difference in their communities by sharing their knowledge with their friends and family (Brand et al. 2014e).

The module is designed to be adapted in any location for any range of hazards. For example, if adapted for a Midwest location, the hazards may focus more on flooding and severe weather than earthquakes and wildfire; for coastal Florida, the hazards may focus on hurricanes, flooding, and other coastal issues (i.e., erosion, rising sea level). The survey includes all hazards but is modifiable so that instructors can choose the hazards that pertain to their specific region. Instructors may add or delete questions as necessary. Finally, we encourage instructors to contact local emergency managers before beginning the module. Emergency managers are often interested in the students' work; in our experience they are willing to speak to the class and, if available, attend the students' final presentations. Emergency managers are also a great resource for finding the most up-to-date local hazard maps and preparedness materials.

Assessment Information on Module Impact: GLE, Systems, and Interdisciplinary, Summative Assessment

Assessment Data

The InTeGrate Attitudinal Assessment pre-module and post-module survey is used to examine students' attitudes and behaviors toward environmental science and sustainability issues. The pre-module assessment was administered prior to the start of the module, and the post-module assessment was administered within a week after the end of the module, typically coinciding with the end of the course. Topics in the assessment included students' career choices, concern for environmental issues, probable use of environmental science, and the effectiveness of the module in positively affecting students' attitudes toward knowledge of geoscience-related challenges facing societies. These topics were chosen as general themes to asses all InTeGrate projects, and therefore some topics do not strictly apply to the "Map you Hazard!" module. Results from students who participated in the "Map Your Hazard!" pilots are compared to those across the InTeGrate-wide sample, the latter of which includes 1125 students who participated in pilot tests of InTeGrate materials between fall 2012 and spring 2015 (Iverson et al. this volume; Kastens 2016). We discuss only the topics that apply to the "Map Your Hazards!" module.

Eighty students completed the InTeGrate Attitudinal Assessments (pre- and post-module) for the "Map Your Hazards!" module pilot across the three institutions (Table 1). Seventy-four percent were enrolled in non-major geoscience courses, and 26% were enrolled in an upper-level social science course that focused on environmental issues. Forty-seven percent of the students were male, 42.5% were female,

Table 1 Course details where the "Map Your Hazards!" course was piloted

Institution	Type	Course enrollment	Course title	Course type
Boise State University	R2; large; 4-year; public university	20	Volcanoes and Society	Upper-level, non-majors
Central Washington University	Medium; 4-year; public university	21	Environmental Sociology	Upper-level social science course, elective for environmental science, and public policy majors
College of Western Idaho	Medium; 2-year; public community college	49	Natural Hazards and Environmental Geology	Introductory geology course, satisfies science general education requirement

and 10% did not report gender. The average age of students was 25.2 years, with a range of 18–52 years. Seventy percent of students identified themselves as white, 11.25% as Hispanic, 5% as Asian, and 2.5% as African American, and 10% did not report ethnicity.

The first series of questions involved student's attitudes regarding the importance of environmental science and sustainability when making future career choices. In the InTeGrate-wide survey, responses to questions regarding the importance of choosing careers where the students can apply their knowledge of the earth and environment, and the importance of working for organizations committed to environmentally sustainable practices, are weighted toward the "Important" half both before and after instruction (Fig. 5a and c, respectively). However, the results from the "Map Your Hazards!" pilot students are mixed and lack of substantial pre-/post-survey change, which likely reflects the dominantly non-geoscience major composition of the pilot module courses (Fig. 5b and d).

Interestingly, the percentage of students with a high interest in pursuing an Earth or Environmental Sciences career increased pre-/post-module from 37.3% to 64.4% (Fig. 6a), suggesting an increased interest in the general field. Students' level of concern for global climate change environmental issues also increased pre- to post-module from 58.7% to 80.4% (Table 2). An increased concern for water resource limitation (from 60.9% to 73.9%), loss of biodiversity (from 41.3% to 52.2%), and population growth (from 60.9% to 67.4%) was also noted pre-/post-module implementation (Table 2).

When asked about their motivation to act in an environmentally sustainable manner, the percentage of students who shifted from low to high in their motivations increased 42.4% between pre- and post-module surveys. In addition, 67.8% of the "Map Your Hazards!" students were highly motivated post-module to create a sustainable society, a trend similar to the project-wide data (Fig. 6b). As environmental sustainability was not directly addressed in the module, the authors speculate that perhaps students equated sustainability with community resilience. For the question concerning students being able to envision using module information to help overcome environmental problems, the overwhelming majority (81.4%) responded positively, which also compares favorably with project-wide data (Fig. 6c).

Assessment Summary

Overall, the assessment data for the module generally follows similar trends as the project-wide datasets. The module assessment data demonstrates the effect of the module in increasing students':

- Consideration of environmental science-related careers
- Concern for several environmental developments
- Sustainable activities
- Motivation to create a sustainable society

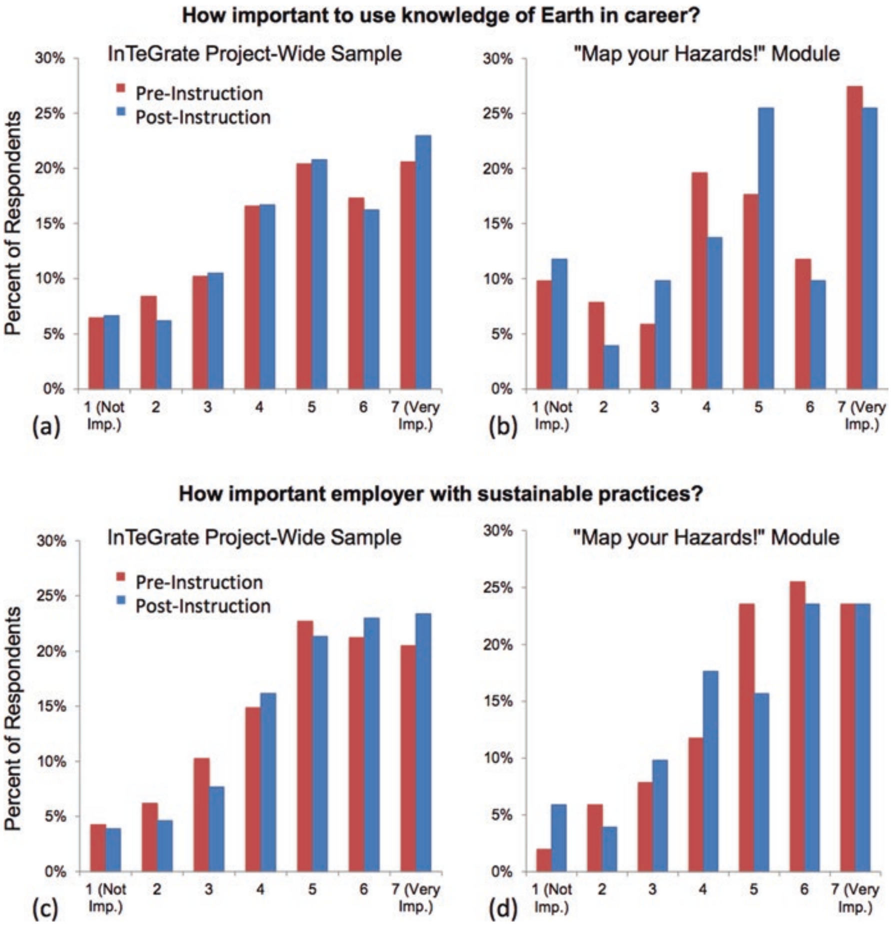

Fig. 5 Integrate-wide and Map Your Hazards module pre- and post-module responses to (**a**, **b**) "…how important is it to you to do work in which you use your knowledge of the earth and environment?"; (**c**, **d**) "…how important is it to you to work in an organization committed to environmentally sustainable practices?". Questions are ranked on a scale of 1–7, with 1 being "not important" and 7 being "very important"

- Use of environmental science reasoning to address societal problems

These trends establish the module as an effective tool in connecting students to the five themes described above. For more information and open question responses from students, the reader is referred to the Instructor Stories on our InTeGrate website (Brand et al. 2014e).

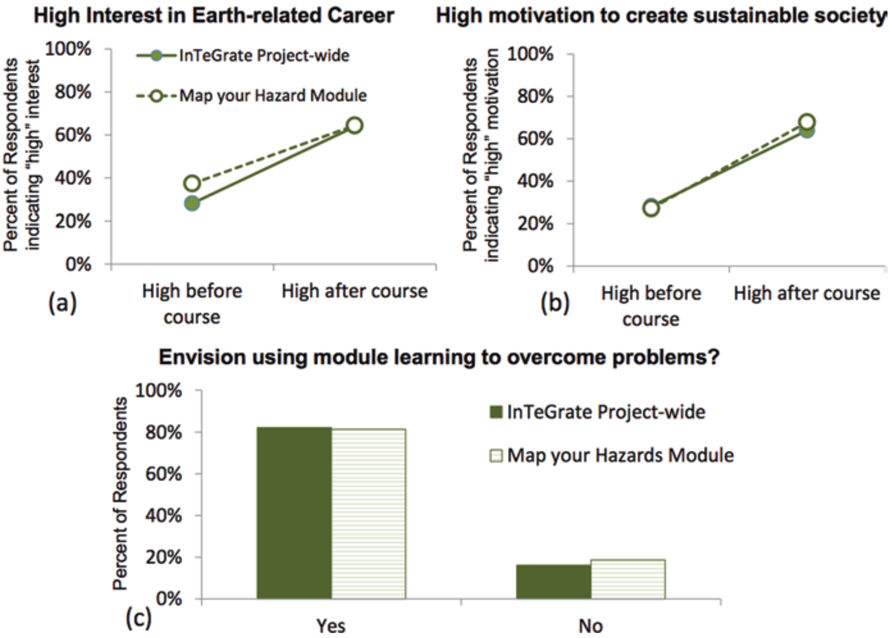

Fig. 6 Integrate-wide and Map Your Hazards module pre- and post-module responses to questions regarding Earth-related careers (**a**), motivation to create a sustainable society (**b**), and using module learning to overcome environmental problems (**c**)

Table 2 Number and percentage of students pre- and post-module who reported a high level of environmental concern for our planet

Environmental concern	Global climate change	Water resource limitations	Loss of biodiversity	Population growth	Mineral resource limitations	Energy resource limitations	Meteor impact
Pre-module							
# of respondents	27	28	19	28	21	29	3
% of respondents	58.7%	60.9%	41.3%	60.9%	45.7%	63.0%	6.5%
Post-module							
# of respondents	37	34	24	31	23	28	3
% of respondents	80.4%	73.9%	52.2%	67.4%	50.0%	60.9%	6.5%

Concluding Remarks, Suggestions, and Opinion of Emergency Managers

In summary, our module provides students with an opportunity to engage in place-based exploration of the causes and consequences of natural hazards; factors that influence of vulnerability, risk, and preparedness behavior; and ways that society could reduce their risk to future hazard events. The active learning nature of the module is effective in engaging students in the material and deepening their understanding and appreciation of natural hazards and risk. Our module applies multidisciplinary approaches to societal problems and strongly fosters systems thinking through connecting geoscience and social science approaches to constrain hazards, vulnerability, and risk. Students responded favorably to our module, and many expressed a motivation to take personal preparedness actions for future events (see Brand et al. 2014e).

The authors recommend that instructors contact their local- and university-level emergency managers a few weeks prior to starting the module and ask them to be involved in the course. In our experience, emergency managers are happy to visit and talk with the class in the first week of the module and willing to return for the Unit 3 presentations. Emergency managers report that the survey data students collect is valuable to them and their organizations. The involvement of emergency managers also helps students recognize their ability to make a community-wide impact and gives more meaning to the module experience than completing as a class project alone.

A final suggestion is to extend the “Map Your Hazards!” module into a full, upper-level (300-level or higher) Natural Hazards, Vulnerability, and Risk course that includes a fourth, service learning-based unit. In this fourth unit, students evaluate existing materials that communicate hazards, risk, and recommended preparedness actions for their community. Based on their analysis, students work with local emergency managers (the community partner) to develop education modules that are based in active learning and/or storytelling. Their modules must target a specific audience and use strategies that enable the participants to personalize their risk and develop positive attitudes toward taking preparedness actions (based in the Protective Action Decision Model of Lindell and Perry 2012).

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Renewable Energy and Environmental Sustainability

Benjamin Cuker, Randy Chambers, and Maurice Crawford

Abstract This paper describes a course focused on renewable energy developed to teach college-level students about the application of geoscience principles that underlie sustainable technologies, the implementation of these technologies, and their societal context. The 11-module Renewable Energy and Environmental Sustainability course uses hands-on, active learning techniques to engage students in data acquisition and analysis. The modules may be taught in their entirety as a complete course or used individually to supplement offerings such as in a general environmental science class. The chapter provides guidance in using the open-access online materials for implementing the course, including a discussion of pedagogy, how to use the supplied learner-centered activities, and assessment tools. The chapter recounts some of the key experiences of professors who piloted the course at three universities. Pre- and post-course assessments documented the improvement of student knowledge and an increased proclivity to include environmental sustainability in their decisions regarding careers and lifestyle choices.

Keywords Renewable energy · Sustainability · Conservation · Interdisciplinary · Learner-centered

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Introduction

This chapter covers the development and implementation of a learner-centered approach to teaching about the technologies and underlying science that inform today's developing revolution in renewable energy and sustainability. The course is called Renewable Energy and Environmental Sustainability (Cuker et al. 2017) and is part of a series of courses and modules developed under the InTeGrate (Interdisciplinary Teaching about the Earth for a Sustainable Future) program, housed in the Carleton College's Science Education Resource Center, and funded by the National Science Foundation (Gosselin et al. this volume; InTeGrate 2018). This course and the other InTeGrate offerings promote environmental and STEM literacy for college students and are designed to help emerging geoscientists work effectively in an interdisciplinary way with members of the community to find sustainable solutions to resource problems.

The overall purpose of this course is to teach basic geoscience principles through an interdisciplinary exploration of environmentally sustainable technologies. During the course students will (1) apply the geoscience principles underlying, and societal implications of, implementing new technologies to advance environmental sustainability, (2) use data to test the efficacy of various green technologies, (3) use learner-centered techniques to organize data and analyze case studies relevant to the adoption of green technologies, and (4) use data that they generated together with data published by others to strengthen their ability to address interdisciplinary problems.

Today's college students are the tenth generation born into a world shaped by the consumption of fossil fuels and the first to come of age at the beginning of the shift to renewable energy. Today's college students are also the first generation born into the information age, characterized by the immediate access to material pertaining to any subject of interest. This chapter describes the development and implementation of a course using teaching modules that embrace the twin revolutions of renewable energy and learner-centered pedagogy (Cuker et al. 2017).

Renewable Energy for a Sustainable World

Civilization advanced when humans discovered how to supplement their own metabolism-based energy budgets with subsidies from nature (Vitousek et al. 1986; Rice 1999; Gupata 2004; Wrigley 2013; Gowlett 2016). In some cases, exploitation of the resource had little environmental impact, such as the use of wind to power sailing vessels (Carter 2006). In other instances, however, overexploitation by growing populations led to devastating effects on fisheries, forests, and rangelands (Roberts 2009; Doughty 2013).

The advent of the Industrial Revolution increased the demand for energy subsidies from the environment. Initially wind, water, and burning of biomass powered this social transformation (Mintz 1985; Wrigley 2013), but it took the concentrated and predictable energy released from the combustion of fossil fuels to complete industrialization. Soot from coal-burning steam engines and smelters blackened the skies and lungs of the nineteenth century. Petroleum and natural gas joined the industrial energy mix in the twentieth century. The air pollution resulting from combustion of fossil fuels killed thousands of people (Bell and Davis 2001). By the International Geophysical Year (1957), climate scientists predicted the warming of the Earth from the CO_2 produced by fossil fuels and understood that much of that gas would be taken up by the ocean (Revelle and Suess 1957).

The Clean Air Act of 1970 codified the US commitment to resolving air pollution from fossil fuels, but the oil crisis of 1974 was the key event that fostered meaningful interest and government investment in renewable energy and sustainability (Hamilton 2011).

Irrespective of the environmental damage done by the acquisition, processing, transport, and consumption of fossil fuels, hydrocarbons are ultimately a finite resource and therefore inherently unsustainable. Society must turn to clean, renewable sources of energy to power a sustainable future. This means educating college students to understand the principles governing, and societal implications, of embracing the new technologies required to harness renewable energy.

Today's college students grew up surrounded by maturing sustainable technologies such as photovoltaic solar panels, wind turbines, and fully electric cars. Although most students are superficially familiar with these technologies, do they understand the underlying science or the social context for their use? How many students can differentiate between a thermal solar panel used to heat water and a photovoltaic panel used to make electricity (Fig. 1)? How many understand that wind energy comes from solar energy, gravity, and the spinning of the Earth? This course teaches the fundamental general science and geoscience principles that inform these technologies and the social implications of their adoption. As such, the course takes a strong interdisciplinary approach that requires the students to integrate basic science, geoscience, social science, and economics in understanding how the new technologies help to build a sustainable society.

The Learner-Centered Approach to Teaching Sustainable Technology

The Industrial Revolution that transformed the human relationship with fossil fuels also influenced our system of education. Mass production required education of the masses to fill the jobs needed by the industry (Lawson and Silver 2013). In the United States, this took shape partly through the Morrill Acts of 1862 and 1890, which established and then expanded the system of land-grant colleges and universities (Florer 1968). These new institutions of higher learning embraced an industrial approach to education, developing along the hierarchical lines of specialization, with the educational tree rapidly developing new, disparate branches of inquiry. The

Fig. 1 Solar panels installed on an adjustable awning on the south-facing side of the first author's house; in the background is a solar furnace wall. Both technologies explored in Modules 3 (Thermal Energy from Light) and 4 (Creating Electricity from Light)

industrial scale of education in the United States grew particularly as a consequence of the post-World War II GI Bill of Rights. That program brought college education to the masses (Bound and Turner 2002). Large enrollments meant large classrooms centered around a sage on the stage who taught by lecturing. To this day, the lecture-centered approach remains the most common form of teaching, despite evidence that it is less effective than active learning methods (Prince 2004; Walczyk and Ramsey 2003; Freeman et al. 2014).

An engaging lecture can capture students with a thoughtful story that introduces new ideas placed in a context relevant to the listener. Lecturing will always contribute to the educational process. However, modern pedagogy moves the lecture from the center of the process to the side, where it is but one of the many tools in the teaching shed. The learner-centered approach means just that the learner now occupies center stage, guided by a professor, and often aided by peers traveling the same journey of enlightenment (Herreid and Schiller 2013). The advent of the Internet means quick access to a diversity of resources and digital tools that ease and enhance the transition to leaner-centered instruction (Ruiz et al. 2006).

The learner-centered approach is to education what the solar panel is to energy production. This course uses this revolution in education to teach about the revolution in energy technologies. This chapter explains the structure of the course, its implementation at three different institutions, and presents information on measures of course efficacy.

Module Overview

Course Goals

The goals of this course trace to the grand geoscience challenge of *how society can use clean energy technologies as part of the response to global climate change*. The overarching goal of this course is to teach basic geoscience principles through an interdisciplinary exploration of environmentally sustainable technologies. The five supporting course goals are:

1. Exploration of the geoscience principles underlying, and social implications of, implementing new technologies to address issues of energy and resource scarcity and environmental sustainability
2. Use of data collected by students from experiments and published sources to test the efficacy of various green technologies
3. Application of student knowledge to develop sustainable energy and resource conservation strategies as individuals and as a society
4. Use of learner-centered techniques to organize geoscience and social science data and to analyze and present case studies relevant to the adoption of green technologies
5. Education of students to learn how to develop meaningful interdisciplinary questions about energy, resources, society, and sustainability that address higher levels of cognition

The course design reflects InTeGrate principles used for developing teaching materials. Addressing interdisciplinary problems is a central feature of the InTeGrate approach. The course examines the various technologies from a broad, interdisciplinary approach. Modules include elements of history, economics, social science, physics, and geoscience.

InTeGrate promotes improving student understanding of the nature and methods of geoscience and developing geoscientific habits of mind. The modules are designed for the students to understand the various technologies in the light of geoscience concepts. The hands-on exercises encourage investigation of geoscience principles related to each technology.

InTeGrate emphasizes the use of authentic and credible geoscience data. All of the modules provide opportunities for students to work with geoscience or related data, either generated through in-class experiments or obtained from the geosciences literature.

InTeGrate stresses the importance of systems thinking. The modules are designed so that students understand the technologies as part of a large and dynamic world, which requires systems thinking. The course is built around understanding and application of various sustainable technologies. Each technology can be taught as a system, and the role of that technology can also be taught as part of the greater Earth system.

Course Genesis

The genesis of this course traces to the first author's efforts to bring his old (1935) wooden-frame house close to energy neutrality. In 2009–2010 Cuker "solarized" the house, and with insulation and conservation, the house was brought to minimal net energy consumption. Cuker then used the house as a teaching laboratory for his Ecology and Environmental Science courses. While the students enjoyed the field trips, it was clear that many of the basic principles underlying the technologies eluded them, despite explanation. Because a 3 h lab was simply too short to provide a fuller understanding, Cuker began developing this course. InTeGrate provided the resources to bring on board co-authors, Maurice Crawford and Randy Chambers, and together they developed an 11-module course with the goal of teaching the emerging technologies of sustainability with emphasis on the underlying science and the social context. Since Cuker, Crawford, and Chambers taught three different courses at three different institutions, the module design incorporated flexibility of implementation.

Course Structure

The course is organized in 13 units, each with a page for the instructor and a comprehensive set of readings and activities for the student. These are designed with the intent that the students will read the units prior to coming to class. The first unit introduces and motivates the course. It places in context the links between the various technologies explored in the course and an interdisciplinary approach to the issue of sustainability. The introduction sets the tone for the course, ending with the statement, "At the end of this class, you will be able to identify and explain various emerging sustainable technologies, understand their application to solving problems, and place them into the context of the greater Earth system."

Interdisciplinary Content Modules

The subsequent 11 units consist of the content modules (Table 1). The first provides a common foundation in the basic principles of physics that inform the interdisciplinary technology specific to the modules that follow. Each of the subsequent ten interdisciplinary modules includes a social and scientific history of the subject, economic and environmental considerations, explanation of the technology with examples, hands-on activities, geoscience relevance, data collection, and analysis.

Module 2 examines energy from wind and the use of wind turbines. Modules 3 and 4 address energy from sunlight (Fig. 2), while Module 5 looks at passive design of structures to optimize thermal regulation and lighting. Module 6 examines passive and active geothermal systems as sinks and sources of energy. Module 7

Table 1 A listing of the 11 modules in the course and the associated hands-on activity

Module	Hands-on activity
1. Electricity, Work, and Power	Build simple circuits, electromagnets, a simple motor, and basic battery
2. Using Wind to Do Work	Test the influence of area on foils for sailboats and wind turbines. Use published data to evaluate wind turbine location
3. Thermal Energy from Light	Use different colored solar collectors to test influence of wavelength. Test a Fresnel lens for running a steam engine and igniting materials. Cooking with a solar oven
4. Creating Electricity from Light	Testing current and voltage production of photovoltaic (PV) panels of different orientation and shading. Using PV panels for hydrolysis of water
5. Passive Design for Optimizing with Nature	Using mason jar models to test materials for the collection and retention of heat
6. Energy from and to the Earth	Building a model ground-exchange thermal system
7. Better ways to Illuminate	Comparing costs and light and heat production of incandescent, fluorescent, and LED lights
8. Efficiency and Conservation are the Cheapest Fuels	Testing different types of commercial insulation in retention of heat
9. Hybrid and Electric Cars	Build model solar electric-fuel cell cars from kit. Use published data to examine return on investment. Drive in hybrid gas-electric car, and use the display to understand regenerative braking
10. Energy from Biofuels	Use different concentrations of sugar to see effects on alcohol production by fermentation Use published data to evaluate the efficacy of using land for biofuel production versus solar electric production
11. Composting Toilets	Examine a small composting toilet to understand the process

explores systems for illumination, and Module 8 addresses building insulation to promote efficiency of energy use (Fig. 3). Module 9 explores hybrid and fully electric vehicles (Fig. 4). Module 10 examines biofuels (Fig. 5), while Module 11 looks at composting toilets.

To illustrate the interdisciplinary nature of the approach used in the course, material content, and organization, consider Module 2, Energy from Wind and its learning objectives (Table 2). The module begins with the geoscience of wind and its global and local patterns of distribution. This is followed by the history of harnessing wind to do work, from early sailing vessels, through medieval windmills, to contemporary wind turbines. It is noted that harnessing wind was essential to the colonization of the new world and the development of the sugar industry that created the triangle trade and the institution of chattel slavery. The next section examines the physics of lift and drag and other considerations in wind turbine design. A section on impediments to adoption of the technology follows. A set of questions helps students use systems thinking and an interdisciplinary approach to address the operation and siting of wind turbines as well as the implications of adopting this technology.

Fig. 2 Students test which colors are best for solar-thermal collectors

Fig. 3 Students use simple and inexpensive materials to test the effectiveness of different types of commercially available insulation and calculate rates of heat transfer

The module closes with a set of exercises. The first asks students to use online maps of wind resources to determine the suitability of wind energy for the area where they live. The next uses actual or model sailboats to examine the relationship between airfoil area, wind velocity, and vessel velocity. The third uses model wind turbines with different numbers of blades to examine the effect of airfoil surface on

Fig. 4 Various kits are available to help teach green energy concepts; here students assemble a solar-powered fuel cell model car

Fig. 5 Students using yeast and sugar to make ethanol

generation of electricity. The final exercise is a web investigation of the current global distribution of electricity from wind turbines and its proportional role in nations' energy budgets. Suggested evaluation includes a formal laboratory report (discussed in the section on student evaluation below) and a simple objective test (Table 3).

Table 2 Learning objectives for Module 2, Using Wind to Do Work

Students will be able to
Use data they collect to test the relationship between airfoil design and energy harnessed
Recount the historical use of wind energy to include power for boats and ships, pumping water, processing grain and sugar cane, and making electricity. Students will evaluate the impact of each of these technologies on the history of social development to include trade, agriculture, and human dispersal
Explain the basic principles involved in transferring wind energy to mechanical energy, to include the roles of lift, drag, velocity, and ways to link foils to rotating shafts
Published datasets to evaluate specific locations for locating wind turbines, to include fluctuations in wind velocity associated with altitude, latitude, and daily and seasonal cycles. Interpret US maps of wind fields—spatial and seasonal. Evaluate their state for wind farms
Articulate the potential negative and positive environmental effects of wind turbines, including economic cost and environmental impacts of wind farms
Compare electrical generating capacity between a wind farm and a natural gas-fired power plant to include the issue of reliable base load generation
Diagram the major circulation pattern of wind on the planet and to detail the underlying principles involved

Capstone Project

The final unit of the course is a capstone project that compels the students to revisit the different technologies studied in the modules and use an interdisciplinary approach to place them in the context of a sustainable community. The students use an interdisciplinary systems approach to design a sustainable community that incorporates site-appropriate technologies. This entails showing the links between the various technologies selected, cost-benefit analysis, socioeconomic implications, and judgments of appropriateness.

Learning Assessments

The course provides five different assessment tools for instructors. A 55-question pre- and posttest quantifies mastery of the basic information related to the course goals. Detailed rubrics are provided for the other four assessments. The first addresses student participation in quiz and class discussion. The second assesses student oral presentations. The third evaluates module reports. The fourth scores performance on the capstone project.

Pedagogy and Adaptability

As noted above, we structured the modules to facilitate the learner-centered approach. Two things are essential for the success of this pedagogy. First, the students must be taught how to write meaningful questions. This is best done at the first

Table 3 Objective questions provided to instructors for aiding in evaluating student performance related to Module 2 (Using Wind to Do Work); note the correct responses are marked with an asterisk

There are prevailing winds that blow in the Northern and Southern Hemispheres, the circumpolar easterlies, the near 40° latitude westerlies, and the tropical easterlies. These winds result from: a. The equal amount of sunlight received by all parts of the Earth b. The atmospheric circulation cells powered by heating from the sun c. The Coriolis effect working on air that is moving north or south d. The tilt of the Earth *e. b and c
The amount of lift generated by an airfoil can be increased by: a. Decreasing the airspeed *b. Increasing the area of the foil c. Increasing the drag in the design of the foil d. Increasing the temperature of the air e. c and d
The structure on a sailboat that counters the tendency for the boat to slip sideway when sailing closer to the direction of the wind is called a: *a. Keel b. Bilge c. Mast d. Halyard e. Bow pulpit
During the seventeenth and eighteenth century, windmills in the United States and Europe were put to work to: a. Produce electricity b. Pump water c. Grind grain d. Power machinery *e. b, c, and d
In order to determine if constructing a wind farm to generate electricity is economically practical, the most important thing one must know is: a. The average solar illumination for the area b. The average temperature for the area c. The average wind speed at a height of 1 m above the ground *d. The average wind speed at 80 m above the ground e. a and b

meeting of class, using a short reading as a basis for question development. We emphasize that science is as much about developing good questions as it is about finding correct answers. Second, the students must thoroughly read the online module prior to coming to class and prepare questions based upon those readings. The course provides additional details on how to implement the learner-centered approach. This includes student-generated quiz and discussion questions, student oral presentations, and lab reports written as formal journal-style papers. The use of the activities suggested in the course website will depend on the amount of class time available to instructors. We present a full suite of activities best suited for a class with 3 h of instruction per week. Instructors with less classroom or laboratory time should select the activities best suited to their situations.

The course is designed to be taught as a whole, with the various modules informing each other. It is possible to extract individual modules for use as stand-alone items as part of another class, such as courses in environmental science or sustainability.

Assessment of the Course

Three instruments were used to assess course outcomes. The InTeGrate team conducted two of these, the GLE (Geoscience Literacy Exam) and the IAI (InTeGrate Attitudinal Instrument). Both were administered pre- and post-course. The GLE tested general geoscience knowledge, while the IAI explored learner attitudes toward sustainability and the geosciences (Gosselin et al. 2015; Fortner et al. 2016; GLE 2018; Kastens 2016; Steer et al. 2012). The third assessment is a pre- and posttest developed specifically for the course and administered by the professors. That assessment used 55 objective questions to gauge understanding of the information delivered in the course.

The course was piloted to a total of 48 students at the 3 institutions where each of the 3 co-authors taught (Table 4). The students ranged in age from 19 to 23 years old, 64% female, 30% male, and 6% neither gender. Ninety-six percent of the students were undergraduates, 6% first year, 22% second year, 20% third year, and 24% fourth year. Students self-identified as 54% white, 14% African American, and 6% Asian American. Some 50% said they took the course because it would be useful in their career. About 48% of students were science majors.

GLE and IAI Assessments

Results from the GLE showed students in the course improved their scores on the GLE by 6.3% between the pre- and posttest. The small increase in the GLE score suggests that the course added some to the geoscience knowledge of the students.

Table 4 The institutions involved in the course pilot, the number of students involved from each institution, and the course names

Institution	Professor	Number of students	Semesters	Course
Hampton University	B. Cuker	12	Fall 2014	Renewable Energy and Sustainability (MES 311/MES 611)
University of Maryland Eastern Shore	M. Crawford	4	Spring 2015 Spring 2016	How Green Technology Works (ENVS/BIOL 288)
William & Mary	R. Chambers	35	Fall 2014 Fall 2015	Alternate Energy Strategies (ENSP 249)

The GLE questions align more closely with what would be taught in an introductory geoscience course than the more specialized Renewable Energy and Environmental Sustainability course considered here.

The pre- and post-survey of attitudes and personal behavior (IAI) appears to show some effect due to the course. After taking the course more students thought it is important to use knowledge of Earth in their career (Likert score 6 or 7) (Fig. 6). In a similar way, the course appeared to motivate some students to desire to seek work with employers that use sustainable practices (Fig. 7).

The course appeared to increase interest in pursuing an Earth-related career. Nearly 65% of respondents began the course with this intent and that increased to about 95% post-instruction. In addition to evaluating this course, InTeGrate surveyed 1124 students distributed among all of the geosciences courses it developed. The percent of students with increased interest in a geosciences career was similar for both the course and the overall group (Fig. 8). Note that the students in the Renewable Energy and Environmental Sustainability course began with an interest in pursuing an Earth-related career about 40 points higher than the overall group (Fig. 8).

The IAI survey scored ten different actions to gauge personal involvement in sustainability: turning off water while brushing teeth; recycling paper, glass, and aluminum; washing clothes in cold water; unplugging appliances; walking or bik-

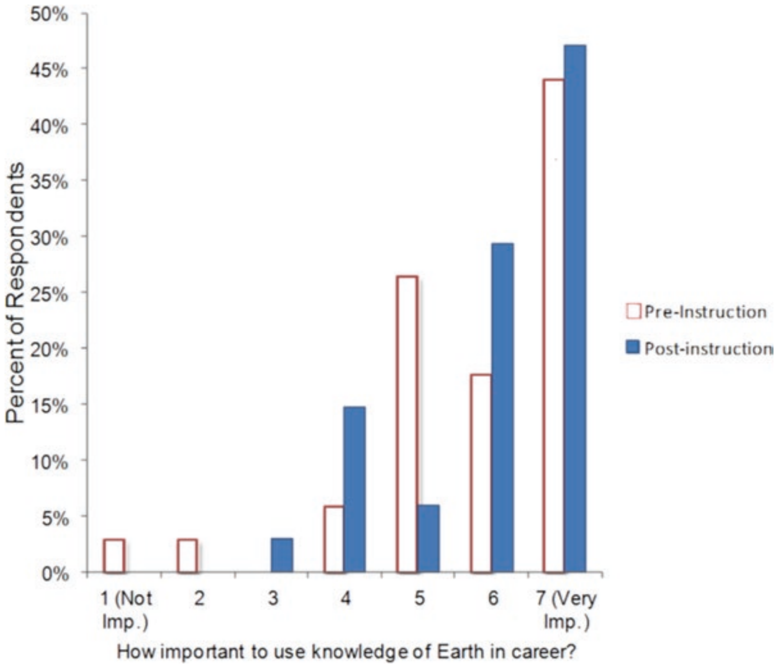

Fig. 6 Pre-/post-survey results regarding the question: "How important is it to use knowledge of the Earth in your career?"

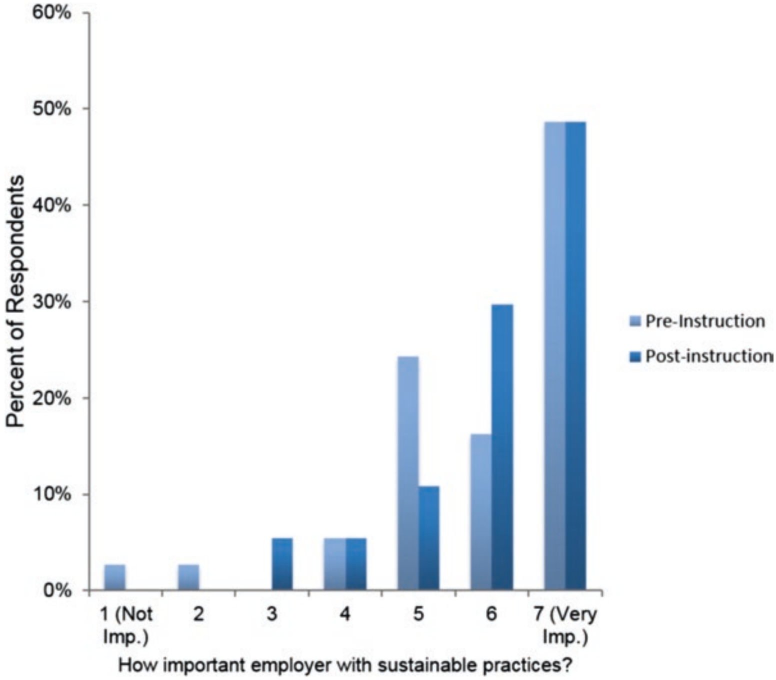

Fig. 7 Pre-/post-survey results regarding the question: "How important is it to seek employment where sustainable practices are used?"

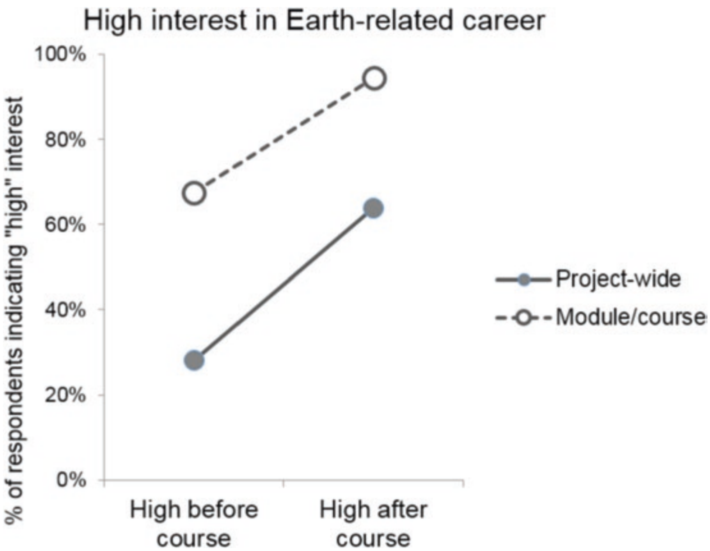

Fig. 8 Students in the Renewable Energy and Environmental Sustainability pilot showed more interest in pursuing an Earth-related career after completing course, as was also true for all InTeGrate course students combined (Project-wide)

Table 5 IAI survey responses for this course and the overall InTeGrate student population around the issue of sustainability; note that the maximum possible score for the sustainability index was 10

	% increase in composite sustainability index over course	% respondents indicating that the InTeGrate course they took influenced sustainability behaviors
For all courses and modules combined	5.1% (increase of mean score from 6.0 to 6.3)	50.1%
This course	14.1% (increase of mean score from 6.95 to 7.92)	56.8%

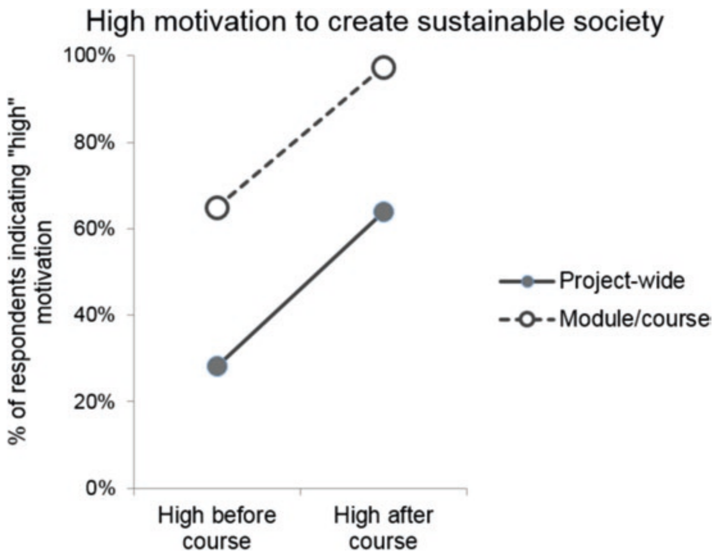

Fig. 9 The course increased the level of motivation for students to help create a sustainable society, as was true for students project-wide

ing; turning off lights; using public transportation; using power saver on computer; buying locally grown food; and bringing reusable bags to the store. The maximum possible score was 10. The average index score increase by 14% for course participants, which was nearly three times the 5% increase found for students across all InTeGrate courses and modules (Table 5).

The IAI asked students about the various influences on their sustainability behaviors. About 57% of respondents for this course reported that their personal actions around sustainability were influenced by the course. This is only somewhat higher than the 51% reported on average for all of the InTeGrate courses (Table 5).

The course increased the percentage of students highly motivated to create a sustainable society from about 62% pre-instruction to nearly 98% post-instruction. The rate of increase was similar to that for students surveyed across all InTeGrate courses and modules (Fig. 9). When asked if the students thought what they learned in the course would help society overcome problems of environmental degradation, 97% of participants in the course said yes, compared to 82% for students across the InTeGrate courses and modules.

Pre-/Posttesting

A 55-question pre-/posttest (5 questions per module) is provided with the course. This pre-/post-summative assessment was piloted in the fall semesters of 2014 and 2015 at both Hampton University and the College of William & Mary. While outcomes varied, in all cases the mean score improved after completing the course (Table 6).

Implementation of the Course at the Three Institutions

The course was developed and piloted at three quite distinct institutions. Hampton University (HU) is a private historically black college that enrolls about 4600 students. The College of William & Mary (W&M) is state supported and enrolls about 8600 students. The University of Maryland Eastern Shore (UMES) is a state-supported historically black college that enrolls about 4500 students. Science or architecture majors populated the courses at HU and UMES, while non-science environmental policy majors took the offering at W&M.

The Hampton University Experience

HU offered the course at the 300 level, and third and fourth year science or architecture majors took the class. It became a required course for students majoring in Marine and Environmental Science during the first year of piloting the program (2014). The course was presented in a weekly 3 h block over the 14-weeklong semester. This allowed the offering of one unit per week, with an additional class meeting used for a field trip to the instructor's solar house. The 3-h block scheduling facilitated flexibility in structuring that day's activities. If the hands-on elements of the course required sunshine or wind, often those would be done first to take

Table 6 Results of the pre- and posttests administered to students at two of the pilot institutions

Institution and semester	Number of students	Pretest mean % score (SD)	Posttest mean % score (SD)	% Point improvement
Hampton U, fall 2014	7	49 (13)	52 (9)	3
Hampton U, fall 2015	6	43 (16)	87 (11)	44
William & Mary, fall 2014	15	59 (20)	69 (28)	10
William & Mary, fall 2015	15	60 (11)	71 (7)	11

SD standard deviation of the mean

advantage of favorable environmental conditions. That moved the quiz, discussion, and student presentations to later in the class meeting.

Students were evaluated on their performance in developing quiz and discussion questions (10%), quiz results (10%), oral reports (10%), journal-style weekly module laboratory reports (55%), the capstone project report (10%), and participation in the pre- and posttests (5%). That most of the course grade depended on the module reports reflects the emphasis placed on the acquisition and analysis of data, with the attendant application of findings to understand how the various technologies worked and their potential role in building a more sustainable society. Providing very specific instructions on how to construct the module reports proved essential for the architecture majors in the classes who had little previous exposure to laboratory science courses. Those students also benefited from a tutorial on how to use Excel spreadsheets for data analysis and graphing.

As the students progressed through the semester, they appeared to draw links between the various technologies and their potential contributions to sustainability. They would invariably raise the question as to why the University doesn't invest in rooftop solar or do a better job with insulation and efficient lighting. This would lead to a deeper discussion of the impediments to adopting more sustainable technologies.

In the first pilot offering, the students were directed to develop their capstone activity around designing a sustainable community using appropriate technologies on land needing redevelopment in the city of Hampton, VA (where the campus is located). For the second year of piloting, the students were given the option to site their sustainable village anywhere. In both cases the students showed a deeper understanding of sustainability that went beyond carbon and water footprints. Proximity to work, schools, shopping, and essential services all appeared in their presentations. Students also seemed to grasp the concept of "appropriate," as none chose to locate large wind turbines or concentrated solar-thermal facilities within the boundaries of their sustainable communities, instead focusing on rooftop solar, super-efficient passive and active building design, urban gardens, composting toilets, electric vehicles, bicycles, and mass transportation. The students did a good job in drawing the links between the different technologies and identifying synergies, such as the connection between rooftop photovoltaic panels and recharging stations for electric vehicles. Allowing the students in the second year to choose their own site for the sustainable community increased the diversity of solutions presented. This proved a useful way to get the students to think about the importance of understanding the local environment, culture, and economy in developing site-appropriate sustainable communities.

The William & Mary Experience

The Renewable Energy and Environmental Sustainability modules were used in a one-credit course called "Alternate Energy Strategies," taught during the fall 2014 and fall 2015 semesters at William & Mary. The 15 undergraduate students each semester were environmental policy majors or minors, i.e., their supporting interdisciplinary coursework was primarily in the social sciences and humanities. No students were natural science majors. The course met once weekly for 80 min, completing one module each week. The short amount of in-class time each week forced the class to focus on hands-on exercises and student presentations, with less time spent on reading reviews and quiz questions. The class also focused on how each alternate energy strategy might be applied on their college campus, and they completed calculations to compare energy costs and energy yields from different renewable energy applications, relative to the current use of fossil fuels. The campus-centric approach allowed students to develop a systems-level appreciation for the complexity of renewable energy adoption, its costs and benefits, and the interaction and feedbacks among natural and human components of the campus system.

The course was envisioned as exposing this group of non-science majors to various alternate energy strategies, using the campus energy needs and available renewable resources to assess the utility of these approaches for William & Mary. A goal was for students to become comfortable with numbers and with common units of power and energy, to allow them to compare relative yields among different renewable energy sources, and to calculate how much the college could reduce its carbon footprint by implementing each renewable energy strategy. Within this context, students were to think critically about each energy strategy. The students quickly discovered that wind and water sources at William & Mary were grossly insufficient to supply more than about 1% of campus energy needs. Even though more energy was available from solar and geothermal sources, students came to realize that energy efficiency and conservation (i.e., reducing the need) could decrease the size of the campus carbon footprint faster than adoption of these alternate energy strategies.

One exercise in particular allowed the students to use authentic data from disparate sources to develop a better understanding of the energy issues at hand and to provide information for decision-making regarding energy use on campus. After dissecting the well-known CO_2 curve from Mauna Loa and observing the historical trend in US CO_2 emissions since the beginning of the Industrial Revolution, students understood that a reduction in reliance on fossil fuels could decrease CO_2 emissions and contribute to a "slowing down" of the increase in atmospheric CO_2. Students then developed a table of campus CO_2 emissions (a product of our annual college energy audit) and saw that emissions had decreased during the same year that the college established an office of sustainability. Although the administration had been quick to point out this happy coincidence, a plot of annual CO_2 emissions as a function of heating degree days (meteorological data obtained from our campus weather station) demonstrated that emissions were linearly correlated with winter temperatures, i.e., more emissions when it was cold and less emissions when it was warm. The students could predict annual CO_2 emissions on campus based on the number of heating degree days. Students then extended their analysis to consider how the change in number of heating degree days might be altered if the campus reduced its heating of buildings by 1°. Using the energy-temperature plot they developed, students were able to determine how that reduction in heating degree days would lead to a concomitant decrease in CO_2 emissions from the burning of fossil fuels for heating. The students were generating information that could be used toward campus policy decisions (i.e., what energy savings and decrease in carbon footprint would be realized if the campus turned down building thermostats 1° during winter?).

Given the brevity of once-weekly meeting times for this one-credit course and the less scientific background of the students, some of the technical focus of the course modules had to be reduced. Overall, students were engaged in the course and in each module, as the hands-on exercises allowed students to explore the renewable energy concepts at a fundamental level. Some scaffolding of learning occurred, but the course did not "build" as quickly as seems to have occurred with the courses delivered at the other institutions. Still, students with social science and humanities backgrounds contributed their interdisciplinary social, economic, and environmental perspectives on sustainable energy approaches, which led to active class discussion. Nowhere was this clearer than in the final written exercise that required students to use their newly acquired knowledge to describe their vision for a community that would incorporate a full range of sustainability approaches in its design.

Students did become engaged in sustainability issues on the William & Mary campus and now have a good sense of what sorts of renewable energy and efficiency strategies are viable in our environment. Some of the students ended up serving on the campus Committee on Sustainability. One student in the course wrote a successful proposal to the College to determine the feasibility of photovoltaic installation on the rooftops of two buildings on campus, and another student proposed the acquisition and installation of a micro-hydropower station at the dam on the campus lake. These post-course examples demonstrate how students are taking their coursework to the next level—a good outcome for a one-credit course.

The University of Maryland Eastern Shore Experience

At the University of Maryland Eastern Shore (UMES), the course was implemented in the spring semesters of 2015 and 2016. The course was offered as a one-credit lab and met for an hour and 50 min each week; during each class period, one module was covered. The course was open to all students including non-science majors and served as an elective for either environmental science or biology majors. Despite being widely offered, enrollment for the course was low with only one student in 2015 and three students in 2016. The students who did enroll were upperclassmen and either biology, environmental science, or agriculture majors. Some of the Renewable Energy and Environmental Sustainability modules were also used in the General Environmental Science course which enrolls 30–50 non-science majors each semester.

In addition to meeting the overall goals of the course, a goal was to strengthen the quantitative skills of the students. Because the students were generating and analyzing their own data, it presented an opportunity to help them learn more about quantitative analysis. One approach to help them feel more at ease with data was to record it on the classroom board and briefly discuss it before the end of class. This helped the students better understand the variation associated with the experiments and how it is expressed. It also gave them a more inherent feel for their data and an understanding that experiments don't always go as planned or expected.

The assessments for this course included the student-developed questions for each module, module reports, presentations, and the final capstone assessment. For grading, the module reports received the most weight, followed by the final capstone assessment. For the latter the students completed that written and oral presentation. This allowed the students to see how their peers fulfilled the assignment and gain a broader view of different approaches. It also provided a basis for discussion on the last day of class.

After taking this course, the students appeared to understand that there are alternatives to technologies that depend on the use of fossil fuels and that we have choices in how we live and those choices have environmental and societal consequences and grasped the scientific principles that are the foundations for the technologies discussed. Some of the students really appreciated how and what they learned could be applied in their lives, such as calculating payback period for energy efficient investments, and I think that connection seemed to help motivate the learning process.

Lessons Learned and Recommendations

Working with the Weather

Of all the activities in the course, students seem to enjoy most the hands-on experimentation. These activities also form the basis for their weekly reports. Since many of these activities require appropriate weather, it is critical to be flexible in their execution. It is best to build a syllabus for your course with the flexibility to quickly change the hands-on activity for the day. While it would be nice to work with photovoltaic cells on the day for which the students had done the readings and preparation for the module, it might be raining that day. So it is best to have at the ready the hand-outs and equipment to do one of the indoor projects and to be prepared to merge some of the activities into subsequent class meetings. This may mean adjusting due dates for module laboratory reports or accepting the absence of some of the data due to the weather.

Keeping Up to Date

Renewable energy technology and its implementation is a highly dynamic field. While the underlying technologies for solar and wind energy are mature, they continue to advance. The adoption of these technologies around the world is increasing at an exponential rate, particularly because wind and solar are now the most cost-effective way to add electricity to the grid. Energy storage technology also rapidly advances. Industrial-sized battery banks can now store enough energy from solar and wind production to compensate for darkness and windless days.

Given the rapidly changing landscape of renewable energy and associated technologies, it is critical to direct students to online sources to provide the most current information. The modules include URLs for such websites, and many of the exercises provided with the course challenge students to find the most up-to-date data on these topics. Some of the best information resides in government agency websites. However, those URLs often lack stability, often disappearing or changing in response to shifts in the political climate. Trade associations and advocacy groups tend to publish the latest data, but it is important to caution students about the potential for bias from those sources. In our experience, YouTube is a very stable platform, and people who post there rarely remove their shared content.

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Part III
Models for Change Within the Higher Education System

Implementing InTeGrate Materials in an Upper-Division Undergraduate Engineering Course

Diane I. Doser and Musa J. Hussein

Abstract A Geology for Engineers course is designed and taught for juniors majoring in civil engineering between 2012 and 2017. Many aspects of the course focused on how engineers help to address the grand challenges facing society and are a natural fit for the use of InTeGrate materials. The first 2 years of the course was taught prior to the availability of InTeGrate materials, but we used active learning methods and group activities. In the remaining 4 years, we used InTeGrate materials in 33–40% of class group activities. We each taught the course for two consecutive years. Results show that students enjoyed the quantitative and data-rich aspects of InTeGrate materials, retaining information from the materials well after completing the activities. Comparable final course grades were obtained by both instructors and showed overall higher grades than obtained from 2012 to 2013 when InTeGrate activities were not used. Grades for our course were also higher than those in the junior-level Geotechnical Engineering course that follows our course. Students in our course had the most difficulty with InTeGrate-related quiz and exam questions that had multiple correct answers and with calculations of groundwater flow.

Keywords Geology for civil engineers · Societal grand challenges

Introduction

One focus of the InTeGrate (Interdisciplinary Teaching about Earth for a Sustainable Future) program was to develop curricula to increase Earth literacy of all undergraduate students (InTeGrate 2017). Although many of the early curricular materials were primarily designed for Introductory Geoscience and Environmental Science courses, we felt it would be worthwhile to test the suitability of the materials in an upper-division course (junior level) that was cross-listed between the Departments of Geological Sciences (GEOL 3321—Geology for Engineers) and Civil

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Engineering (CE 3335—Geological Engineering) at the University of Texas at El Paso (UTEP). This course (hereafter referred to as Geology for Engineers) is required for all civil engineering majors and is a prerequisite for a junior-level course in geotechnical engineering. Over 95% of the students enrolled in our course are civil engineering majors. The occasional geoscience major or major from another engineering field takes the class as an elective.

InTeGrate materials seemed a good fit for the course since it focuses on how engineers use geoscience to address grand challenges facing society. Published textbooks on the subject (e.g., Kehew 1988; West and Shakoor 2018) also emphasize how engineers use geology to solve societal issues such as the development of mineral and water resources or to help mitigate natural hazards. The final project in the class focuses on how geoscience is applied to local engineering challenges (such as building new transportation or water systems for our growing transborder community). During the 4-year period that we have used InTeGrate materials, the course has been taught by two different instructors, allowing us to gauge if two instructors can achieve similar results.

In this paper we present information on student outcomes and student and instructor feedback from teaching Geology for Engineers between 2012 and 2017. We used InTeGrate materials in the course between 2014 and 2017. Doser taught the course between 2012 and 2015. Hussein taught the course for the very first time in 2016 and taught it again in spring 2017.

Course Background and Development Using InTeGrate Materials

Engineering is an attractive career choice in our local community. In 2015 about 1.7% of the UTEP undergraduate student body majored in civil engineering (UTEP Engineering 2015). Hispanic and female students are traditionally underrepresented among engineering students in the United States (National Science Foundation 2017). The Department of Civil Engineering reported that 74% of all undergraduate civil engineering majors were Hispanics with US citizenship (UTEP Civil Engineering 2015). The same report indicated that 14% of civil engineering majors were Mexican nationals and 28% were women. Hispanic students (both US citizens and Mexican nationals) comprised 85–97% of our courses from 2014 to 2017 (Fig. 1), and 17–33% of our enrollment were women. Many of these students do not speak English as a first language at home, and Spanish is often the language of choice during in-class group activities. Thus we have made an effort to provide Spanish-English glossaries and links to web materials written in Spanish to assist the students in learning the geological vocabulary associated with the course.

Geology for Engineers has been taught at the University of Texas at El Paso (UTEP) for over 30 years. It has generally been taught by faculty within the Department of Geological Sciences that have a strong background in engineering

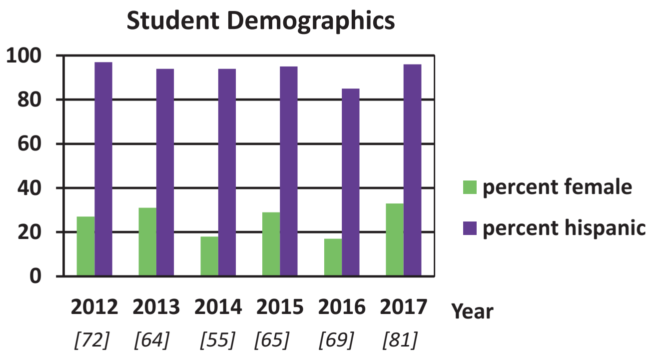

Fig. 1 Class demographics. Numbers in brackets refer to numbers of students each year

geology, geophysics, and rock mechanics, although it is occasionally taught by civil engineering faculty. In the late 1990s, Doser met with the civil engineering faculty to insure that the content of the course aligned with their degree program and adequately prepared students for subsequent courses in soil mechanics and geotechnical engineering. The course focuses on the basics of physical geology but also includes aspects of structural geology, geophysics, and historical geology.

Special attention is given to geological and engineering problems facing the local region such as availability of freshwater, flood control, slope stability, and behavior of desert soils. Semkin (2005) and Semkin and Butler Freeman (2008) have shown that place-based learning is especially appealing to minority students who are closely tied to their community and who want to find solutions to local problems that will benefit their communities.

Doser worked with a number of graduate teaching assistants to develop a series of laboratories and eventually a laboratory manual (first tested in 2005) that focused on these topics of interest. The laboratories emphasize hands-on, inquiry-based learning and focus on local problems. The main topics covered in the lecture and laboratories for the course are given in Table 1.

Since its inception, the course has consisted of two 50 min lectures and a 3 h lab each week with an enrollment of 55–80 students. It is usually taught each spring semester, but when the demand rises, it is also taught in the fall semester. The small number of geoscience graduate students that have the necessary background in geophysics and engineering geology to serve as laboratory instructors for the course and our limited access to laboratory space has kept the class from growing to over 80 students per semester.

One aspect of the course that is popular with students is a semester-long group project that focuses on a realistic site investigation/preliminary design of an engineered facility such as a light rail system, aqueduct, housing development, or tunnel. Students investigate local geological and geophysical aspects of possible sites for the project as well as evaluate its impact on humans and the environment. The last 3 weeks of the laboratory are devoted to developing a topical group poster presented during the last week of class to their peers. This allows the students to

Table 1 Major topics in course

Week	Lecture/activity	Lab
1	Introduction/none	No lab due to Monday holiday
2	Plate tectonics/form groups, geologic hazards at plate margins	Geography, topographic maps
3	Minerals/people and minerals[a]	Minerals
4	Igneous rocks/boom and bust[a]	Igneous rocks, volcanic hazards
5	Sedimentary and metamorphic rocks/ metallic sulfides[a]	Sedimentary rocks, hazards from sedimentary rocks, topographic cross sections
6	Exam/sedimentary mining[a]	Metamorphic rocks, hazards from metamorphic rocks, engineering properties of rocks
7	Rock properties/mining impacts[a]	Soils, campus arroyo and outcrop tour
8	Rock properties/geotechnical site investigation and soils[b]	Soils, soils testing
9	Structural geology/local structural geology part 1	Structural geology, geologic cross sections
10	Geophysics/local structural geology part 2	Geophysics, seismic techniques, earthquakes
11	Geophysics /geologic time[b]	Geophysics, non-seismic techniques
12	Rivers, groundwater/geophysics[b]	Flooding, rivers, groundwater
13	Exam/floods[b]	Slope stability
14	Slope stability/groundwater[a]	Work on final project work
15	Weathering/slope stability[b]	Project presentations

[a]InTeGrate-based activity
[b]Teach the Earth-based activity

immediately see how the geoscience concepts they are learning in class can be applied on the job. The semester-long project was initially introduced into the course by Doser over 25 years ago, before she became familiar with extensive studies that demonstrate how project-based learning succeeds in engaging students in the analysis and interpretation of data, builds scientific writing and oral communication proficiency, fosters collaboration, and sharpens investigative skills (e.g., National Research Council 2003; Allen and Tanner 2003; Bhattacharjee 2005; Mitchell and Graziano 2006; DiBartolmeis 2011).

The use of a nationally published textbook was eliminated following a student poll in 2010 that indicated that over 60% of the students did not use or read the assigned textbook, choosing instead to use study guides and lecture notes developed for course that included links to web-based supplementary materials. In spring 2011, no perceptible difference in student performance was observed without the use of textbook, and since then, the course has relied strictly on instructor-supplied materials. This change, as well as participation in a workshop by Edward Prather on lecture-tutorial approaches to teaching (e.g., Prather et al. 2005; Prather et al. 2009), led Doser to the development of the current class format in 2012 where one 50 min period each week is composed of a mini-lecture interspersed with think-pair-share, “voting card” responses, and short reflections. The other weekly 50 min class period starts with a quiz and then is followed by a short, in-class group activity. The

3-h-long laboratories allow for more lengthy activities such as construction of topographic profiles, analysis of geophysical data, campus field trips, or soil testing. Introducing InTeGrate activities into the weekly in-class, 50-min-long, group activities seemed a natural fit to the course.

In this study we consider 2012 and 2013 as "pre-InTeGrate" years. At this point, active learning and group activities occurred in class each week, but no InTeGrate materials that aligned with the course content were yet available for use. The classroom setup consisted of movable chairs around fixed tables, allowing for reasonable group interactions for our 64–72 students. We adopted some group activities from the Science Education Resource Center's "Teach the Earth" collection (Science Education Research Center 2017) and created some from scratch (Table 1).

By 2014 the InTeGrate module on "Humans' Dependence on Earth's Mineral Resources" (HD) (Bhattacharyya et al. 2014) became available, and activities from 5 of the units of the module were adapted for our 55 student course (Table 2). In addition to using the materials in class, the students were assigned homework activities related to rechargeable batteries (Unit 2, activity 1) and formation of sulfide deposits from undersea black smokers (Unit 5). The class was held in a room with fixed desks and was not ideal for group activities.

In 2015 the InTeGrate module on "Environmental Justice and Freshwater Resources" (EJ) (Perez et al. 2015) was available for use. We adapted portions of Unit 5 (Love Canal) and Unit 6 (Ogallala aquifer) into one class activity (Table 2) and assigned homework on finding water well information from the US Geological Survey (Unit 6) prior to class. By adding this activity, over 40% of group work was InTeGrate based. We were able to teach in a classroom with completely movable furniture that was ideal for group interactions among the 65 students.

In 2014, we substituted the five new InTeGrate HD units for existing group activities on desert processes, soil formation, and three general activities on rocks and minerals. In 2015, we substituted material from the InTeGrate EJ module for a

Table 2 Specific InTeGrate materials used in classes

Week	Module[a]/activity	Years used
3	HD/Unit 1.1, 1.3 (People, Products and Minerals)	2014–2017
4	HD/Unit 2.1 (Boom and Bust: How Econ 101 Relates to Rocks, Rechargeable Batteries)	2014–2017
5	HD/Unit 5 (Resources Created by Igneous and Metamorphic Processes)	2014–2017
6	HD/Unit 4 (Mineral Resources Created by Sedimentary Processes)	2014–2017
7	HD/Unit 6.2 (Mining, Society and Decision-Making, Phosphorous Mining)	2014–2017
14	EJ/Units 5 and 6 (Hazardous Waste and Love Canal, Groundwater Availability and Resources)	2015–2017

[a]*HD* Humans' Dependence on Earth's Mineral Resources, *EJ* Environmental Justice and Freshwater Resources

group activity that focused on determining the depth to the water table and contaminant transport directions from a hypothetical dairy farm. Thus, much of what we eliminated was similar in content to the added InTeGrate materials. We still covered soil formation in the laboratory (Table 1), and the students often had to consider the impact of desert processes during their semester-long projects.

Hussein taught the course for the first time in 2016, using all the materials developed in 2015. The classroom again had movable furniture allowing for ease of group interactions for the 69 students. In 2017 the demand for the course was very high with 81 students enrolled. This year, the classroom had fixed tables but movable chairs.

Methods

After obtaining approval from the UTEP IRB to introduce and assess the use of InTeGrate materials in our class, we developed a common set of multiple-choice and open-ended assessment questions related to the InTeGrate activities that we gave on quizzes and exams and tracked over the 4-year period from 2014 to 2017. We took some assessment questions directly from the published online modules. We designed others to determine how long the students retained the material and whether they could apply the concepts they learned to local geoscience problems (Table 3). During the first week of each class, we informed all students in written and oral form that we planned to collect data on their responses. We assured them that we would keep their responses anonymous and allowed anyone who wished to opt out of the study, although during the 4 years of our study no one did.

We used activities from the HD module from weeks 2 to 7 of the class (Table 2). These activities highlighted the importance of rocks and minerals, the geologic processes that form these materials, and the economic, environmental, and social aspects of mining for minerals (Table 2). In week 14 we combined activities from two units of the EJ module (Table 2) related to groundwater and contaminant flow.

From 2014 to 2017, we tracked the responses to six multiple-choice questions related to the HD module (questions 1–6, Table 3 and Fig. 2). Questions 1–5 were single-answer multiple-choice questions, but question 6 asked the students to identify all factors that could increase the cost of a mineral resource. Question 5 extended the concept of crystalline (chemical) sedimentary rocks to rocks of the El Paso region. The “R” in Fig. 2 indicates when we repeated a question on either another quiz or exam. We kept the wording of the questions the same each year, although we varied the order of multiple-choice answers from year to year.

We tracked the responses to two questions related to the EJ module (questions 7 and 8, Table 3 and Fig. 2) from 2015 to 2017. Question 7 was a multiple-choice question about how water interacted with clay layers. In question 8, we gave students the permeability and distance between a contaminant spill and a house and asked to calculate how long it would take the contaminant to reach the house. The students had completed a similar problem as a group activity in class the week before.

Table 3 Assessment questions

Question number	Specific question	Module/unit[a]
1	The titanium mined by DuPont in Florida was found in a ____________ deposit (a) Igneous (b) Lake (c) Beach (d) Sand dune (e) Lava flow	HD/4
2	Yellowstone National Park is located above a _____________: (a) Convergent boundary (b) Hot spot (c) Transform fault (d) Metamorphic core complex	HD/5
3	Naturally how does phosphorous end up in the soil? (a) Decay of animals and plants on the surface (b) Weathering of rocks (c) Dissolves from atmosphere (d) From streams and lakes	HD/6
4	____________ is an example of a mineral extracted from *crystalline* (chemical) sedimentary rocks. (a) Rutile (b) Staurolite (c) Salt (d) Titanium	HD/6
5	An example of a chemical sedimentary rock found in the El Paso area is: (a) Granite (b) Conglomerate (c) Basalt (d) Limestone (e) Quartzite	Extension of HD/6
6	Which of the following will increase the price of a mined resource? (a) Because of higher operating costs, many mines in the US close (b) Mining companies need to invest in new technology to meet more stringent environmental regulations (c) More mines open up, so that more of a resource is mined (d) A popular new product uses a lot of that mineral resource (e) Global population increases, and this mineral resource is used in products owned by most people (f) Global health officials find that the mineral resource is harmful to human health (g) A new, relatively cheap mineral resource is found that can be used instead of the mineral resource (whose price we care about)	HD/1
7	An underground clay layer that is relatively flat lying, when interacting with water will: (a) Absorb the water (b) Expand on contact with the water (c) Act as a barrier so water will not infiltrate any further (d) Become more permeable than a sand layer	EJ/5
8	If it was 150 m from a toxic waste dump to a house, estimate how long it would take for the waste to move if the soil had a permeability of 10^{-5} cm/s (there are 86,400 s in a day)	EJ/5

[a]*HD* Humans' Dependence on Earth's Mineral Resources, *EJ* Environmental Justice and Freshwater Resources

We also tracked the responses to several open-ended questions related to HD and EJ content. The class completed two activities in HD Unit 1 (People, Products and Minerals). In the first activity, they needed to match common household items such as toothpaste and baby powder with their respective minerals. In the second, they examined how consumption of minerals is related to gross domestic product (GDP), with one portion of the activity specifically focusing on India's use of minerals found in fertilizers. A week later, we gave a quiz that included the question "What was the most interesting thing you learned in last week's group activity on the

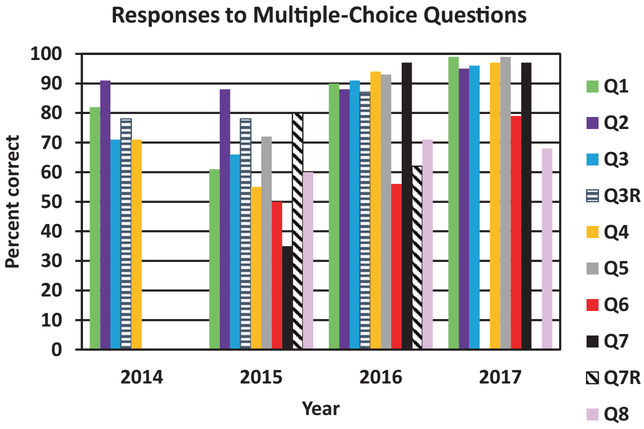

Fig. 2 Response to various questions (Q). See Table 3 for topics of questions. "R" indicates responses for a question that was asked a second time on a subsequent exam

everyday uses of minerals and mineral economics?" We assessed the responses by generating word clouds as shown in Fig. 3 (for 2014–2017). Word clouds have been used as assessment tools in a variety of educational settings including college-level writing courses (Kitchens 2014) and middle school mathematics classes (Nickell 2012). Our word clouds were generated using software found at the website https://www.wordclouds.com/. Note that the word clouds was generated after removing the words that formed part of the original question (e.g., most interesting thing, everyday uses of minerals). The captions to the word clouds indicate how the size of the words is related to the number of times a particular word was mentioned by the students.

Prior to HD/Unit 5, we assigned the students homework where they read material on black smokers (undersea hydrothermal vents), watched a video clip about them, and then answered questions and drew a concept map they turned in to our online classroom management system several hours prior to class. Many of the students produced exceptionally good concept maps, reflecting their ability as engineers to diagram the feedback and interconnectedness of systems. We asked the students "What is a black smoker? How are they associated with mineral deposits?" in class 2 h after the homework was due. Figure 4 shows their responses for 2015–2017.

A quiz given 1 week after the EJ activities on groundwater asked "What was the most interesting thing you learned last week about aquifers?" We show responses in Fig. 5.

We added the question "which in-class activity did you like best and why?" to the final exams in 2016 and 2017 in order to determine how many students enjoyed and recalled the InTeGrate-based activities. By this time, we based over 40% of the in-class activities on InTeGrate material. Table 4 tabulates the specific InTeGrate and non-InTeGrate topics mentioned by the students. Table 5 in the Appendix provides samples of the actual student responses to the question.

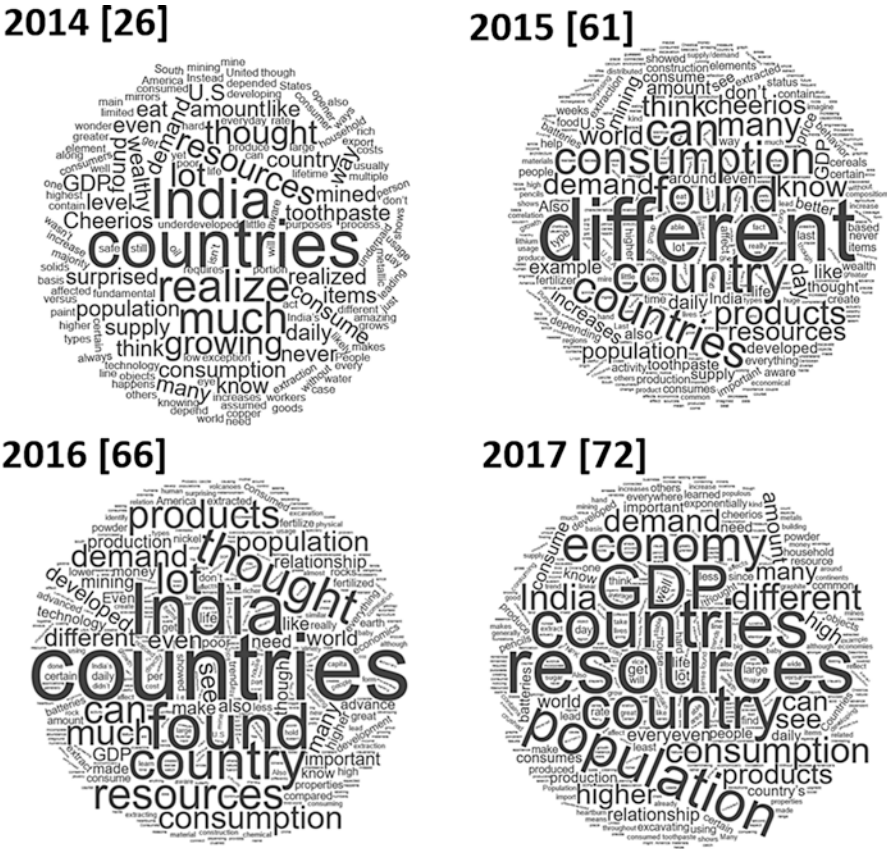

Fig. 3 Word cloud comparisons for question given 1 week after covering HD/Unit 1. Words mentioned in response to the question "What was the most interesting thing you learned in last week's activity on the everyday uses of minerals and mineral economics?" Words forming part of the original question were omitted from the word cloud. Numbers in brackets indicate number of student responses used to generate each word cloud. The sizes of the words are proportional to the number of times the words were mentioned in the responses. For example, in 2016 the word "countries" was mentioned 26 times, "India" 20 times, "resources" 14 times, "GDP" 5 times, and "high" 3 times

In addition to collecting student responses, we tracked final course grades between 2012 and 2017. All courses during this 6-year period contained the same number of activities, quizzes, and exams and the same total number of points to insure each year's grades were comparable. We also developed grading keys and rubrics that were used both in lecture and laboratory to insure all instructors were consistently assigning the same number of points for similar responses. We varied some material from year to year (such as exam questions, project topics, topographic maps, and samples used in laboratories) so that students could not simply memorize answers obtained from classmates who took the course in previous semesters.

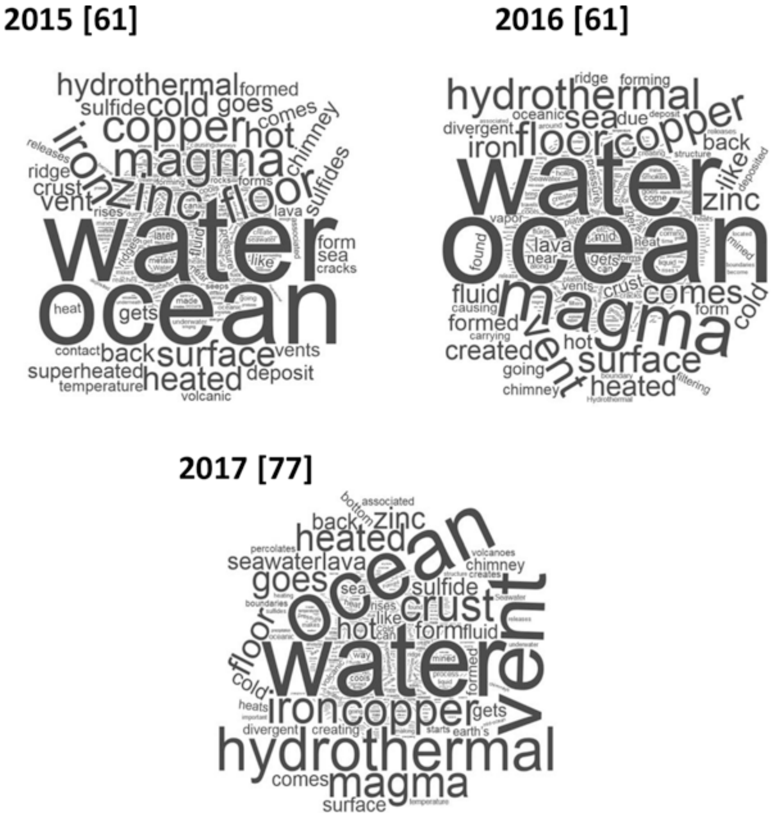

Fig. 4 Word cloud comparisons for question from HD/Unit 5 on black smokers given 4 hours after a homework assignment on black smokers was due. Words mentioned in response to the question "What is a black smoker? How are they associated with mineral deposits?" We omitted words forming part of the original question from the word cloud. The numbers in brackets indicate the number of student responses used to generate the word cloud. The sizes of the words are proportional to the number of times the words were mentioned in the responses. For example, in 2016 the word "water" was mentioned 60 times, "magma" 40 times, "heated" 15 times, and "boundary" 5 times

Results

Figure 2 indicates that the lowest overall correct responses to HD-related multiple questions (questions 1–6) occurred in 2015 with correct responses steadily increasing in 2016 and 2017. This observed increase could possibly be the result of students from previous semesters sharing old quizzes and exams. Question 6 was the HD-related question with the lowest number of correct responses (50–79%) each year it was asked. This is not surprising, as it was a more difficult question that required students identifying multiple factors that could influence the increase in the price of a mineral. In 2015 students appeared to have a difficult time identifying the

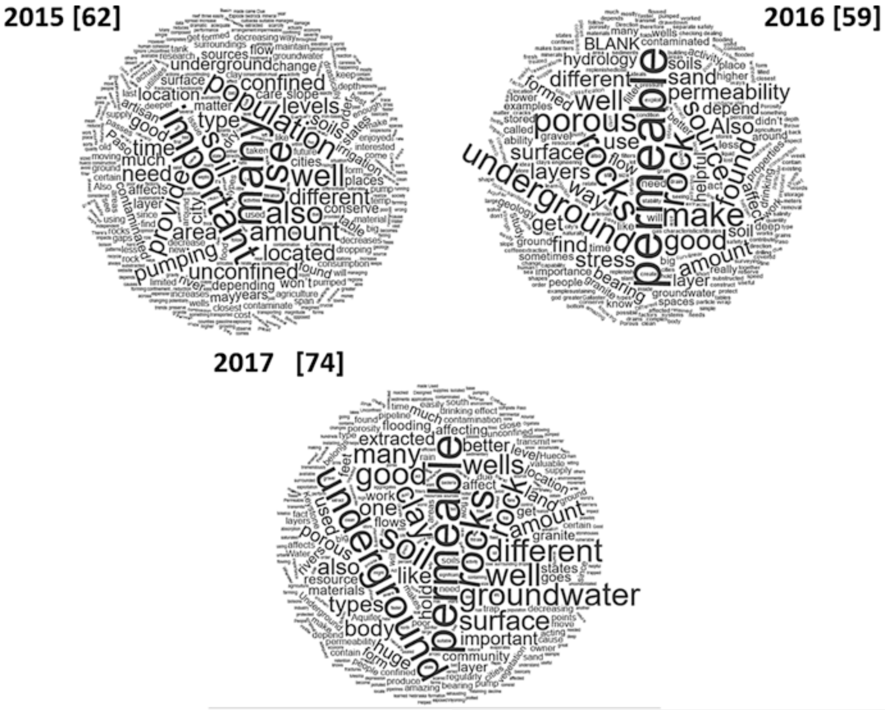

Fig. 5 Word cloud comparisons for question given 1 week after completing EJ/Units 5 and 6. Words mentioned in response to "The most interesting thing I learned about aquifers last week was…" We omitted words forming part of the original question from the word cloud. The numbers in brackets indicate number of student responses used to generate the word cloud. The sizes of the words are proportional to the number of times the students mentioned them in the responses. Students mentioned the word "water" over 50 times each year. If included in the word cloud, it would have been so large that it would have been impossible to see the other words. In 2016 the word "permeable" was mentioned 20 times, "underground" was mentioned 15 times, and "different" was mentioned 5 times

source of phosphorous in soils (question 3, 66% correct), but more were able to answer correctly (78%) when the question was repeated on a later quiz or exam. Interestingly, in 2016 slightly more students answered question 3 incorrectly when it was repeated.

The word clouds for the open-ended HD questions (Figs. 3 and 4) indicates that students had a good recall of materials a week after an in-class activity (Fig. 3) and homework they completed 2 h or more before class (Fig. 4). It seems that many students felt the relation of mineral consumption to a country's GDP and population (Fig. 3) was important. In all but the 2015 class, it appears many students recalled from the activity that although India had a low GDP, it had a very high usage of minerals that were major components of fertilizers. Students also recalled common everyday items containing minerals such as toothpaste and cheerios. The word clouds for the open-ended question related to black smokers (Fig. 4) shows that

Table 4 Topics of responses to final exam question "Which in-class activity did you like best and why?"

Topic	Percent (2016)	Percent (2017)
HD/Unit 1—everyday uses for minerals	7	7
HD/Units 1 and 2—supply and demand	12	9
HD/Unit 2.1—batteries	12	10
HD/Unit 4—titanium mining from beach deposits	1	0
HD/Unit 5—black smokers/igneous processes	1	0
HD/Unit 6.2—phosphorous mining	7	3
EJ/Unit 6—groundwater	3	9
Total all InTeGrate units mentioned	*43*	*38*
Slope failure (in-class activity, week 15)	4	–
Mineral identification (lab, week 3)	1	1
Voting cards (entire class)	1	1
Geologic time, relative age dating (in-class activity, week 11)	7	10
Plate tectonics (in-class activity, week 2)	14	11
Contour maps (labs, weeks 2, 5)	8	–
Geotechnical site investigation (in-class activity, week 8)	6	–
Final project (week 15)	4	10
Structural geology (in-class activity, weeks 9, 10)	3	3
Geophysics (in-class activity, week 12)	6	3
Rock mechanics (lab, week 6)	–	7
Field trip to arroyo on campus (lab, week 7)	2	9
Volcanic hazards (lab, week 4)	–	1
Flooding (in-class activity, week 12)	–	6
No response	1	–
Total of all other activities mentioned	*57*	*62*

students had made connections between magma, the ocean (water), and hydrothermal processes that produce the black smokers. They also recalled that the hydrothermal process produced deposits of copper, iron, and zinc.

In comparison to the HD activities, Fig. 2 indicates the students had difficulties in most years with answering EJ questions. In 2015 only 35% correctly answered that clay would serve as a barrier to groundwater flow (question 7), although when the question was repeated on the final exam, 80% answered it correctly. Conversely, in 2016 nearly 95% of the students answered question 7 correctly on the quiz, but then when it was repeated on the final, the correct responses fell to 62%. Several other non-InTeGrate activities in the class and laboratory had previously highlighted the impermeability of clay, so the lack of retention of this concept suggests some confusion about the concept that impermeable materials (like clay) serve as barriers to water flow.

It was also surprising that so many students (more than 30%) had trouble with a calculation (question 8) that was primarily a dimensional analysis problem that should not be unfamiliar to engineers. It was similar to a problem that they had already worked on as a group in class the previous week for materials with two different permeabilities. This suggests not all group members were actively participating in the in-class exercises or that the students did not realize this type of calculation had similarities to many engineering problems that involve dimensional analysis.

The one open-ended question we tracked that was related to the EJ module (i.e., the most interesting thing I learned about aquifers from last week's activity was) was given the week following the EJ module. The word cloud results (Fig. 5) indicate students recalled that aquifers contained groundwater that was often pumped by wells, that an aquifer depended on porosity and permeability, and that, as the population grew, impact on aquifers increased. In some cases students indicated a specific material (e.g., soil, sand) that would make a good aquifer.

Table 4 indicates that on the final exam, 38–43% of the students mentioned their favorite activity came from an InTeGrate unit. This was unexpected as many of these InTeGrate activities took place over 2 months before the final exam. The most popular InTeGrate activities seemed to be some of the earliest ones introduced, including minerals in household products, mineral supply and demand, and the role of minerals in the manufacture of rechargeable batteries (Table 4). Maybe this reflects when the students first made connections between geology and their everyday lives, it was a memorable experience. More students found the activities on groundwater of interest in 2017 than in 2016.

The most popular non-InTeGrate activity students mentioned (11% and 14%) was the very first class activity related to plate tectonics (Table 4). This may again reflect the fact that students immediately found the activities appealing and different from the standard lectures they experienced in other classes. Another popular activity students mentioned both years (7–10%) required them to piece together a sequence of events related to geologic time. Many students felt this activity was like an engaging puzzle (Appendix). In 2016 >5% of the students mentioned activities that used geotechnical descriptions of soils to determine the best location for a construction project (week 8) and an activity that involved designing a geophysical survey to detect the location of underground utilities (week 12). In 2016 >5% of the students mentioned liking an activity where they determined the extent of flooding from a river (week 13). The project was also popular in 2017 (10%), although this activity was primarily associated with the laboratory. Laboratory topics mentioned by >5% of the students included a field trip to an arroyo located on campus (week 7) where students observed sediment deposition and collected samples for grain size and plasticity analysis (9% in 2017), construction of topographic maps and profiles (8% in 2016) (weeks 2 and 5), and a lab that involved Mohr circles and rock mechanics problems (7%) (week 6) that students felt helped reinforce what they were learning in other engineering classes (Appendix).

Figure 6 compares final grades in the courses between 2012 and 2017. The inclusion of InTeGrate materials in-class activities, quizzes, and exams began in 2014. Since this is an upper-division course, few students fail the course. The first observed change is that the number of C's (score of 70–80) decreased significantly between

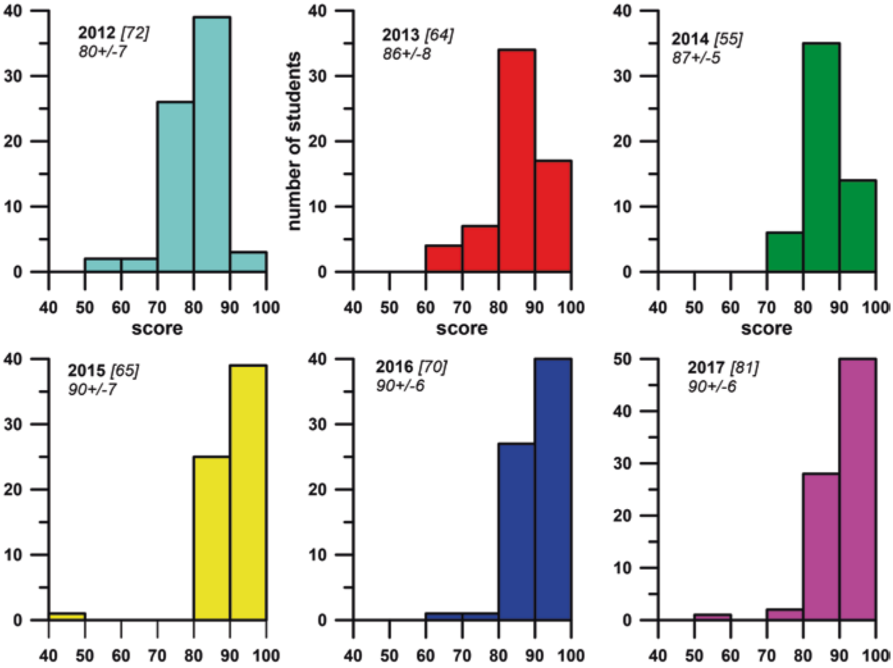

Fig. 6 Final scores in Geology for Engineers class by year. The number in brackets is number of students in the class. Other italicized numbers indicate the yearly average score and standard deviation

2012 and 2013 and remained low in subsequent years. The second change is an increase in the number of students receiving A's that occurred in 2015 with a similar pattern occurring in 2016 and 2017. The change between 2012 and 2013 could be due to a combination of the instructor becoming more effective at adopting and using active learning activities and an insistence on teaching in classrooms where the layouts enhanced group learning. A Student's T-test indicates that the observed change in the mean scores between 2014 (first InTeGrate materials) and 2015 is significant at the 99% confidence level. This suggests that as the instructor became more comfortable with the materials, the student learning improved. Note that there is no difference in outcomes between 2015 and 2016 when two different instructors taught the course (Student's T-test indicates change in the mean is significant at only a 27% confidence level), indicating that experienced and newer faculty can both use these materials to achieve similar outcomes. It is possible that some sharing of course notes and old exams between consecutive groups of students led to some of the observed increase; however most exams and quizzes contain about 20–30% open-ended questions, requiring students to explain and synthesize materials rather than memorize answers.

Figure 7 shows grade distributions for 2015–2017 for Geotechnical Engineering, a required course taught by civil engineering faculty. Students cannot enroll in this

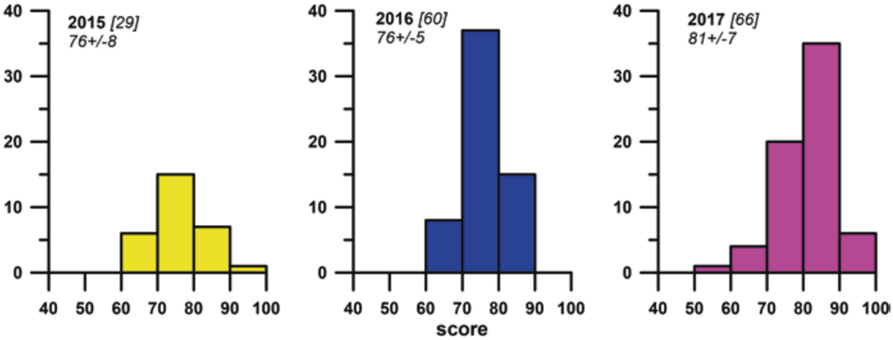

Fig. 7 Final scores in geotechnical engineering class from 2015 to 2017. Geology for Engineers is a prerequisite for this course. Numbers in brackets are number of students. Other italicized numbers are the mean and standard deviation for each year

course unless they have received a "C" or better in the Geology for Engineers class. The Geotechnical Engineering course also consists of two 50 min lectures and a 3 h lab each week. The instructor uses a few active learning strategies such as think-pair-share in the lecture portion of the course. Notice that the class average is lower than for the Geology for Engineers course with few students in the 90–100 range and more in the 70–80 range, although the class average appears to have increased over the past year. It is difficult to make one-to-one comparisons between two completely different classes, but it appears that students who have successfully completed Geology for Engineers were not as successful in the Geotechnical Engineering course.

Discussion

Most students adjusted to the group activities quickly and worked well in groups. It was clear that they felt the InTeGrate material helped show them the relevance of geosciences to their lives and to their future careers as engineers. We felt that the structured readings and power points available for each assignment, as well as glossaries of terms, were helpful to many of our students who do not speak English as their first language. As engineers, they especially liked the materials that involved interpretation of real datasets presented in graphical form (Appendix), and once they understood the concept mapping, they did an excellent job of producing innovative maps of interrelationships.

We found that class discussions often spilled over into topics of local interest or were related to topics they were learning about in other engineering classes. For example, during the class discussion about groundwater (EJ/Unit 6), students brought up questions about fracking and wastewater disposal and their possible relationships to earthquakes and how to best conserve our remaining groundwater supply. Students who had taken field trips in other courses to a local wastewater treatment plant, desalination plant, or limestone quarry were eager to discuss what they saw and how it related to the course. Although business and economics courses are required for the civil engineering degree, many students indicated that they felt the economics issues covered in the HD units made them see connections between GDP and mineral resources that they had never considered when taking these other required courses (Appendix).

Each semester usually three or four students feel that they did too much work in the course, that the material was irrelevant to their degree, or that the courses would be better if civil engineering faculty had taught them. But the number of students who enjoyed the course and actually sought the instructors out after the course to continue to ask questions—even after they were employed by local companies—argues that most left the course feeling it enhanced their education.

Lessons Learned

We found many strengths to the use of InTeGrate materials. The activities helped reinforce lecture material and provided continuous feedback to the students throughout the semester. They were engaged in hands-on work every week with quizzes and assignments scaffolded, so they could not simply cram for exams to pass the class. Some students liked homework they did on an individual basis, and others enjoyed group activities. Visual learners appreciated the graphs, concept maps, and videos provided in InTeGrate assignments. Others appreciated thinking more deeply about issues and considering problems from different viewpoints (Appendix). Student outcomes (Fig. 6) indicate the students thrived and learned in a setting that used InTeGrate materials and other hands-on activities.

It required some time and initial effort to organize the materials and find methods that worked for facilitating groups in a large classroom setting. However, once the materials were organized, new instructors, such as Hussein or another instructor who taught the course for the first time in fall 2017, could readily use the materials. More time was required to grade weekly assignments and quizzes compared to the course that uses only lectures and exams. We feel that 80 students is near the size limit of what one instructor can handle, although with help from teaching assistants, the class size could be expanded.

Although we used materials from only two InTeGrate modules (some of the first that were publically available), we feel it would be worthwhile to revisit the InTeGrate materials to incorporate other units into our course. Activities from the "Living on the Edge: Building Resilient Societies on Active Plate Boundaries" (Goodell et al. 2015) or "Water Sustainability in Cities" (Burian et al. 2016) modules would connect well with our students' interest in plate tectonics and water issues (Table 4, Appendix).

Conclusions

Civil engineering students in Geology for Engineers courses found InTeGrate materials that focused on "Humans' Dependence on Mineral Resources" and "Environmental Justice and Freshwater" interesting and engaging (Appendix). They especially liked the materials that involved interpretation of real datasets presented in graphical form. They made connections between the materials and engineering problems such as management of groundwater and the construction and operation of mines. Students were able to recall important aspects of the materials at the end of the semester, 2 months or more after the activities took place. Student outcomes were similar regardless of the instructor (Fig. 6). Forty-three percent of the 2016 class and 38% of the 2017 class indicated they liked InTeGrate-based activities, the best of all course-related activities (Table 4). These results indicate InTeGrate materials can be easily adapted to an upper-division engineering course and give students meaningful insights into how geosciences can be combined with engineering to help address society's grand challenges.

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Appendix

Table 5 Example of responses to question "Which in-class activity did you like best and why?"

	Type of activity[a]
Responses from 2016	
Phosphorus and fertilizer as well as the battery activity. It is always good to know and see the uses of everyday minerals benefited and put to use	I
I liked the very first class activity, learning about the different tectonic plates and how convergent, divergent, and transform boundaries cause material disasters and earthquakes, volcanos, landslides, etc. It was interesting to learn the cause of all these activities was due to tectonic plate activity	O
The activity where we went out and explored the sediments of the channel. The going outside collecting soil and then running the plasticity test were an excellent way to become more involved with geology. I really like this	L
I like the activity where we talked about supply and demand because it taught me how the amount of minerals or elements in each affects the prices of utilities we use today. Also the process they use in mines could affect the price on those minerals	I

(continued)

Table 5 (continued)

	Type of activity[a]
The one we had to design a new building and a new parking lot to be. Because it was interesting to kind of incorporate some designing	O
The final project is the activity I liked the most out of this class. I say this because it gave me a real-life situation to think about that, I will be working with in the future career	L
My favorite activity was the one where we dated the rocks in a cross section. I found the methods of calculating the ages very interesting as well as learning about the different ages where a specific type of rock was formed	O
Learning how to make contour maps, read them, and analyze them is what I most enjoyed. I didn't even know how important it is to know how to read them and then make a profile. It was very educational, and I know I'll never forget this knowledge	L
I liked the economics of minerals parts I and II because I understood where and why minerals are mined and the causes of how it affects cost when demand uses and balls. And I also know a relationship between the minerals a country has and its wealth. But it didn't always indicate a country to be wealthier	I
Phosphorus and phosphate activity—because I learned how important phosphorus is in life. Serves as a fertilizer and can mine, extracted from rocks, and there's no substitute for phosphorus	I
The slope stability activity was more interesting to me because I have worked in materials construction areas where we have to control potential slope hazards on the field	O
The geophysical survey activity was the one I liked the most, by selecting the tools, to locate underground utilities, sketching the geophysical signature, within the boundaries, and the responses we concluded	O
I like the one that we had to plan a location for a construction of a building, so we had to figure if the construction area was safe, in a good elevation out of floods, or other kinds of materials that affected the foundation	O
I liked the activity of the aquifer because I learned how aquifer gets water and how we can use the rainfall to both instantaneous aquifer to retain water	I
I liked the voting cards. Much cheaper alternative to the clickers and it created class participation	O
The class activity I liked more was determining contamination of water wells or water table in the event of an oil spill or other types of contaminations with the use of a topographic map. This activity allows us to better understand and better plan and design any water wells so that way they will not be contaminated	I
I liked all the class activities because it was a new thing that I do in my classes and we got a chance to think. The activity I liked more was the first activity we did when we selected a city and considered its plate tectonic location	O
Responses from 2017	
My favorite class activity was finding what batteries were efficient and what type of elements they contained. It was interesting to find out more about lithium and copper batteries because I didn't really think they were efficient batteries	I
I liked Mohr's circles because I could use it in geotech class	O
I really enjoyed walking down the arroyo during the lab because we got to see and analyze how streams move rocks and erode the floor	L
I enjoyed the relative age dating of the different layers of rock within a cross section. It felt like a puzzle, and I got excited to solve it	O

(continued)

Table 5 (continued)

	Type of activity[a]
I liked the economic activity. It showed me how business is involved with geological features. As I grow older, I can justify my decisions in business and apply what I learned	I
I really enjoyed the final project. Everyone was very creative and presented their garage sites well in the groups	L
I liked the class activity where we had to compare two articles about phosphorous. It was the first activity I liked because it showed the two sides of a problem and it made you analyze it	I
The one where we determined how minerals increased or decreased in price depending on the circumstances because I find it interesting how the same material cost differently depending on the circumstances	I
The one about aquifers because I learned that some of the southern states of the United States share an aquifer	I
The one I liked was the plate tectonics activity because we got to learn about the different types of plates and what they can cause as well as discussing about the San Andreas Fault	O
The project was awesome!	L
The class activity I liked the most was the one where we used information from a webpage about the wells in a certain area and used the information to answer the questions. I liked this because I learned how to use the webpage and got to see the amount of wells there are in certain areas of Texas and/or the United States	I
I liked the activity about identifying what minerals each product contained. I was impressed to realize there were minerals in things: baby powder, cheerios, etc.	I
I liked the river flooding where we looked at elevations and determined how an area would react to changes in water level	O
The class activity I liked the most was dealing with the economic factors of food, land resources, and cost. Most impoverished countries had a low GDP but high demand due to population	I
I liked the aquifer activity. I liked it because water purification methods are a big attraction in El Paso and this activity gave me more insight into the problem of water usage and the need to replenish what is taken from the ground	I
I liked the geophysical methods because those techniques came up in my interview for Halliburton	O

[a]*I* integrate-based activity from 50 min "lecture" session, *O* other activity from "lecture session," *L* activity from laboratory session

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Modified Use of InTeGrate Curriculum in the Sustainability General Education Program at California State University, Chico

Rachel Teasdale, Colleen Hatfield, Janine Stone, Philip W. Clements, Lee Altier, Don Hankins, and Eric Willard

Abstract As part of an Implementation Project, InTeGrate materials were adopted by faculty who teach courses in the Sustainability Pathway, a program of the general education (GE) curriculum at California State University, Chico. Units were selected from InTeGrate modules to best suit the learning goals of courses and the student learning outcomes (SLOs) of the GE program. Faculty collaborated in the selection and use of curriculum materials during the 2-year project. In some cases, InTeGrate materials were used as written, but in other cases, units were modified to support new and existing course activities. Where entire units didn't work for their course, they were able to incorporate data and other resources from units to enhance their course activities. Faculty involved in the project report that materials are important and that activities are useful to their courses. The Implementation Project allowed faculty in the Sustainability Pathway to work together, when they otherwise had not done so previously, and also resulted in the use of high-quality, student-centered course activities.

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Keywords Implementation team · General education · Sustainability · Student engagement

Introduction

Motivation and Goals

In 2012 California State University, Chico, redesigned the general education (GE) program as a collection of GE courses linked by a common theme known as a pathway. Each of the ten topical pathways fulfills lower- and upper-division course requirements in nine content areas (CSU, Chico 2017). This model of GE was envisioned to provide students with intellectual experiences that explore a central theme from diverse perspectives throughout their undergraduate education (e.g., Kuh 2008). For example, the Sustainability Pathway explores multiple perspectives surrounding environmental issues and the interdependencies among equitable societies, vital economies, human innovation, and goods and services provided by healthy global ecosystems (CSU, Chico 2017).

The InTeGrate curriculum (InTeGrate 2017a) provided the basis for developing intentional connections between courses in the Sustainability Pathway. Furthermore, the geoscience approach to InTeGrate materials offers a breadth throughout the Sustainability Pathway by exposing students to geoscience-based grand challenges facing society (Zoback 2001; NRC 2001; Kershaw 2004), which are not typically encountered in liberal arts courses. Several InTeGrate modules were well suited for the Sustainability Pathway courses. The goals of the implementation program aligned well with the need for cohesive, interdisciplinary curriculum for Sustainability Pathway courses, both in the content of individual units and use of student-centered pedagogies known to increase student learning (Implementation Program 2017; InTeGrate 2017b, 2017c).

In adopting InTeGrate curriculum, the goals of the Chico Implementation project were twofold:

1. To introduce students to the idea that scientific disciplines provide a means of developing solutions to societal issues by providing opportunities for students to use and interpret scientific datasets that have important applications to societal issues
2. To adapt curriculum to the Sustainability Pathway utilizing pedagogical strategies that engage students in the course material

The InTeGrate project has several overarching strategies focused on a wide array of issues facing society that require solutions with geoscientific perspectives (InTeGrate 2017b). Progress in addressing and finding solutions to such problems will come from diverse stakeholders, all of whom will benefit from geoscientific literacy. The disciplinary breadth and depth of the InTeGrate materials also provided an innovative means for including geoscientific literacy across the Sustainability

Pathway curriculum. Furthermore, the selection of InTeGrate activities was based on perceived relevance to students to improve their interest and engagement (e.g., Mitchell 1993; Pintrich 1999; Hidi and Renninger 2006) and thereby enhance student learning (e.g., Hulleman and Harackiewicz 2009; Teasdale et al. 2015).

Connections to Interdisciplinarity

The environmental, economic, and social dimensions of sustainability issues necessitate students' engagement with perspectives from multiple disciplines in both STEM (e.g., biology and environmental science) and non-STEM (e.g., history, economics, ethics, and justice) fields (e.g., Caviglia-Harris and Hatley 2004; Daugherty and Carter 2017). Just as research in sustainability requires interdisciplinary data, teaching sustainability must also consider interdisciplinary perspectives (Newell and Klein 1996; Kurland et al. 2010).

Sustainability issues are complex and can be connected in nonlinear ways (Newell and Klein 1996). Examples include political decisions using scientific results and essential ecosystem services, the value of which is largely ignored in the marketplace. InTeGrate modules illustrate these complex relationships through examination of facts and personal decisions. For example, in *Environmental Justice* Unit 2 (*The Hydrologic Cycle and Freshwater Resources*; Perez and Villalobos 2015), students record and discuss their personal water use to consider the relationship of their decisions to hydrologic cycle processes.

The diversity of InTeGrate concepts and materials appealed to participating faculty because it allowed them to select materials that corresponded with the intended student learning objectives (SLOs) of their courses. For example, students in the Environmental Economics course participated in economic analyses of mineral resources and EPA safety guidelines to learn that "efficient" solutions to environmental problems in the context of economics are not always achievable due to social, political, and scientific constraints.

Actions

Our initial vision for the end product of this project was the development of a program that could serve as a model for all of the General Education Pathways at CSU, Chico. The rationale for this effort was based on the need to improve student learning and engagement as well as faculty collaboration and peer professional development. The Sustainability Pathway theme and SLOs, which also closely coincided with the GE program SLOs, provided the organizing framework. Results of our work were consistent with project goals, in that we successfully developed and implemented this model of common curricular concepts taught with engaging pedagogical practices within the Sustainability Pathway.

Timeline

In 2015, faculty in the Sustainability Pathway at CSU, Chico, were awarded funding to support work as an Implementation Team (Teasdale et al. 2016a) to adopt InTeGrate materials in Sustainability Pathway courses. P.I.s identified interested faculty who were teaching courses from different GE content areas within the Sustainability Pathway (Table 1).

Faculty in the project represented diverse disciplines, lower- and upper-division courses, and seven of the nine content areas of the GE curriculum. The intent of the project was not to redesign courses or the pathway but to enhance and support the learning goals of pathway courses. The resulting team of eight faculty represented seven different departments and taught ten pathway courses in seven of the nine GE areas in the Sustainability Pathway (Table 1). Faculty diversity included STEM and non-STEM disciplines, a range of teaching experience (first-year faculty to more than 25 years' experience). Faculty included tenured (5), tenure-track faculty (1), and lecturers (2), some with PhD's and others without. Including lecturers was important because pathway courses are often developed by tenured faculty and then passed among lecturers without sufficient transfer of course design philosophies. Lecturers are often not included in faculty professional development (e.g., Gappa 2000; Wallin 2004), so their participation in this project provided an important opportunity for tenured/tenure-track faculty and lecturers to collaborate together.

Initiation of InTeGrate in the Sustainability Pathway

In summer 2015 the Chico Implementation Team met for the first time at a project kickoff workshop. This was also an opportunity for some faculty to meet one another, in spite of having taught in the same pathway for several years. We introduced our courses to provide each other with a sense of our diverse perspectives and disciplines. Faculty spent time exploring InTeGrate materials to find modules and units appropriate to their courses and relevant to students as they progress through the Sustainability Pathway. This exploration was a mixture of group time spent discussing the use of specific InTeGrate materials in different courses and independent work by faculty to adapt the InTeGrate curriculum to their courses.

One important topic discussed was if students would encounter the same materials as they progress through the pathway and if this would be a negative experience. There was a consensus, in fact, that students would gain a deeper understanding by experiencing the materials from the context of courses representing the perspectives of different disciplines. So, some InTeGrate units were adopted by several courses.

Table 1 Organization of GE discipline areas required for all pathways, courses involved in this project for the Sustainability Pathway, and the academic semesters in which InTeGrate activities were used for each course

GE discipline areas (Upper/lower division)	Department (course)[a]	Module[b]	Used Fa15	Used Sp16	Used Fa16	Used Sp17
Foundations-Science with Lab (LD)	Geological and Environmental Sciences (Introduction to Environmental Sciences)[a]	CofC Unit 2	✓			
		CofC Unit 4	✓			
Societal Institutions (LD)	Geography and Planning (The American West)	CofC Unit 2	✓	✓	✓	✓
		Soil Unit 4	✓	✓	✓	✓
Individual and Society (LD)	NA	NA				
Humanities (LD)	Religious Studies (Religion, Ethics, and Ecology)	CofC Unit 6	✓	✓	✓	✓
Arts (LD)	NA	NA				
Learning for Life (LD)	Biology (Environmental Literacy)[a]	CofC Unit 5	✓	✓	✓	✓
		CofC Unit 6	✓	✓	✓	✓
		EnvJust Unit 1			✓	✓
		EnvJust Unit 2	✓	✓	✓	✓
		EnvJust Unit 4				✓
		EnvJust Unit 5	✓	✓	✓	✓
		Minerals Unit 2	✓	✓	✓	✓
		Minerals Unit 6	✓	✓		✓
Social Sciences (UD)	Economics (Environmental Economics)	Minerals Unit 2	✓	✓	✓	✓
		Minerals Unit 3	✓	✓	✓	✓
		Minerals Unit 6	✓	✓	✓	✓
Arts and Humanities (UD)	History (American Environment)	CofC Unit 4	✓	✓	✓	✓

(continued)

Table 1 (continued)

GE discipline areas (Upper/lower division)	Department (course)[a]	Module[b]	Used Fa15	Used Sp16	Used Fa16	Used Sp17
Natural Sciences (UD)	Plant Science: (Food Forever)[a]	CofC Unit 6	✓		✓	
		Soil Unit 1	✓		✓	
		Soil Unit 4	✓		✓	
	Plant Science: (World Food and Fiber)[a]	CofC Unit 1		✓		✓
	Geological and Environmental Sciences (Environmental Science)[a]	CofC Unit 2	✓	✓		✓
		CofC Unit 4	✓	✓		✓

Seven of the nine GE content areas were included in the project
[a]STEM course
[b]*CofC* Climate of Change, *EnvJust* Environmental Justice and Freshwater Resources, *Minerals* Humans' Dependence on Earth's Mineral Resources, *Soil* Soil Resources

Selecting InTeGrate Units to Enhance Learning Goals and Outcomes

From the initial proposal stages of this project, faculty were committed to incorporate InTeGrate curriculum in ways that supported existing SLOs of the GE program, the Sustainability Pathway (SP), and their own courses. Faculty selected InTeGrate units that address the GE SLOs that prepare students to:

- *Describe and explain environmental dynamics associated with human activities and assess the value of balancing social and economic demands with the Earth's ability to sustain physical and biological resources and cultural diversity (GE SLO 7 and SP SLO 4)*, which is addressed in modules, *Climate of Change* and *A Growing Concern: Sustaining Soil Resources through Local Decision Making*, (referred to as "Soils").
- *Demonstrate knowledge of and apply research techniques and information technology appropriate to the intellectual and disciplinary context (GE SLO 5 and SP SLO 10)*, which is addressed in modules: *Climate of Change* and *Humans' Dependence on Earth's Mineral Resources* (referred to as "Minerals").
- *Demonstrate knowledge and skills necessary to take responsibility for one's own life and actions and to recognize opportunities and responsibilities to become engaged in our various local, regional, national, and international communities (GE SLO 6 and SP SLO 2)*, which is addressed in the units *Climate of Change* module that were used (Units 1, 2, 4, and 6).

Because of the breadth and depth of the InTeGrate materials, faculty were able to select modules and/or units that complemented their individual class SLOs. Faculty participants determined several important areas of student learning that the InTeGrate units are well suited to address the following:

Use of Scientific Data

Unit 2 of the *Climate of Change* module (*Climate Variability in the Equatorial Pacific*; Shellito 2014) has students use real-world sea surface temperature, wind, pressure, and precipitation data from the central Pacific Ocean to describe ENSO patterns. This unit was implemented in both an upper- and lower-division Environmental Science courses to explore "the basic laws of matter and energy that govern the environment" by having students use relationships between flows of energy and matter in the environment as they connected pressure and temperature data associated with the movement of moisture within the atmosphere.

Critical Thinking

Unit 6 of the *Minerals* module (*Mining, Society, and Decision Making*; Branlund and Joseph 2014) was used in the Environmental Literacy course to engage students in viewpoints of multiple stakeholders affiliated with phosphate mining. Students developed mitigation strategies to decrease negative impacts of phosphate mining while continuing to increase food production. This activity enhanced the course SLO by incorporating *evidence-based reasoning and critical thinking* in the context of societal issues related to sustainable agricultural practices. Another activity in Unit 6 addressed the critical thinking SLO for the Environmental Economics course as students investigated supply and demand of gold and critically assessed factors causing shifts along supply and demand curves.

Unit 4 of the *Climate of Change* module (*Slow and Steady?*; Walker 2014a) was used by the History course and both lower- and upper-division Environmental Science courses to address SLOs of each course, including using critical thinking skills and experiencing the process of science. Unit 4 addresses both SLOs by guiding students in examining real-world albedo data and radiative forcers used by climate scientists to describe causes, impacts, and future climate change.

Societal Issues and Human Behaviors

Unit 6 of the *Climate of Change* module (*Adapting to a Changing World*; Walker 2014b) was used by the Environmental Literacy, Religious Studies, and Plant Science courses to examine students' level of concern about climate change. This was compared to the levels of concern of the general US population and corresponding behaviors and decision-making (KQED 2016; Yale 2017). Not surprisingly, all three courses using this unit have course SLOs aligned with the GE and Sustainability Pathway SLOs (listed above in the section on Selecting InTeGrate Units to Enhance Learning Goals and Outcomes) that personalize impacts of sustainability issues and human behaviors so that students:

- Evaluate choices in your life and make informed decisions affecting your own resource use (Plant Science).
- Identify key issues for sustainability on spatial and temporal scales from local to global (Environmental Literacy).
- Analyze the ideological and ethical conflicts surrounding selected environmental, social, and economic issues (Religious Studies).

This unit is well suited for each course and relevant SLOs as it proceeds from the personal "climate personalities" of students to explore adaptation and mitigation strategies for dealing with changes to the Earth's climate.

Human behaviors are also addressed in activities of Unit 2 in the *Soils* module (*Soil Characteristics and Their Relationship to Land Use Practices*; Fortner et al. 2014a) in which students in the Plant Science course examined characteristics of soil in the context of relationships among soil quality, water use, and plant growth. In doing so, Unit 2 incorporates the societal context of food production to the science of soil characteristics. Similarly, the Geography course adapted Unit 4 of the *Soils* module (*Using SoilWeb to Investigate the Soil Beneath You*; Fortner et al. 2014b) to more closely examine local soils with the SoilWeb application as a means of better understanding different types of soil in the context of the distribution of local agricultural areas and wildland vegetation.

The *Environmental Justice and Freshwater Resources* (Perez et al. 2015) module addresses societal issues and human behaviors. Unit 2 activities are particularly well aligned with SLOs of the Environmental Literacy course. Students reviewed the hydrologic cycle and then tracked their personal water use for a week using the water footprint included in the unit (Perez and Villalobos 2015). This topic was timely, given that one of the California's worst droughts on record occurred during this project. Students compared their water usage with that of area households, using information from water providers. In examining the water resources required to support their lifestyles, students used local and global water usage data to critically evaluate different perspectives of sustainability. This activity directly addressed the human behavior SLO of the Environmental Literacy course.

Implementation of InTeGrate in the Sustainability Pathway Project

From fall 2015 through spring 2017, InTeGrate materials were implemented in eight courses per term (note: a total of ten courses were involved in the project, but only eight were taught during each semester). Each faculty participant attended another faculty member's class when they used InTeGrate materials, so all team members observed and were observed during each of the four semesters of the project. Following peer class visits, the instructor and the faculty team member who observed the class session met to debrief and collaboratively discuss practices in the units that worked well or areas that could provide improvements. After teaching with InTeGrate materials, faculty team members completed a self-reflection of the class session to document their own thoughts about the areas of the class that went well or could be improved (some comments from faculty reflections are quoted in this chapter).

In summer 2016, the team of project faculty met to review work completed in the first year of the project and discuss successes and areas in need of improvement within the curriculum materials and pedagogical strategies used in InTeGrate modules. Conversations and activities in summer meetings centered on major or minor modifications of InTeGrate materials and also included review of new modules.

Modifications to InTeGrate Activities

Over the course of four semesters, project faculty used InTeGrate materials and collaborated to optimize them for each course. Based on faculty self-reflections and discussions following peer observations, modifications were made as necessary. In some cases, materials were not changed at all (e.g., *Climate of Change*, Unit 2 for Introductory Environmental Sciences and The American West courses). But in other cases, significant modifications evolved over the four semesters.

For example, three units from the *Minerals* module were used in the Environmental Economics course during the first semester of the project, but the instructor determined that using the full activities as written did not flow well with other course materials. In subsequent terms, she integrated datasets and examples from units in the *Minerals* module with other course activities. Some examples include:

- A supply/demand activity from *Minerals* Unit 2 was used to teach the origins of demand and supply curves, movement along the curves, and shifters of supply and demand and other economic concepts (consumer surplus, welfare changes, and externalities) in the context of mineral resources.
- Using *Minerals* Unit 3 students explored the EPA's website for drinking water contaminants and the list of national Superfund sites to determine which contaminants would likely result from mining. Then using a "safety" versus "efficiency standard" approach, they identified which contaminants should be regulated.
- Students read examples of mining-related mercury and arsenic contamination in northern California and Nevada in *Minerals* Unit 6 and then completed a cost-benefit analysis for possible changes to the safe arsenic standard. Following discussion with the whole class, students determined an optimal arsenic standard

for drinking water. Each group then presented their solution to the class, explaining how costs and benefits were calculated.

While individual InTeGrate units were modified (after the first semester), materials provided a means of incorporating scientific data and geoscience context into the Environmental Economics course and, in some cases, provided local examples (e.g., *Minerals* Unit 6 mentioned above).

Units from *Climate of Change* were also modified but, in most cases, to smaller degrees. The Environmental Science and Geography courses updated the unit by adding current events relevant to ENSO and scientific exploration of Greenland's ice sheets for Units 2 and 4, respectively. Unit 6 was collaboratively updated each semester by faculty in the Implementation Team with additional examples of adaptation and mitigation, and new data was compiled from the Six America's Climate Personality survey (Yale 2017) to keep the content current. Faculty also inserted recent data from a Gallup Poll survey showing that Americans were more concerned about climate change in March 2016 than they had been in previous years (Saad and Jones 2016). In addition, the Religious Studies class added an introduction to the greenhouse effect, major greenhouse gases, and their sources, by drawing on the NOAA data (NOAA 2017), to provide student background information for class activities in Climate of Change Unit 6 (Walker 2014b).

Unit 2 of the *Environmental Justice* module (Perez and Villalobos 2015), used in the Environmental Literacy course, connected students' water use with their ecological footprint (Global Footprint Network 2017) and to their Slavery Footprint (Fair Trade Fund, Inc. 2017), which resulted in rich class discussions around humans' impact on the environment and the freedoms (or lack thereof) of other humans.

Outcomes and Impacts

The Implementation project at CSU, Chico, accomplished both goals of (1) merging scientific data with societal issues using several InTeGrate modules in STEM and non-STEM courses of the Sustainability Pathway and (2) use of active learning pedagogical strategies embedded in the InTeGrate curriculum to engage students in course material and served as a model for faculty to incorporate more active learning in their pathway courses and elsewhere in their teaching practice. Success with each goal was the result of the quality, diversity, and flexibility of the InTeGrate modules.

Effectiveness of Merging Scientific Topics with Exploration of Their Social Implications

One of the appeals of the InTeGrate materials used in this project was the ability to combine science and social aspects around a central unifying theme or content area (e.g., climate change). Generally, class learning objectives, content, and activities were enhanced by bringing more scientific data and methodologies to non-STEM courses and deeper social perspectives to STEM courses. Adaptation of curriculum by faculty from a broad range of disciplinary expertise to a suite of courses spanning diverse content areas and levels (introductory 100-level courses to upper-division 300-level courses) is a testament to the rigorous design and development of the InTeGrate modules.

An example of the integration of social perspectives in STEM courses includes an *Environmental Justice* module's *Love Canal* case study (Unit 5; Schneiderman and Stewart 2015a) that was used with students in the introductory Environmental Literacy course. Students first learned about the social, health, and political consequences of the Love Canal story and then tied the geologic properties and constraints to the social impacts. Finally, students became more aware of the challenges of managing fresh water when they studied both physical and cultural constraints in dealing with water shortages in diverse geographic settings in Unit 4 of the same module (*Women and Water*; Schneiderman and Stewart 2015b).

InTeGrate materials provided an impactful approach for linking scientific data and methodologies to societal issues for use in the non-STEM classes. Instead of listening to a lecture, students in the Geography course used *Climate of Change* Unit 2 (Shellito 2014) to explore climate data and forecast climate change. The data-rich unit gave students experience in developing hypotheses, reading data, and interpreting it (sea surface temperature, atmospheric pressure, precipitation, and wind data). Likewise, the upper-division History class students independently analyzed and interpreted albedo measurement data from Unit 4 of the Climate of Change module (Walker 2014a). To do so, they first synthesized the data using key concepts of albedo, anomalies, and seasonal change. Students then took their evidence to small group discussions where they had to make an evidence-based case for their interpretation of the data, and, in some cases, an evidence-based case against their peers' interpretations. This is an embodiment of the critical thinking SLO of the Sustainability Pathway as well as an excellent opportunity for students to integrate scientific data with one of society's grand challenges (NRC 2001).

The *Climate of Change* module also provides unifying, time-relevant material for courses in the Sustainability Pathway. Seven of the eight courses in this project used units within this module, including courses from 100-level to 300-level (lower division and upper division) and in STEM and non-STEM disciplinary areas. Two non-STEM examples are given previously. Perhaps one of the most diverse implementations of similar material was in using Unit 6 (Walker 2014b), which was adapted by the introductory Environmental Literacy course, the 200-level Religious Studies course, and a 300-level Plant Science course. Students individually used an online survey to calculate their climate personality (KQED 2016) and shared their results in class. Perhaps not surprisingly, the majority of the students ranked their level of concern to be on the upper end of the concerned categories (e.g., "concerned" or "alarmed") compared to national averages (Yale 2017). A non-STEM faculty's reflection indicates, "I feel much more confident in my students' abilities to reason…because I repeatedly witnessed groups of self-identified non-scientists successfully grapple with the technical, abstract concepts of Climate of Change."

Other examples of individual InTeGrate units used in diverse class settings demonstrate the ability to adapt the curriculum to different audiences, different disciplines, and class levels. The introductory Environmental Literacy course used the rare earth elements activity in the *Minerals* module (Unit 2; Bhattacharyya and Branlund 2014) as a means to illustrate societal factors such as hidden costs of technology. It also illustrated societal and environmental consequences of the students' complicity in the consumption of these elements. In contrast, the 300-level Economics course used this unit to incorporate the geologic context of resources used to make batteries with economic perspectives on supply, demand, and externalities. The Economics instructor reported, "It wasn't hard (to modify the unit) and it aided my classes a lot."

Similarly, a lower-division geography class used scientific classifications of soils in the *Soil Resources* module (Unit 4; Fortner et al. 2014b) to familiarize students with connections between soil properties and land use. The upper-division Plant Science course used the same unit to connect soil quality with social implications of food supply and added local examples. The professor indicated, "It's easy to change photos to improve the context and to make the concepts more course-specific." Through different approaches, all of these classes used InTeGrate units to merge scientific principles in a social context to help meet the goals of the project while retaining their course goals. This illustrates the flexibility and varied applicability of the InTeGrate modules to a wide range of course topics, which allowed the project team to accomplish goal 1 of this project.

Use of Pedagogical Strategies

Faculty selected InTeGrate curriculum materials based on how well they enhanced existing curriculum topics of Sustainability Pathway courses. Faculty were also drawn to the active learning strategies (e.g., non-lecture) used in the InTeGrate modules because they include high- impact practices known to improve student engagement and student learning (e.g., Hake 1998; Prince 2004; Kuh 2008; Freeman et al. 2014). Additionally, as noted in the design of InTeGrate materials (InTeGrate 2017a), one of the major themes of the curriculum was to use sustainability to provide relevance to course topics, in order to enhance student interest, commitment, and achievement (e.g., Lizzio et al. 2002). The pedagogical style of InTeGrate modules and their relevance to students helped the team accomplish goal 2 of the project.

Activities in the *Climate of Change* module included students using authentic scientific data (e.g., Units 2 and 4), an explicit goal of this project (Goal 1), and provided structure for students to work together to construct their learning. This was generally attractive to instructors, and one STEM instructor noted, “The InTeGrate materials enhanced the climate change and water resources portions of my class by encouraging students to work with the content in a more active manner.” This instructor goes on to say, “The group- based learning and jigsaw activities help me to incorporate the communities of practice model into my classrooms.”

Importantly, the InTeGrate curriculum introduced faculty involved in this project to new ways of engaging students. A STEM faculty member noted:

> Prior to the project, the course I inherited was only lecture based and full of facts and details. Student engagement was allocated to weekly assigned readings and summary papers and some limited team work. The InTeGrate framework allowed me to make major changes to engage students more, provide relevant examples that relate more to their lives and also increase active learning. The first semester was a bit rough, getting used to all the pre and post testing in addition to implementing the new materials. But I have seen a consistent increase in SETs (Student Evaluations of Teaching) since implementing the InTeGrate curriculum.

A non-STEM instructor found the group work familiar, but “only with InTeGrate materials did the activities engage scientific practices and norms. That was a welcome enhancement to my course curriculum, and a welcome change to my normal classroom.” The use of data was equally important to a STEM instructor who commented that the “Rare Earth Elements activity (Minerals Unit 6) provided active engagement with plotting and interpreting data trends.”

Faculty also gained professional development from the Implementation Project and the use of InTeGrate materials. One non-STEM faculty member, who joined the project in the first year of her tenure-track position, indicated that introduction to the InTeGrate curriculum through the project was valuable to her in her first experience using group work and in-class activities, especially those that provided her students with interdisciplinary applications.

Unexpectedly (although perhaps not surprisingly) some faculty participants found that the InTeGrate curriculum inspired pedagogical changes to their larger teaching practice. In post-instruction reflections, a STEM instructor indicated that she liked the structure of InTeGrate activities that include pre-class work and in-class activities and indicated that she is revising activities for other courses with the same patterns. Another STEM faculty member indicated that “experience with the InTeGrate curriculum gave me ideas on how to bring active learning activities into my other classes.” A non-STEM faculty member was also inspired by the structure used in InTeGrate curriculum and has produced a similar *series of worksheet-based, student-led, group inquiry* (activities) *employing experiential-learning practices for all of my courses.* While pedagogical change in other areas of instructor’s teaching practice was not an explicit goal, it is considered a serendipitous outcome of the project.

The ability to edit InTeGrate modules was also noted by participating faculty as a strength of the curriculum and its use in the classroom. Several instructors (STEM and non-STEM) noted that the curriculum structure facilitated opportunities for students to participate in deeper learning, for example, "pre-class readings were very valuable in giving students context for environmental economics topics discussed in class. As an example, instead of merely talking about supply, demand, and externalities, we talked about how and why externalities develop in the first place as a result of mining production processes." A STEM instructor indicated that front-loading content in pre-class work "provided students with a foundation to expand on for class activities," which is reinforced by a non-STEM instructor who noted that "having the students do the climate personality survey and assigning them case studies to read prior to class added an active homework exercise," which engaged students in considering their own behaviors in the context of other students and averaged responses from the broader nationwide respondents.

Lessons Learned and Recommendations

The InTeGrate curriculum provided the opportunity to build connectivity among courses in the Sustainability Pathway. The addition of the InTeGrate curriculum successfully brought social perspectives into STEM courses and scientific data and perspectives into non-STEM courses, illustrating the often complex interdisciplinary relationships. These opportunities helped us achieve our goal (#1) of introducing students to scientific perspectives of societal issues such as climate change, sustainable soil management, and implications of using mineral resources. As anticipated, InTeGrate modules also helped refine instructors' teaching practice, which helped achieve goal 2 of the project. Faculty found that course activities and teaching strategies used in InTeGrate materials, readily extended to other topics within their courses throughout their teaching practice.

The project also brought together faculty who would not normally have interacted in curriculum development or course design. Inherent in the participating faculty was a willingness to open up their classes and their minds to exchange ideas with fellow faculty. The class visits were a great avenue for faculty to see colleagues in action and to give one another feedback. Follow-up discussions proved to be a rich venue for exchanging ideas and discussion of ways to improve delivery. It was essential that faculty were open to these discussions. An additional benefit from the faculty exchange was that in many instances, the reviewing faculty also came away with ideas for their own teaching practice, including with the use of InTeGrate curriculum and in other courses.

All faculty in the project reported benefits from collaboration and communication. The project also provided important professional development to early-career faculty who benefitted from working with colleagues outside their department on the use of new teaching techniques. The team also supported faculty going through tenure and promotion processes; more senior faculty wrote letters that described the collaborative project and faculty member's use of new curriculum and innovative pedagogical practices for more junior-level faculty to submit in their annual reviews.

Sustaining Change

As noted above, the Implementation Project at CSU, Chico, has accomplished both goals of integrating scientific methods and data with societal impacts (goal 1) through the use of engaging pedagogical practices (goal 2). In doing so, the project has proven beneficial to all faculty involved, ranging from adjunct/lecturers to tenure-track faculty. Based on the success of the Implementation Project, the faculty team is committed to continued use of InTeGrate materials in the Sustainability Pathway courses. Fall 2017 was the first semester after the Chico Implementation project officially ended. With the exception of one retired faculty member, we each planned to continue using InTeGrate curriculum in our Sustainability Pathway courses. In some cases, faculty are adapting units for use in other courses, including other introductory level and major-specific courses. This magnifies the impact of the Implementation Project. Thus, after four semesters using and refining the materials, the InTeGrate curriculum has become integral to our courses. In addition, faculty involved in this project are reviewing newer InTeGrate modules that have become available more recently to adapt for courses. Examples include The Wicked Problem of Food Security; Water Sustainability in Cities; Carbon, Climate, and Energy Resources; and Interactions between Water, Earth's Surface, and Human Activity (InTeGrate 2017a).

Faculty turnover is a potential issue in the long-term impacts of the project. While our faculty team was consistent throughout the course of the project, one retired as the project ended and the new faculty member assigned to the course has not adopted the InTeGrate materials. Another issue is that the teaching schedules for lecturers (nontenure track) tend to change frequently. The two lecturers we had on the project were dedicated and committed collaborators, who strengthened the project outcomes, but their continued teaching of the same courses is not a given. One lecturer in the project team continues to use InTeGrate materials in his courses, but the second lecturer has recently been reassigned to different courses in another department. The course in which he used the InTeGrate curriculum is now taught by a different instructor who does not use InTeGrate materials. Curriculum continuity in projects such as this will be an ongoing challenge at CSU, Chico, and we expect in other programs as well. Our solution has been to reach out to new faculty who inherit courses, but the choice to incorporate InTeGrate materials remains the discretion of the instructor.

Another concern for the long-term use of InTeGrate materials is the availability of updated datasets and accessibility of materials. In some cases, datasets presented are from periods of time that readily show phenomena of interest (e.g., El Nino events in 1997–1998), but those timeframes are already quite old in the eyes of students, many of whom are barely as old as the data. Presenting current and relevant information is critical for continued student engagement. Another example of remaining current is the use of the *Climate Personality* survey, which has been hosted by KQED (2016). However, their funding period has expired, so the survey was not available in the fall 2017 classes, which negatively impacted the

Environmental Literacy course. The instructor indicated that because students could not actually take the survey and could only look at previous years' data, the students couldn't compare their own results and so were less engaged in the activity. Similarly, software compatibility is dynamic and rapidly changing, so continued efforts need to be in place to accommodate compatibility issues. For the *Women in Water* activities (Unit 4, *Environmental Justice*), one of the three case studies was initially dropped until a student discovered a way for the files provided to be compatible Macs. We strongly encourage updates and maintenance of the valuable InTeGrate resources.

Long-Term Impacts and Next Steps

Results presented here demonstrate that we successfully met our project goals of developing and implementing a model of common curricular concepts. With the use of InTeGrate materials, our pathway courses used scientific content in the context of societal issues focused on sustainability through the use of engaging student-centered pedagogical practices. Faculty involved in the project are committed to continued use of InTeGrate materials used in the project. In doing so, the impact of integrating scientific data and methods with societal issues will be long-lived for our future students. Additionally, the professional development of the Implementation Project will continue to expand as we continue to modify our pathway courses.

Founded on improving student learning and student engagement, as well as faculty collaboration and peer professional development, the Sustainability Pathway Project is a successful model that can be emulated in all of the GE Pathways at CSU, Chico, and elsewhere. Each of the other GE Pathways could similarly adapt curriculum goals with common topics to coordinate curricular themes or concepts across courses. We have presented results of our project in multiple venues across campus to expose faculty and administration to the strength of this approach, including at the annual conference for the Center for Excellence in Learning and Teaching (CELT; Teasdale et al. 2016b) and at two This Way to Sustainability Conferences (Teasdale et al. 2016c and Teasdale et al. 2017). Given our success and dissemination activities, we are optimistic that similar collaborations can be developed based on successes and lessons learned from the use of InTeGrate curriculum across the Sustainability Pathway courses. We have also invited college deans, the provost, and the university president to attend team meetings and classes in which the curriculum is used. The administration has been supportive of this project, referring to it as a model for other GE Pathways in its shared use of curriculum and for the faculty learning community (FLC) aspect of the project. The project has also been presented at the system-wide CSU to facilities staff, administrators, and faculty who work in areas of sustainability across CSU campuses (Hatfield et al. 2016). Broader dissemination has also occurred to the Geoscience Education community (Teasdale et al. 2016d).

Based on our own experience with this project, we recognize that making changes to courses that result in more coordinated curriculum in GE Pathways requires multiple faculty from different departments and colleges within the university being willing to engage. Establishing the Implementation Team in the Sustainability Pathway was possible with funding from the InTeGrate program, which provided us with the time to focus our efforts as well as motivation to develop and complete our project goals and to collect, compile, and interpret our data. As innovative and compelling as the InTeGrate curriculum is, the funding was critical in bringing together faculty to collaborate in its implementation. Though the actual amount of funding that each faculty member received was not large, it was sufficient to pique their interest and secure their work for the 2-year commitment. In one case, a STEM faculty member indicated that what "made it possible to implement many of the InTeGrate modules into the class was the InTeGrate grant. Otherwise, this major effort would have been much more difficult to achieve in a timely manner." A similar financial commitment may be necessary for additional pathway faculty groups to dedicate the time and energy required to adapt a similar project as the connected curriculum used in the Sustainability Pathway.

We have already engaged other faculty who teach courses in other pathways and in courses not necessarily associated with a pathway to share the utility of the InTeGrate curriculum in general and in the goals and results of this project specifically. We plan to continue working with faculty beyond our team to help find opportunities to adopt our pathway model. This includes the pursuit of funding to make that possible because, as evidenced in this project, funding is a key to allocation of the time required to make a project like this successful. We will continue to invite university administrators and interested faculty to attend our classes when we use InTeGrate materials and to learn more about the Chico Implementation Team as a successful model for other faculty groups. The diverse courses engaged in this project represent a viable example of the ability to use InTeGrate curriculum across a wide range of disciplines. Thus, the experiences and insights gained in a project like this can have wide-reaching effects beyond the scope of the project itself.

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Use of InTeGrate Materials to Engage Instructors and Encourage Curriculum Change in the El Paso Higher Education Community

Diane I. Doser and Joshua I. Villalobos

Abstract Over the past 5 years, the El Paso Higher Education Community implemented InTeGrate-based teaching materials to promote curricular and pedagogical change and alignment of courses between institutions. We introduced InTeGrate materials through a series of hands-on workshops, one-on-one consultations, and classroom observations. InTeGrate materials have reached over 3400 students from freshman to graduate level. Materials are predominantly used in face-to-face courses and laboratories, but 30–40% of online introductory courses also use the materials. Many senior instructors (>5 years teaching experience) were far less likely to adopt InTeGrate materials, citing lack of time, difficulty in using the active learning-based materials in large lecture sections, or misalignment of material with their courses. Over half the instructors using InTeGrate materials have been teaching assistants for Physical Geology laboratories at the University of Texas at El Paso (UTEP). The success in the adoption of InTeGrate materials in these introductory laboratories indicates the optimum way to reach the most students at UTEP is through their use in a laboratory setting. Material adoption across the community has been slow, but a core group of ~12 instructors use the materials on a regular basis and ~5 new instructors try the materials each fall semester.

Keywords Instructor engagement · Curriculum change · Curriculum alignment · Transfer pathways

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General Overview

The El Paso Higher Education Community (EPHEC) developed a collaboration that was one of the first implementation programs initiated as part of InTeGrate's plan to enhance undergraduate geoscience curriculum, increase the number of geoscience majors, and provide professional development to educators. One focus of the EPHEC implementation program was to assist instructors and staff involved in geoscience and environmental science education at the University of Texas at El Paso (UTEP) and El Paso Community College (EPCC) in adopting and adapting InTeGrate curricular materials for their introductory courses. We felt the InTeGrate materials and their associated pedagogical techniques would allow us to better align curriculum and enhance the transfer pathways between institutions.

Numerous studies have shown that the alignment of courses between 2-year and 4-year institutions to ensure that 2-year students are well prepared for upper-division course work is critical for transfer success (e.g., Handel 2011). Supporting an "ecosystem" for transfer students also requires joint curriculum and pedagogical development to insure that instructors at all institutions feel they are equal partners working toward a common goal of student success (Dowd 2012). We felt that the use of InTeGrate materials would help us to provide a student-centered, learning-centered focus on teaching within our higher education community, a focus that is a key component for the success of students in transfer programs (e.g., Albertine and Elrod 2012).

Student-centered courses are not only important for EPCC transfer students but all students taking earth science. We felt that many Introductory Earth Sciences classes at UTEP could benefit by the use of InTeGrate materials that focus on societal issues, systems thinking, and working with authentic geoscience data using active learning approaches. These materials would allow us to attract more majors and increase geoscience literacy in a community that faces many earth science-related challenges such as dwindling water resources, increased salinization of agricultural soils, and prolonged summer heat waves.

In this paper, we focus on the methods we used to engage and encourage instructors within our community to adopt InTeGrate materials, the feedback we received from instructors regarding the materials, and our successes and challenges in the implementation process. Separate studies (e.g., Doser and Hussein this volume; Doser 2017) focus specifically on student outcomes obtained using InTeGrate materials.

Background on the EPHEC

The EPHEC serves the El Paso County, Texas, region with a combined population of ~838,000 (US Census Bureau 2016). Over 82% of the population is Hispanic or Latino, 26% is foreign born, and 72% speaks a language other than English at home

(US Census Bureau 2016). About 20% of the population lives in poverty, and the median household income is ~$41,000 (US Census Bureau 2016). Between 80 and 94% of UTEP and EPCC students, respectively, come from El Paso County (University of Texas at El Paso 2013; El Paso Community College 2016), with student populations mirroring the population of the county. Forty to fifty percent of UTEP and EPCC students are the first generation of their family to attend college (University of Texas at El Paso 2013; El Paso Community College 2016). The El Paso region is considered an "educational closed loop" as most of its K-12 teachers graduated from UTEP. Many science instructors teaching at EPCC also obtained their MS or PhD from UTEP.

EPCC has six main campuses and serves ~30,000 students (El Paso Community College 2016). Geological science courses are taught at all six campuses as well as online, and the college offers an associate's degree in geological sciences.

UTEP serves ~25,000 students (University of Texas at El Paso 2017) with undergraduate programs in geological sciences, geophysics, and environmental science. UTEP and EPCC have clearly articulated paths for students planning to transfer between institutions. During any given semester, many students are co-enrolled at both institutions. Students tend to take their university core classes, as well as other science and math prerequisites, at EPCC due to its affordability, smaller class sizes (20–30 students), and proximity to home and work. Thus, a strong link between course content and pedagogy at the two institutions is desirable.

Our implementation program focused on adapting InTeGrate modules and materials and providing professional development for instructors teaching four introductory classes that are common to both institutions: Physical Geology, Historical Geology, and Principles of Earth Sciences I and II. Courses taught at EPCC have built-in labs where many InTeGrate modules could readily be used. Large lecture sections (100–200 students) are common at UTEP, while labs are generally restricted to 20 students/section due to space restrictions and availability of lab supplies. At UTEP, labs are taught separately from lectures in the Physical Geology and Historical Geology sequences, and some non-majors may only be required to take one laboratory in the two-course sequence. Instructors from additional lower-level courses at EPCC and UTEP such as Introduction to Environmental Science, Environmental Geology, or Blue Planet also adopted InTeGrate materials.

The following sections describe the process we followed to interest instructors in adopting and adapting InTeGrate materials for their classes and assisting them in using new pedagogical techniques. Throughout the process, we administered anonymous surveys, conducted face-to-face or phone interviews, and held focus groups. In spring 2015, we collected teaching logs to gauge the success of our efforts but found this level of reporting was burdensome to instructors and discouraged adoption of materials by others, so the process was discontinued. We provide copies of these instruments, along with selected qualitative feedback we obtained from instructors, in the Appendix.

History of the Implementation Program

Adoption of InTeGrate materials began in 2013 and has continued through the fall 2017 semester. Table 1 provides a list of all InTeGrate modules used by the EPHEC and the associated abbreviations we use when referring to them in this paper. Figure 1 shows the timeline of activities related to the implementation process between fall 2013 and fall 2017.

Pilot Testing

Initial testing of the material began in the 2013–2014 academic year (Table 2) with the use of a developmental version of the "Climate of Change: Interactions and Feedbacks Between Water, Air and Ice" (CC) (Shellito et al. 2014) module in an Introduction to Environmental Science course taught in fall 2013 by Doser. In spring 2014, Villalobos and Perez piloted a developmental version of the "Environmental Justice and Freshwater Resources" module (EJ) (Perez et al. 2015) in two of their Physical Geology courses. Doser used units from the CC and the "Humans' Dependence on Earth's Mineral Resources" (HD) (Bhattacharyya et al. 2014) modules in an upper-division geology course for civil engineers (Doser and Hussein this volume).

Our first large-scale efforts to pilot curricular materials in introductory courses at UTEP and EPCC took place in the fall semester 2014 (Table 2). Five instructors were involved in the fall 2014 pilot test, two from EPCC and three from UTEP (where one instructor's courses served as the control group). We used one or more units of the CC module (Shellito et al. 2014) in courses in Historical Geology, Introduction to Environmental Science, and the Blue Planet. We used two sections

Table 1 List of InTeGrate modules used by the EPHEC

Module name	Abbreviation	Module authors
Climate of Change: Interactions and Feedbacks between Water, Air and Ice	CC	Shellito et al. (2014)
Carbon, Climate and Energy Resources	CCE	Bentley et al. (2016)
Environmental Justice and Freshwater Resources	EJ	Perez et al. (2015)
A Growing Concern: Sustaining Soil Resources Through Local Decision Making	GC	Fortner et al. (2014)
Exploring Geoscience Methods	GM	Ebert et al. (2014)
Humans' Dependence on Earth's Mineral Resources	HD	Bhattacharyya et al. (2014)
Living on the Edge: Building Resilient Societies on Active Plate Boundaries	LE	Goodell et al. (2014)
Mapping the Environment with Sensory Perception	ME	Darby et al. (2015)
Natural Hazards and Risks: Hurricanes	NH	Gilbert et al. (2014)

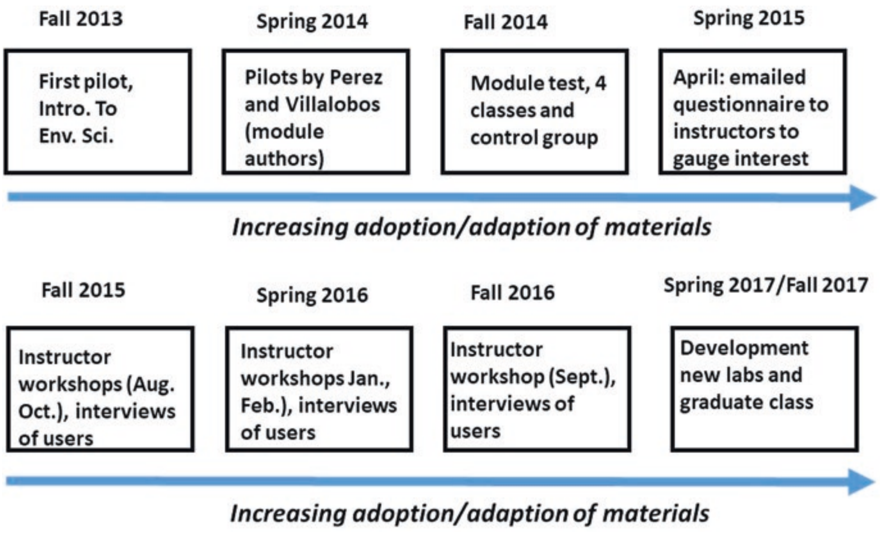


Fig. 1 Timeline of activities related to adoption and adaptation of InTeGrate materials by the El Paso Higher Education Community

Table 2 Information on initial pilot studies (fall 2013–fall 2014)

Semester	Instructor[a]	Course	InTeGrate module[b]	Number of students[c]
Fall 2013	S	Intro. to Envir. Science	CC	222
Spring 2014	S	Historical Geol. (EPCC)	EJ	12
Spring 2014	A	Historical Geol. (EPCC)	EJ	40
Spring 2014	S	Geol. for Engineer. (upper div.)	HD	55
Fall 2014	S	Introduction to Envir. Science	CC	122
Fall 2014	J	Blue Planet	CC	8
Fall 2014	S	Historical Geology (EPCC)	CC	8
Fall 2014	A	Historical Geology (EPCC)	CC	60 (O)
Fall 2014	S	Intro. to Envir. Sci./Phys. Geog.	None—control group	304

[a]*S* senior (full-time with >5 years teaching), *J* junior (full-time ≤5 years teaching), *A* adjunct, *T* teaching assistant
[b]See Table 1 for abbreviations
[c]*(O)* online course

of Introduction to Environmental Science and a section of Introduction to Physical Geography, which also covered topics related to climate change, as a control group. At the end of the semester, we asked all students in these courses a series of 3–5 questions related to climate change. We found that classes using InTeGrate materials scored higher on answering these questions than the control group, although all classes still had difficulties understanding negative feedback in climate systems (Doser et al. 2014).

The positive responses of students and instructors to the quality and content of the InTeGrate material and its ease of adaptability by instructors provided results that could be shown to other potential instructors (Doser et al. 2014). Unfortunately, few InTeGrate modules were publically available in the late fall 2014 (to prepare for spring 2015 courses), although the authors had access to additional units under development that they tested in spring 2015 (Table 3). Three new instructors also used CC modules in their courses (Table 3). The Appendix (Table 5) contains excerpts from teaching logs of the few instructors who used InTeGrate materials in spring 2015.

Workshops, Interviews, and Focus Groups

In April 2015, we emailed all UTEP and EPCC instructors who had taught or were teaching introductory environmental science or geological sciences courses a questionnaire they could complete anonymously to gauge their interest in attending workshops on using InTeGrate materials (Appendix Table 6). Only 38% (9 of 24) of those sent the survey responded, but 88% of the respondents indicated they would be interested in attending a workshop as more materials became publically available.

By the end of summer 2015, a sufficient number of modules were available to encourage other UTEP and EPCC instructors to adopt/adapt materials for the 2015–2016 academic year. We held workshops in August and October 2015 and in January and February 2016 to introduce these materials, as well as writing a users' guide that summarized where we had used modules at UTEP and EPCC from fall 2013 to spring 2015 and the plusses/minuses of their use. The Appendix gives workshop surveys and responses from attendees of several workshops (Table 7). Table 4 and Fig. 2 give the breakdown of attendees by instructor type.

Attendees of the August 2015 workshop were able to test drive either an activity from the CC (unit 3.1—El Niño/La Niña cycle) or EJ (unit 6—Ogallala aquifer) InTeGrate modules. In October 2015, workshop attendees could test drive of an activity from the CC (unit 6—adaptation to climate change and heat waves) or HD (unit 2.1—rechargeable batteries) modules. We compare the instructors who attended the workshops and those who did not subsequently use InTeGrate materials in classes in their fall 2015 classes in Table 4.

Five instructors attending the August workshop had follow-up conversations with the authors about how to adapt the materials for their courses and two instructors came

Table 3 Instructor use of InTeGrate materials (2015–2017)

Semester	Module(s)[a]	Instructor type[a, b]				Course	Number of students[c]
		S	J	A	T		
Sp2015	CC	1N				Intro. to Env. Sci.	129
Sp2015	CC			1N		Intro. to Env. Sci.	48
Sp2015	CC		1N			Blue Planet	40
Sp2015	HD,EJ	1				Geol. Engineers (upper division)	65
Sp2015	CC,EJ	1				Hist. Geol. (EPCC)	12
Sp2015	CC			1		Hist. Geol.	85
Sp2015	CC,HD			(1)		Principles ES (EPCC)	7 (H)
F2015	CC,EJ,HD,GC	1			2N	Intro. to Env. Sci.	128
F2015	HD,CC				6N	Phys. Geol. Lab. (11 sections)	192
F2015	CC			1		Hist. Geol.	50 (O)
F2015	EJ			(1)		Phys. Geol.	65
F2015	HD,EJ,CC,LE,GM	1				Princip. Earth Sci. 1 (EPCC)	44 (O)
F2015	LE	1N				Prin. Earth Sci. 1 (EPCC)	27
F2015	HD			1N		Prin. Earth Sci. 1 (EPCC)	9
F2015	HD,CC	1N				Geoscience Methods for Teachers (grad level)	8
F2015	CC		1			Blue Planet	36
F2015	CC,EJ,HD			1		Env. Geol. (EPCC)	4 (H)
Sp2016	EJ			1		Phys. Geol.	75 (O)
Sp 2016	CC			(1)		Hist. Geol.	75 (O)
Sp2016	EJ			(1)		Phys. Geol. (EPCC)	12
Sp2016	CC			(1)		Hist. Geol.	5 (H)
Sp2016	EJ	1				Phys. Geol. (EPCC)	25
Sp2016	EJ,GM,LE,CC,HD	(1)				Prin. Earth Sci. 1 (EPCC)	26
Sp2016	LE,CC	1				Prin. Earth Sci. 1 (EPCC)	23
Sp2016	CC,EJ,HD			1		Env. Geol. (EPCC)	5 (O)
Sp2016	HD,EJ			1N		Geol. Engineers (upper division)	68
Sp2016	EJ			1N		Intro. to Env. Sci.	28
Sp2016	HD,CC,EJ				1, 5N	Phys. Geol. Lab. (11 sections)	190
Su2016	EJ			1		Phys. Geol.	93 (O)
Su2016	CC			(1)		Hist. Geol.	26 (O)
Su2016	HD			1		Prin. Earth Sci. 1	22
Su2016	EJ	1				Phys. Geol. (EPCC)	20 (O)

(continued)

Table 3 (continued)

Semester	Module(s)[a]	Instructor type[a, b]				Course	Number of students[c]
		S	J	A	T		
Su2016	EJ	(1)				Hist. Geol. (EPCC)	20 (O)
Su2016	EJ, LE	(1)				Phys. Geol. (EPCC)	8
Su2016	EJ			1		Intro. to Env. Sci.	27
F2016	CC,EJ,HD			1		Intro. to Env. Sci.	22
F2016	CC,EJ,HD,GC,ME	1			2N	Intro. to Env. Sci.	105
F2016	HD,GM				1	Phys. Geol. Lab (for majors)	17
F2016	EJ,HD		1N			Prin. Earth Sci. 1 (EPCC)	39
F2016	EJ,HD		(1)			Phys. Geol. (EPCC)	20
F2016	CC		1			Blue Planet	19
F2016	LE	1				Prin. Earth Sci. 1 (EPCC)	48
F2016	HD		1			Prin. Earth Sci. 2 (EPCC)	25 (O)
F2016	HD,CC,EJ		(1)			Phys. Geol.	25 (O)
F2016	CC				2, 3N	Phys. Geol. Lab. (9 sections)	171
Sp2017	HD,EJ			1		Geol. Engineers (upper division)	81
Sp2017	GM,CC				1	Hist. Geol. Lab (for majors)	13
Sp2017	EJ		1			Phys. Geol. (EPCC)	20
Sp2017	LE,CC,CCE		(1)			Prin. Earth Sci. 1 (EPCC)	7
Sp2017	CC		1			Phys. Geol.	25 (O)
Sp2017	CC		(1)			Hist. Geol.	12 (O)
Sp2017	LE,CC	1				Prin. Earth Sci. 1 (EPCC)	62
Sp2017	CC,EJ,HD			1		Intro. to Env. Sci.	26
Sp2017	CC,EJ,HD			(1)		Envir. Geol. (EPCC)	8 (H)
Su2017	CC			1		Hist. Geol.	23 (O)
Su2017	CC,EJ,HD			1		Intro. to Env. Sci.	11
F2017	HD,EJ		1N			Geol. Engineers (upper division)	30
F2017	HD,EJ,CC,GC	1				Active Learning in Geosciences (grad level)	6
F2017	CC	1				Blue Planet	12
F2017	HD,EJ,CC,GC,ME	1N				Intro. to Env. Sci.	105
F2017	HD,EM,GC				1N	Phys. Geol. Lab (for majors)	13
F2017	GM,CC,HD,EJ,LE,CCE				1, 2N	Phys. Geol. Labs (4 sections)	80

(continued)

Table 3 (continued)

Semester	Module(s)[a]	Instructor type[a, b]				Course	Number of students[c]
		S	J	A	T		
F2017	EJ		1			Phys. Geol. (EPCC)	20
F2017	LE,CC	1				Prin. Earth Sci. 1 (EPCC)	48
F2017	CC			1		Phys. Geol.	83 (O)
F2017	HD,CC,EJ			1		Envir. Geol. (EPCC)	8 (H)
F2017	NH			(1)		Prin. Earth Sci. 1 (EPCC)	24

[a]see Tables 1 and 2 for abbreviations
[b]*N* new instructor *(1)* instructor teaching more than one section
[c]*H* hybrid course

Table 4 Workshop attendance (2015–2016)

Workshop date	InTeGrate modules (Units) demonstrated[a]	Number of instructors attending[a]				Instructors who did not use active learning techniques during semester of workshop				Reported using other active learning techniques during semester			
		S	J	A	T	S	J	A	T	S	J	A	T
August 2015	CC (3.1), EJ (6)	8	3	6	4	4	1	1	1	3		1	
October 2015	CC (6), HD (2.1)	4		2	3	1		1		1			
January 2016	None-overall informational session (EPCC)	4		2		2		1					
February 2016	GC (1)				3								
September 2016	CCE (1)	1		2	4	1		2					

[a]See Tables 1 and 2 for abbreviations

to one of our classes as observers. We conducted a focus group meeting in December 2015 with six teaching assistants who had used InTeGrate materials in Physical Geology laboratories to receive feedback on their experiences (Table 8). We also interviewed six UTEP and EPCC instructors that had used the materials in their courses (Table 8). Two teaching assistants involved in aiding an instructor with group-based activities (about 30% InTeGrate based) in a class of ~125 students also provided input.

We conducted two workshops in the spring 2016 semester (Fig. 2 and Table 4). We held an informational meeting with six EPCC faculty at a pre-semester development day in January and a hands-on workshop for three UTEP teaching assistants in February. In February we demonstrated a "jig saw" activity from the module "A Growing Concern: Sustaining Soil Resources through Local Decision Making" (GC), unit 1 (Fortner et al. 2014) (Table 7). We provide a breakdown of instructors who attended the spring 2016 workshops versus those who attended but did not use

InTeGrate materials in their spring 2016 in Table 4. We interviewed four instructors and held a focus group for three teaching assistants at the end of the spring 2016 semester to receive feedback about their teaching experiences (Table 8).

We held one final workshop related to InTeGrate materials in September 2016 (Fig. 2 and Table 4). In this case, we focused more on introducing materials to graduate teaching assistants and staff who supervise graduate teaching assistants by modeling styles of active learning using examples from several InTeGrate modules. Four teaching assistants, two adjuncts and one senior-level instructor attended. Hands-on demonstrations on identifying misconceptions and logical fallacies were taking from unit 1 of the "Carbon, Climate and Energy Resources" (CCE) module (Bentley et al. 2016).

Results

We show the variation in numbers of students and instructors within the EPHEC that used InTeGrate materials over the past 5 years in Fig. 3 and Tables 2 and 3. As of fall 2017, a total of 3453 students and 34 separate instructors have used materials from 9 different InTeGrate modules.

To provide a better sense of the impact of InTeGrate materials at UTEP, Fig. 4 compares the percentage of students that were enrolled in seven specific introductory courses or laboratories in geological or environmental science where InTeGrate materials were used to the total number of students enrolled in these courses. Figure 4 also indicates the percentage of instructors involved in using InTeGrate materials in these seven courses. These seven courses include Physical Geology (lecture), Physical Geology (lab), Historical Geology (lecture), Historical Geology (lab), Principles of Earth Science I and II (combined lecture-lab delivery), and Introduction to Environmental Science (lecture). These seven courses are the highest enrollment introductory courses at UTEP that have geoscience content and hence are offered in multiple sections every fall and spring semester. They are also the earth science-related courses most frequently taken by non-majors to fulfill the University's natural science core requirements and are one way to attract new majors. Principles of Earth Science I is specifically required for K-8 education majors.

EPCC has only one or two full-time instructors at each campus that teach geoscience-related courses. Four full-time and two adjunct instructors teaching at three of the six campuses used InTeGrate materials between 2013 and 2017.

Figures 3 and 4 and Table 3 indicate that the number of instructors using InTeGrate materials was greatest during the fall 2015 semester. Note that instructor and student use has a cyclic nature since less introductory courses are offered in the spring and summer semesters, especially at UTEP. However, it appears that there is a background level of about 12 instructors and 400 students using the materials each fall semester. Figure 3 and Table 3 indicate that we continue to add 4–5 new instructors who use InTeGrate materials each fall. The following sections discuss results and feedback received from instructors who attended workshops or used InTeGrate materials during the fall and spring semesters when the greatest number of students was enrolled. Budgetary constraints often do not allow more than one or two geoscience-related classes to be offered in the summer at either UTEP or EPCC. For completeness, we include information on use of InTeGrate materials in summer semesters in Table 3.

Semester by Semester Usage

Spring 2015

Respondents to our spring 2015 email request to preview the limited InTeGrate materials then available felt the materials were at the appropriate level for their courses (Table 6) but hoped more topics on the atmosphere, biogeochemical cycles, environmental policy, or more traditional earth science topics (e.g., sedimentation, Earth's interior, plate tectonics) would soon be added. A small minority (11%) felt they would not want to spend their time developing new curriculum or that they were satisfied with what they were presently using.

Although the number of InTeGrate materials available in spring 2015 was limited, feedback from the six instructors (including three new instructors) who used InTeGrate materials in their classes indicated many positive results in their teaching logs (Table 5). They reported their students enjoyed the discussions and interactions associated with the materials. The students felt taking online surveys, viewing videos, making predictions, and working to interpret real data sets were a welcome break from "PowerPoint overload." One instructor of a night class felt the activities helped keep everyone awake and focused.

Figure 4 indicates that over 30% of UTEP students in lecture sections of the high-enrollment Introductory Earth Science courses used InTeGrate materials in spring 2015. Over 50% of online sections of these courses also used InTeGrate materials.

Fall 2015

Figure 2 and Table 4 indicate that the largest group attending the fall workshops was senior instructors (40%). The percentages of teaching assistants and adjuncts were nearly equal. The workshops were held on late Friday afternoons to insure the maximum number of EPCC and UTEP instructors would not have course conflicts that prohibited their attendance. The first 15 min of the workshops followed a "meet-and-greet" format so that EPCC and UTEP instructors could get to know one another better.

Survey information from the fall 2015 hands-on workshop attendees (Appendix Table 7) showed that a number of instructors felt the activities were text heavy and provided too much detail for students to use or to read in the short time period of a class. There were also concerns about whether the poor reading levels of students would discourage them from completing activities. However, most instructors

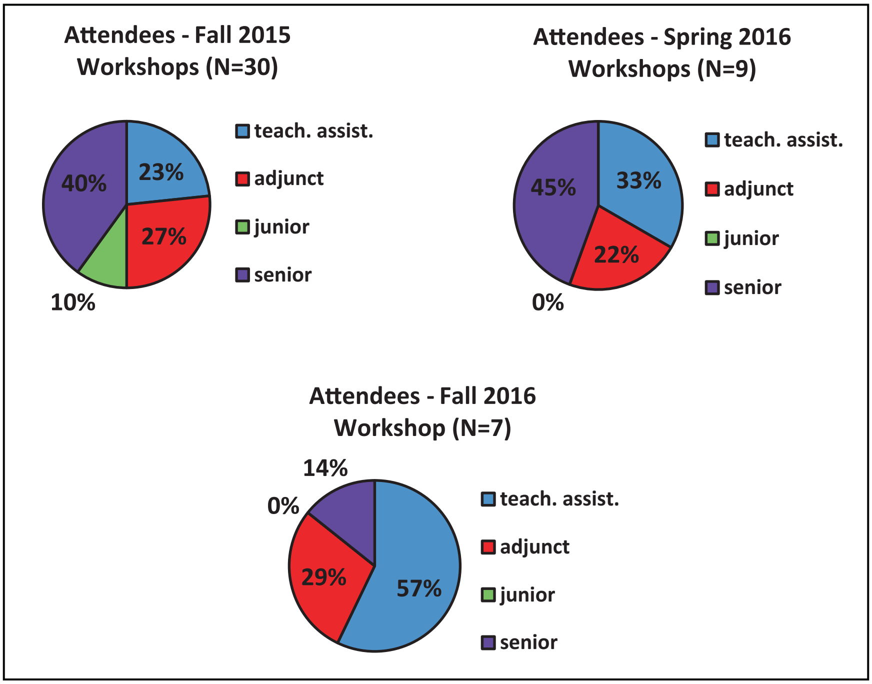


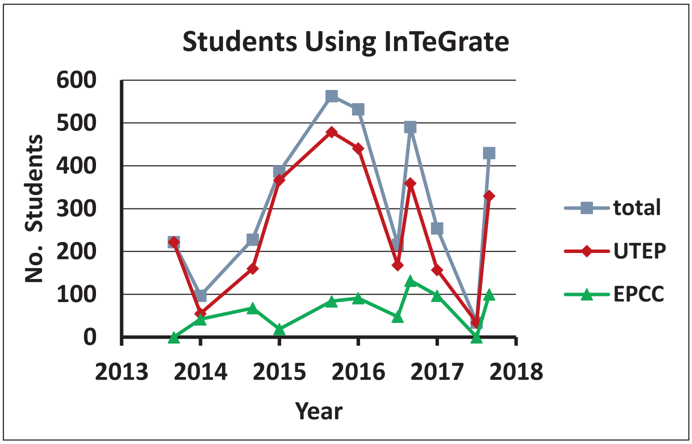
Fig. 2 Pie charts comparing percentage of instructors who participated in workshops from 2015 to 2016. N denotes total number of attendees. Junior instructors are full-time instructors who have taught 5 years or less. Senior instructors are full-time instructors who have taught more than 5 years

thought the students would enjoy the activities, and some even felt the text-rich nature of materials would help serve as a study guide for students.

Only 1 of 7 (14%) teaching assistants attending the workshops did not go on to use InTeGrate materials in the classroom in fall 2015, whereas 5 of 12 (42%) senior instructors reported not using the materials (Table 4). However, four of these five senior instructors reported using "other active learning" techniques such as clickers, voting cards, or think-pair-share. None of the reported "active learning" approaches appeared to make use of the interdisciplinary, societally relevant, data-rich content available in InTeGrate materials. One of three junior instructors and two of eight adjuncts (25%) also reported they did not use InTeGrate materials in fall 2015, with one adjunct reporting they used "other active learning" techniques.

The greatest users of InTeGrate material in fall 2015 (Table 4) were teaching assistants (all at UTEP) and adjunct faculty. A focus group meeting with teaching assistants revealed they felt the curricular organization of InTeGrate activities was particularly helpful. They immediately could see the objectives of a unit and understand what they needed to teach and how they could accomplish it.

A graduate-level course offered for in-service teachers pursuing a Master of Arts in Science Teaching also used several InTeGrate modules (Table 4). The instructor



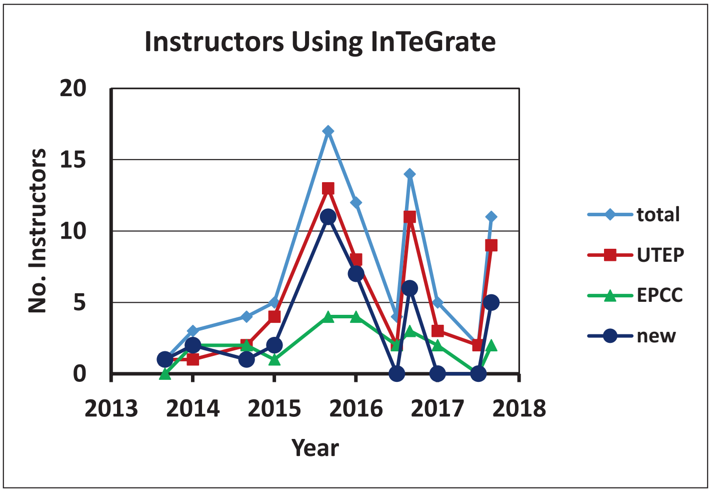


Fig. 3 Change of number of students (top) and instructors (bottom) using InTeGrate materials between the fall 2013 and fall 2017 semesters at the University of Texas at El Paso (UTEP) and El Paso Community College (EPCC). "total" is UTEP and EPCC combined. A new instructor is one who used InTeGrate materials for the very first time

felt the modules provided helpful examples of data-rich, active learning that could be modified and used by the teachers in their own classrooms.

One-on-one interviews with online instructors using InTeGrate materials in fall 2015 (Table 4) reported challenges in moving materials into their learning management systems and insuring that the links to other content were easy to reach. They reported it was hard to tell how engaged students were in the content and struggled with chat sessions to encourage discussion. However, most went on to use the materials again in the spring 2016 semester.

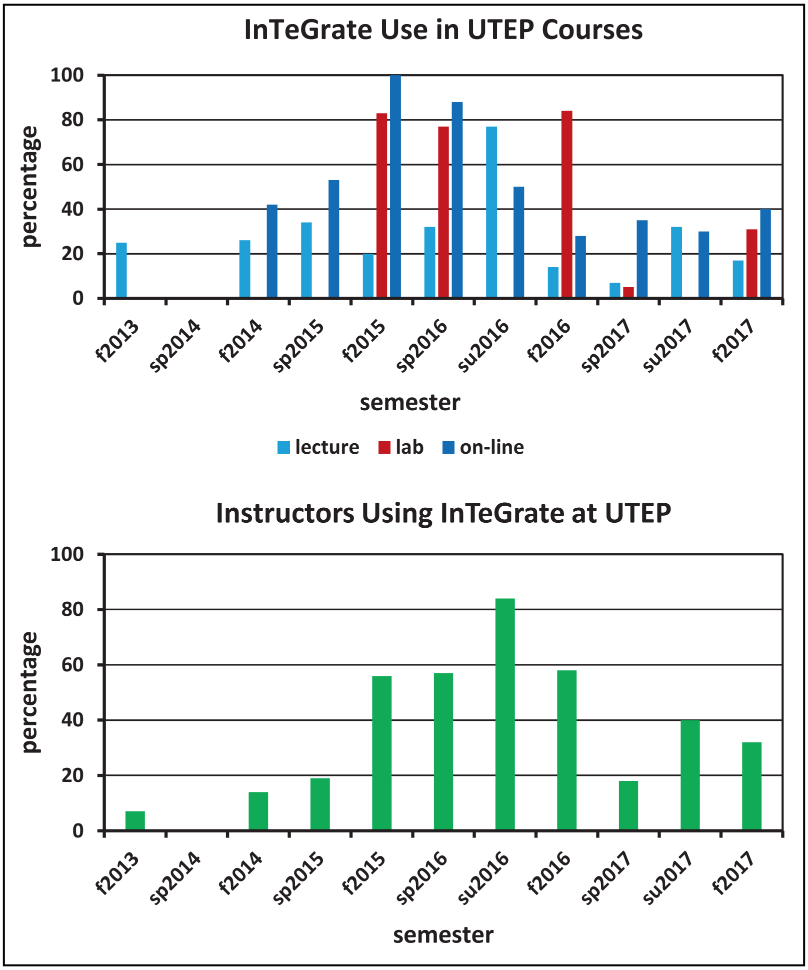


Fig. 4 (Top) Change in the percentage of students using InTeGrate materials relative to all students taking seven high-enrollment UTEP classes by semester (i.e., Physical Geology lecture and lab, Historical Geology lecture and lab, Introduction to Environmental Science, Principles of Earth Science I and II) (see text for details). Bars for each semester show percentage of students taking lecture and combined lecture-lab-based sections (Physical Geology, Historical Geology, Introduction to Environmental Science, Principles of Earth Science I and II), lab-based sections (Physical and Historical Geology laboratories), and online sections (Physical Geology, Historical Geology, Introduction to Environmental Science, Principles of Earth Science I and II). For example, in fall 2015 20% of the students in lecture sections, 80% of students in lab sections, and 100% of students in online sections of these high-enrollment courses used InTeGrate materials. (Bottom) Change in the percentage of instructors using InTeGrate materials relative to all instructors teaching sections of the seven high-enrollment UTEP classes. For example, in fall 2015, 56% of all instructors teaching sections of these high-enrollment courses used InTeGrate materials

Users in face-to-face classroom settings in fall 2015 reported the InTeGrate materials appealed to a mix of students. They indicated that discussion/debate activities were popular with outgoing, people-oriented students, while data-centered, interpretation-based activities were favored by less outgoing students. Many students were very interested to see how real data were collected and used (e.g., marine temperature, precipitation, and pressure data used in CC activities). The instructors reported that some students appeared to struggle with the meanings of words such as the "trend" of a data set or the difference between a "country" and a "continent." The instructors felt the students became much more aware of situations outside El Paso (e.g., how many poor people live in India) and that it was easy to make connections between the activities and current events (e.g., relation of drought in California to the El Niño-Southern Oscillation). EPCC instructors felt that the InTeGrate emphasis on societal issues fit in well with newly mandated revisions by the Texas Higher Education Coordinating Board to the content of their Principles of Earth Sciences courses.

Instructors felt that some activities were difficult to complete in a 50 min class period and that they had a steep learning curve to implement some activities. However, many instructors felt comfortable calling on more experienced instructors for help when they were preparing material for a class.

Figure 3 indicates that 80% of students in UTEP high-enrollment introductory lab sections used InTeGrate materials in fall 2015. The high level of instructor involvement (50% instructors used InTeGrate) reflects the large usage of materials by teaching assistants (Table 3). Virtually all online sections for the high-enrollment UTEP courses included InTeGrate materials.

Spring 2016

We held two workshops in spring 2016 (Table 4 and Fig. 2). The January workshop was an informational session for EPCC instructors. It provided user's guides and information on InTeGrate modules but did not offer a test drive of an InTeGrate activity. The February workshop was held for teaching assistants. Table 7 gives feedback from this workshop. The February participants felt the "hands-on" jigsaw activity was an effective way to engage all students in the learning process, helping to eliminate the tendency for one or two students in a group to "hijack" an activity and making it easier to determine who was only doing minimal work.

All teaching assistants participating in the February workshop used InTeGrate materials in spring 2016. However, only two of four senior instructors and one of two adjunct instructors at the January EPCC workshop went on to use InTeGrate materials.

Feedback from instructors following the spring 2016 semester indicated that they felt InTeGrate activities helped make the class time go quickly and encouraged communal thought. An instructor of one upper-division course reported that part way through the semester, the students began to realize they were learning more quickly and deeply by participating in group activities. Some activities that required significant computer access were a barrier to use at EPCC and in some UTEP classrooms where internet access was poor. In these cases, students did the Google Earth or spreadsheet intensive parts of unit activities as homework.

We did not conduct interviews or focus groups with users of InTeGrate materials in fall 2016 or in subsequent semesters. We felt we had received sufficient feedback to assist new instructors in adopting or adapting the materials for future semesters.

Fall 2016

In fall 2016, we offered a workshop that was attended by seven instructors (Table 4). No junior-level instructors (Fig. 2, Table 4) attended the workshop. All teaching assistants participating in the workshop used InTeGrate materials during fall 2016. The senior-level faculty member and adjuncts that attended either were not teaching that semester or were not teaching a course that was aligned with InTeGrate content. Although no junior-level instructor attended the workshop, one new EPCC junior-level instructor taught a course that was over 50% InTeGrate based.

Figure 4 indicates that InTeGrate use in high-enrollment labs was high (84%), but only 14% of the students in high-enrollment lecture sections received InTeGrate content. Instructors teaching many of the high-enrollment lecture sections were hesitant to use InTeGrate materials either due to time limitations (50 min class sessions) or large class size, although several instructors were willing to share examples of how they used InTeGrate materials in classes of 100–150 students.

In fall 2016, we offered the first semester a research-based laboratory in Physical Geology at UTEP as part of a Howard Hughes Medical Institute (HHMI) grant to the College of Science to introduce freshman-level research-based laboratories across the college. Geoscience and environmental science majors were encouraged to enroll in this Physical Geology laboratory during freshman orientation sessions. The laboratory drew on several InTeGrate modules to prepare students for a mid-semester field research experience. Cervantes and Doser (2017) reported on lessons learned from the first semester of this course.

Spring 2017

We did not provide workshops in 2017 for a number of reasons. First, the steady decline in workshop attendance (21 at first workshop, 7 at last) indicated we were unlikely to convince more senior-level instructors or adjunct instructors who teach on a frequent basis to use InTeGrate materials through workshops. Second, the interest and use of InTeGrate materials by teaching assistants and the large percentage of UTEP students that take introductory laboratories suggested we focus more on working with teaching assistants and developing a variety of InTeGrate-infused laboratories for the high-enrollment sections at UTEP, as well as graduate-level courses that focused on teaching geoscience using InTeGrate materials. Third, we were finding that more experienced users of InTeGrate materials were passing off these materials to new instructors and effectively coaching these instructors on a one-to-one basis.

Unbeknown to the authors and others from the EPHEC involved in implementing InTeGrate materials, the introductory Physical Geology laboratories at UTEP were reorganized in spring 2017 to emphasize the use of a workbook that was highly recommended by an adjunct professor who supervised the laboratory sections. Thus, we observed an unexpected drop (to 5%) in the use of InTeGrate materials by teaching assistants (Table 3, Fig. 4) since they were strongly encouraged to "teach to the workbook." The high cost of the workbook (~$100) for a one-credit course and undergraduate student dissatisfaction with the workbook materials led to the summer 2017 development and fall 2017 piloting of a new set of activities for Physical Geology laboratories that contain about 60% InTeGrate-based materials.

A second research-based lab in Historical Geology was piloted in spring 2016 (Cervantes and Doser 2017), but no new instructors used InTeGrate materials. Figure 4 indicates only the percentage online sections of UTEP high-enrollment courses (37%) were comparable to previous semesters.

Fall 2017

Fall 2017 saw an increase in the use of InTeGrate materials compared to the previous 2 semesters (Table 3, Figs. 3 and 4). Fifteen new lab assignments (containing 60% InTeGrate-based materials) designed for use in UTEP Physical Geology labs were piloted by three teaching assistants. The laboratories were also disseminated to EPCC instructors. A new senior- and junior-level instructor adopted InTeGrate-based modules for their courses. This led to 17% of the lectures, 31%of the labs, and 40% of the online high-enrollment courses at UTEP using InTeGrate materials.

Interest by graduate students and the UTEP staff member in charge supervising teaching assistants of introductory geology laboratories led to the development of a course on "Active Learning Techniques in the Geosciences" (1 credit hour) that was taught for the first time in the fall 2017 semester with an enrollment of six graduate students. In the first third of the class, activities from InTeGrate modules were used as "hands-on" examples of pedagogical sound active learning techniques (e.g., jig saw, gallery walk). The middle third of the class covered learning styles and curriculum design. During the last third of the class, students were required to develop a lesson plan for an active learning-based activity for an introductory laboratory. The lesson plan required an assessment of their activity. The students also needed to have a classmate attend the activity as an observer to provide feedback and suggestions for improvement.

Based on the positive feedback from students in the course, it will be offered in fall 2018, targeting newly enrolled graduate students. A growing interest from graduate students in geoscience education also led to the design of a two-credit hour graduate course that will be taught in fall 2018 and will focus on "Teaching Dynamic Undergraduate Labs."

Adoption and Adaption of Specific Modules

As the number of available InTeGrate modules grew, the variety of courses that used the material also grew (Table 3). Figure 5 shows the specific courses using InTeGrate by the total percentage of students enrolled in courses using InTeGrate from 2013 to 2017. Most students were introduced to InTeGrate materials in large sections of Introduction to Environmental Science offered at UTEP. This was partly influenced by the fact that some of the earliest available modules (CC, EJ, HD) fit well with the content of this course. Usage was also high in Physical Geology lectures and labs. InTeGrate materials were used about equally in Principles of Earth Science (primarily taught at EPCC), Historical Geology, and upper-division/graduate-level courses that included a Geology for Engineers class (Doser and Hussein this volume).

Since the beginning of the implementation program, faculty have adopted materials from nine different InTeGrate modules (Fig. 6). The modules that were available the earliest in the program tended to be used the most, with CC, HD, and EJ comprising 82% of the total materials used by the students. "Living on the Edge: Building Resilient Societies on Active Plate Boundaries" (LE) (Goodell et al. 2014) was a popular module at EPCC since it was well aligned with the Principles of Earth Sciences II course content mandated by the Texas Higher Education Coordinating Board. The GC module was primarily used in Introduction to Environmental Science courses. Exploring Geoscience Methods (GM) (Ebert et al. 2014) now forms an important part of the first laboratories in the research-based sections of Physical and Historical Geology at UTEP to allow students to examine how geoscience methods

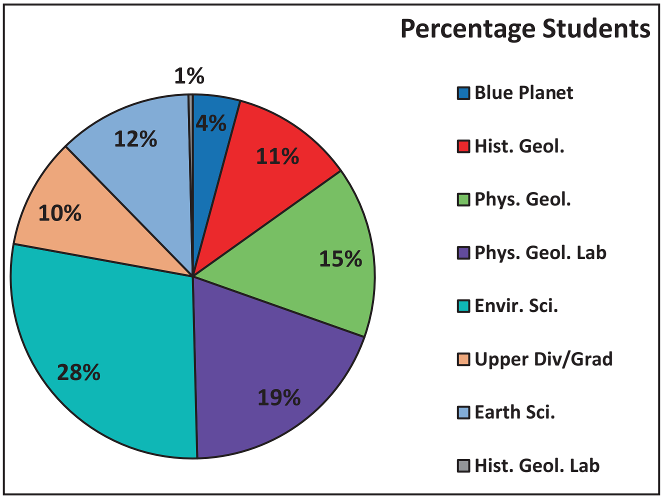


Fig. 5 Percentage of students enrolled in classes where InTeGrate materials were used. Blue Planet, Physical Geology laboratory, Environmental Science, Historical Geology laboratory, and upper-division/graduate classes were only offered at UTEP. All others were taught at both institutions

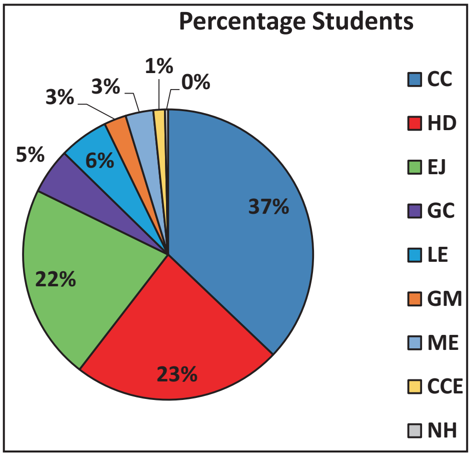


Fig. 6 Breakdown of module use by percentage of students. Module abbreviations: *CC* Climate of Change: Interactions and Feedbacks Between Water, Air, and Ice; *CCE* Carbon, Climate, and Energy Resources; *EJ* Environmental Justice and Freshwater Resources; *GC* A Growing Concern: Sustaining Soil Resources Through Local Decision Making; *GM* Exploring Geoscience Methods; *HD* Humans' Dependence on Earth's Mineral Resources; *LE* Living on the Edge: Building Resilient Societies on Active Plate Boundaries; *ME* Mapping the Environment with Sensory Perception; *NH* Natural Hazards and Risks: Hurricanes

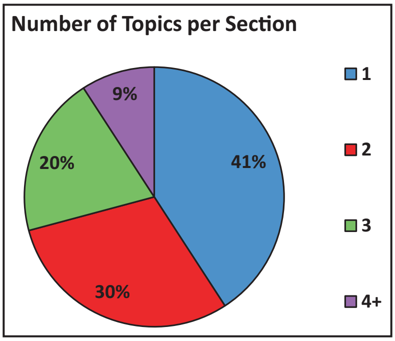
of inquiry differ from that of other sciences. Material from more recently introduced modules such as "Mapping the Environment with Sensory Perception" (ME) (Darby et al. 2015) and CCE are gaining in usage. One instructor chose to use materials from "Natural Hazards and Risks: Hurricanes" (Gilbert et al. 2014) (NH) in fall 2017, given the "teachable moment" related to hurricanes Harvey, Irma, and Maria.

The two most common adaptions of InTeGrate materials involved either shortening a unit to better fit the time length of a class or adding place-based material. Examples of place-based materials included evaluation of water levels in El Paso wells as part of EJ unit 6, comparing water footprints of El Paso residents to those of Ciudad Juarez in EJ unit 2, examining how El Paso might cope with increasing summer heat in CC unit 6 and finding out what types of materials and where materials can be recycled in El Paso as part of HD unit 2.

Figure 7 shows that most instructors (41%) used material from just one module, but they often used several units within the module to cover 1–2 weeks of their course. About a third used two modules, 20% used three modules, and 9% have used four or more modules, adding up to about 60% of their total course content.

Although there was no requirement to continue to use InTeGrate materials, instructors using InTeGrate were highly pleased with results and all used materials when repeating a class. Many (~60%) added new material when the class was taught again. The instructors were more likely to use materials "as is" rather than modify it the first time they used it. However, about half reported some sort of minor modifications if they used the materials a second time.

Fig. 7 Percentage of instructors using one, two, three, and four or more modules



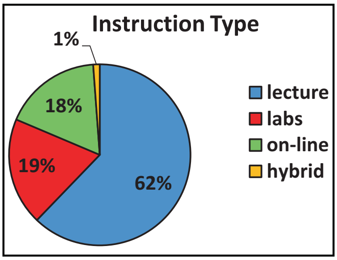


Fig. 8 Percentage of InTeGrate courses by instruction type. Some laboratories at UTEP are taught as a separate class, often by teaching assistants, whereas classes at EPCC are taught as combined lecture-lab course taught by the same instructor. For this study, we counted EPCC courses with this format as "lectures." Hybrid classes generally meet face to face once a week for ~1 h with other course work completed online

Types of Course Delivery

InTeGrate materials were used in online, face-to-face, and hybrid classes (Fig. 8). At EPCC, classes that were delivered in a combined lecture-laboratory format were classified as "lectures" along with standard lecture-type classes given at UTEP. The largest usage was in the lecture (UTEP) or lecture-lab (EPCC) format (62%), followed by stand-alone labs (UTEP, 18%) and online courses (UTEP and EPCC, 18%). All online courses offered at two branches of EPCC use InTeGrate materials, as well as 30–40% of UTEP online courses (Fig. 4).

Distribution of Instructors

Figure 9 shows the overall breakdown of instructors who used the materials between 2013 and 2017. This analysis counts each instructor who has used InTeGrate material only once, although many have used the material multiple times in multiple classes. The figure indicates that teaching assistants have played a critical role in teaching

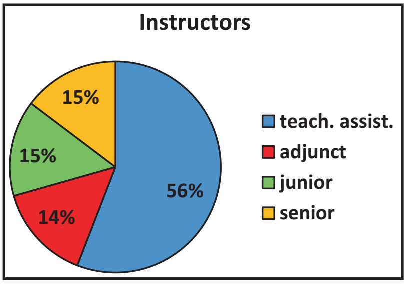


Fig. 9 Overall percentages of instructors who taught courses incorporating InTeGrate materials between fall 2013 and fall 2017

students using InTeGrate, comprising 56% of all instructors. This is partly since many InTeGrate activities, especially those that involve computer work or small group learning, are more manageable in the smaller classrooms (less than 25 students) and longer times (2–3 h) afforded by many labs. It was also easier to gather teaching assistants together to hold workshops and training opportunities and to create graduate-level classes to give them credit for learning new pedagogical techniques.

Our ability to attract adjuncts to use materials was mixed (14% total). Many adjuncts at UTEP have taught courses for a considerable length of time, often teach large lecture sections where some InTeGrate activities may be challenging to use and seem satisfied with their present teaching styles. On the other hand, adjuncts at EPCC often are called at the last minute to teach, do not have as much teaching experience, and are willing to consider InTeGrate materials if it will help save them time in course preparation.

Except for a few individuals willing to take up the challenge of learning new material, most senior-level instructors only had moderate interest in the materials (15% total). There have been a few opportunities (outside of workshops) to engage these instructors if they volunteer to teach a new course or teach a course after a several year hiatus. In the case of EPCC, InTeGrate materials became helpful after the Texas Higher Education Coordinating Board changed the focus and scope of an established class.

Junior-level instructors' interest was also mixed (15%). Some who were just beginning their teaching careers, especially at EPCC, found InTeGrate materials an excellent way to build student-centered courses. Junior-level instructors at UTEP who taught smaller lecture sections (<50 students) also were more likely to adopt InTeGrate lessons, while those teaching larger sections were often not up to the challenge of using the materials.

Lessons Learned

Based on interviews, surveys, focus groups, and informal conversations with EPHEC instructors, it appeared the main barriers to adopting InTeGrate materials included (1) initial reporting requirements, (2) reluctance to try new methods (partly due to time constraints), (3) lack of alignment between materials and courses, and

(4) perceived difficulties in using the materials in large classrooms. We had mixed success in overcoming these barriers.

The InTeGrate program initially required that instructors testing InTeGrate materials register their classes with the program to enable collection of attitudinal data and administration of pre- and post-course geoscience literacy exam questions. While this was necessary for documenting student outcomes, it prevented many instructors from adopting the materials or showing any interest in the program beyond the first workshop. It was difficult to hold a workshop before the beginning of the fall semester since most instructors were out of town. Consequently, by the time a workshop could be held at the end of the first week of classes, instructors interested in using the materials were already behind on attempting to register their courses and collecting pre-course data. Some who attempted to register had difficulties with the process and gave up. In subsequent semesters, we did not require registration or collection of pre- and post-survey information from students. Thus, we were able to convince more instructors to use InTeGrate materials. One-on-one interviews and focus groups still allowed us to collect information on instructor perceptions and satisfaction with the materials, but this was at the cost of not collecting student outcome information.

A reluctance to try new materials appeared to be driven by two elements. First, it takes time to adopt and adapt new materials. For UTEP junior and senior instructors, this affects their research-related activities, which are still the most important factors for tenure and promotion decisions. Second, many well-established instructors feel their lecture style is adequate since most students do well in their courses and they do not receive negative student reviews. We had no good solutions for addressing these factors.

In some cases, the apparent lack of alignment between a course and InTeGrate materials was superficial. InTeGrate materials covered more "traditional" topics such as rocks and minerals or plate tectonics, but their focus might be on how these topics were related to sustainability (e.g., rocks and minerals) or to societal hazards (e.g., plate tectonics), rather than on whether a student could draw the rock cycle or a plate boundary. One solution to this problem was to have an early adopter share material with a colleague teaching the same course to demonstrate how using the InTeGrate materials provided similar student outcomes to content-related assessments. In retrospect, we could have provided summaries of new InTeGrate materials as they became available in 2016 and 2017 to point out how they covered additional content not available in fall 2015.

Lecture sections at UTEP often contain 100–250 students that are taught by senior-level faculty or adjuncts who have had multiple years of teaching experience. Most of these instructors perceived there would be difficulties in scaling up the use of InTeGrate materials for a large group of students, in condensing them to fit into a 50-minute class period or in finding time to implement and grade the materials. This was in spite of the fact that Doser (2017) showed the benefits to students and instructors of using InTeGrate materials in these large sections and invited instructors to observe her use of the materials in large "lecture" sections. Consequently, in most semesters, we were not able to reach more than ~30% of the students enrolled in large lectures at UTEP. This led us to focus on infusing more InTeGrate materials into laboratories at

UTEP where teaching assistants had longer class periods and smaller numbers of students. They were also less likely to have spent significant time in developing their own course materials and appreciated the well-organized InTeGrate content complete with instructors' stories and other pedagogical hints for teaching the materials.

Although we had hoped that most full-time EPCC instructors might adopt InTeGrate materials to provide more a more student-centered program that would help prepare geoscience and environmental science majors for transfer to UTEP, we were only able to convince 50% of the instructors to use the materials. Historically most students awarded associate's degrees in geoscience and who transfer to UTEP (with or without the associate's degree) are students coming from the campuses where some or all full-time instructors adopted InTeGrate materials. This suggests these instructors may have already been predisposed to providing student-centered support and could readily see the advantage of using InTeGrate to attract and maintain student interest in the geosciences.

Conclusions

We have found it difficult to change the established teaching routines of many EPCC and UTEP even if they are given opportunities to test drive InTeGrate activities or are shown compelling data documenting the increase in the success of our students in courses where these materials are used. Many simply do not feel they have the time to invest in change, do not feel their course content adequately aligns with InTeGrate materials, or do not have the confidence to try moving away from a lecture format, especially in large classes.

The lack of instructor use in lectures at UTEP has led us to focus on revising introductory laboratories, commonly taught by graduate teaching assistants, to include more InTeGrate-based content in order to reach more students. Not only are the teaching assistants learning sound pedagogical methods, they are clearly seeing results of their students' engagement in the InTeGrate material. As students themselves, they can also appreciate how their own learning is facilitated by instructors using these techniques. We have completed revision and testing of 15 new Physical Geology laboratories (60% use InTeGrate materials). Over the summer of 2018, we plan to develop similar materials for the Principles of Earth Sciences I and Historical Geology laboratories that will be tested during fall 2018. The use of InTeGrate materials in the Principles of Earth Sciences laboratories will especially benefit majors in K-8 education who are required to take the course. In addition, we are developing new graduate-level courses in geoscience education to aid our teaching assistants.

We had hoped that over 50% of instructors within the EPHEC would adopt InTeGrate materials to help provide a student-centered approach to enhance the alignment of courses between institutions and transfer pathways. Although we did not achieve this goal, we have built a core group of ~12 full-time and adjunct instructor that use the materials each fall semester, reaching about 400 students/year. This core group has also become heavily involved in other joint EPCC-UTEP activities such as student research and service learning-based projects that continue to attract students into our programs, enhance student transfer pathways, and lead to completion of associate's and bachelor's degrees in a timely manner.

Acknowledgments We thank the many instructors at UTEP and EPCC who agreed to attend workshops, focus groups, teach courses, collect data, and share their views on InTeGrate materials with us. We also thank the EPCC and UTEP students who have participated in classroom activities and provided us with their honest feedback about the successes and failures in our adoption process. We thank two anonymous reviewers and co-editor D. Gosselin whose comments greatly improved a previous version of this manuscript. This research was supported through grant DUE-1125331 (STEP Center: InTeGrate: Interdisciplinary Teaching of Geoscience for a Sustainable Future) from the National Science Foundation. Initial work on developing the research-based freshman Physical and Historical Geology laboratories that used InTeGrate materials was supported by HHMI Sustaining Excellence Award No. 52008125 to S. Aley as part of the UTEP PERSIST Program.

Appendix

Table 5 Excerpts from teaching logs kept by instructors in spring 2015

Selected comments by instructor
Instructor 1 (Climate of Change module) My students seemed to enjoy the "Days of Future Past" unit of the Climate of Change module. Mostly because although they are to base their predictions on scientific data that they have worked with over the last 2 weeks of classes, they have a little bit of freedom to predict the results. They really have fun with the presentations plus it really helps them to work in groups, presentation, and communication skills
Instructor 2 (Climate of Change module, all 6 units) These activities were very beneficial to the class as far as introducing them to several concepts associated with climate change. They were interactive, using the online survey, PowerPoint slides, and various handouts, to illustrate and promote thinking and enhance discussion of the topics. And they were also very easy to use
Instructor 3 (Climate of Change module, unit 1) The feedback I got from the students was generally that they dreaded another reading assignment at the outset (but they wanted the extra points). The article got them interested quickly, and at the end, they enjoyed the reading and thinking about the concepts of climate change and how cultures adapted
Instructor 3 (General Notes on Modules) The modules provided great resources on many topics central to our classes. They also provide alternatives to the "PowerPoint overload" method of teaching. I liked that the activities were very interactive and they provided good breaks in the normal class routines. The activities were thought provoking, and we had lots of good discussions based on the materials that I used in my classes. I plan to use several of the activities again and also plan to scope out using some of the others that are available
Instructor 4 (Climate of Change module, unit 3) The students were very engaged and interested. They seemed to enjoy working on the activity and asked many questions. I had them refer to material in their books to help them answer some of the questions about ocean circulation. I think that to many of them, it was a new way of learning and they liked it
Instructor 5 (Environmental Justice module, unit 6) Had students read background material on groundwater and the Ogallala aquifer. I assigned the homework of finding water well data for the Ogallala aquifer and then had them complete a group activity following a quiz about groundwater that had questions from the freshwater module. It appears that about 2/3 of the class did not review the information on sand and clay, and their permeabilities as quiz scores were not very high where the students had to predict contamination from a storage tank. The students brought up questions about induced seismicity and its relationship to fracking and waste water injection/groundwater withdrawal in class. Most students appeared to have few problems with the activity itself

(continued)

Table 5 (continued)

Instructor 6 (Climate of Change module, unit 1) Students were quite engaged on the Gallery Walk and communicated with team members effectively to answer questions. I included three questions on an exam several weeks after the activity. Students had difficulty with a question on negative feedback (12.5% correct) but did very well on questions related to factors causing the collapse of the Maya civilization (88% correct) and why the Vikings may have abandoned Greenland (100% correct)

Table 6 Responses to emailed questionnaire (sent May 2015 to 24 instructors, 9 responses received)

Question	Response
Would you consider using any of these materials in an undergraduate course you teach?	• Yes (7 responses) • Maybe—depends on modules and class • Yes but not all of them. My class is 50 min long, and it is not easy to finish such activities in 50 min or less
If not, why?	(a) I am already using materials which I think are well tailored to my course and don't think I need anything new (b) I am bombarded with so many such analogous things that the time commitment to evaluate new curriculum modules may be not be worth it (c) The levels don't match: i.e., modules on topic of interest are designed for advanced course, but I want them for intro course; module for intro course is on topic I want for advanced course. I wish there were two modules available for each topic: one for an intro course and one for an upper-division course
If yes, which materials would be of interest?	• Earth's mineral resources; hydrological cycles; interactions between water, Earth's surface, and human activities; exploring geoscience methods, climate change, and variability • Climate of Change: Interactions and Feedbacks Between Water, Air and Ice; Natural Hazards and Risks: Hurricanes; A Growing Concern: Sustaining Soil Resources Through Local Decision Making; Interactions Between Water, Earth's Surface, and Human Activity • Module: Climate of Change; Interactions Between Water, Earth's Surface, and Human Activity; and Human's Dependence on Earths Mineral Resources • Maybe the soil and mineral resources modules
Which courses do you envision these materials could be used in (could be your own courses or others' courses)?	• Can be used in Blue Planet, Earth Science, Weather, and Climate • Classes to be used: Blue Planet (intro level to non-major) Hydrogeology (advanced level to majors), Physical Geology, and Fundamentals of Earth Science • Most of them • Climate of Change: Interactions and Feedbacks Between Water, Air and Ice; Natural Hazards and Risks: Hurricanes; A Growing Concern: Sustaining Soil Resources Through Local Decision Making; Interactions Between Water, Earth's Surface, and Human Activity. These materials could be used in the "Introduction to Environmental Science" class, but since they are time-consuming, I think it is better to use these materials for labs other than lectures. In addition, I am thinking to develop a new course for spring 2016 for the Environmental Science program, and I think I might be able to use some of these materials. • I may try to use some of the materials in my University Seminar class. I need to check with you in order not to give the students repeated activities since our two courses are linked in the learning community

(continued)

Table 6 (continued)

Question	Response
Are there topics that are not covered by InTeGrate that you would like to see included?	• Environmental policies that are closely related to earth sciences and environmental practices • Most of Physical Geology and Fundamentals of Earth Science topics are not covered. It would be nice to have more traditional material like sedimentation or interior of the earth • The hydrologic cycle! (per se, without anthropogenic focus like the ones I see there which touch on it are): volcanism, mass wasting/ landslides, and plate tectonics • Yes, I would like to see more topics related to environmental science such as atmospheric science and air pollution, water pollution, waste management, energy sources, land-use planning, and human population Anything that could slot into a course I am teaching I would consider using—for example, C, N, and other element cycling modules • Other environmental science-related topics such as population ecology, biodiversity and conservation biology, air pollution, water contamination, waste management, and nonrenewable and renewable sources
Many of the InTeGrate materials include active learning, group learning, or use of the Internet (Google Earth, etc.). These activities may be difficult to try in a large class or a 50 min long class but might work well in introductory labs. Do you see any material that would be particularly good for labs?	• Humans' dependence on Earth's mineral resources, sustaining soil resources • The units in Climate of Change that involve analyzing plots/figures may be particularly good for labs • I would use most of it in a lab setting rather than a large classroom • I'd have to look over this material in more detail (probably several hours work), which I cannot dedicate time to doing right now • I don't teach labs
If you are a faculty member that oversees labs for a particular course sequence, would you like to have me work with your teaching assistant(s) to help introduce materials into laboratories over the coming year?	• N/A but would do for the future • Maybe, we can talk about it. I am also trying some other new materials, so timing is a bit uncertain • No, but please remind us on a regular basis every few months about the availability of these modules, because we're likely to forget over the summer • I am not a faculty member. (2 responses) • I don't have labs right now but I will keep it in mind
Are there any other comments regarding adoption of InTeGrate materials that you would like to share?	• Is it possible to build a platform to allow interaction of users and creators of the modules to interact online (through InTeGrate website as chat box, etc.)? This is to share experiences and for Q/A too • Looks awesome. I love to see these active learning modules. They can be a lot of work to develop, but I think students respond really well to them, so I appreciate what you all have done. Good luck with your further work on them

Table 7 Examples of workshop feedback

Question	Response
August 28, 2015 workshop (21 attendees)	
Do you think the modules will facilitate your style of teaching? Explain	• Yes. The modules include useful tools that cater to all learning styles • The module will be good. I tend to be more hands-on. But you need to think about ALL students • Yes, I touch on or lecture on several of these topics. It will be good to try new activities • I got some ideas for more interactive question/answer for my lecture on ENSO (El Niño-Southern Oscillation) • Will potentially include this activity in a lab in future years
What was the most exciting aspect of the modules? The least exciting aspect?	• Most was understanding and learning about predicting weather patterns; least was text heavy • Most was actually tracking and drawing my own data on the maps. Least was lack of personal knowledge of the subject • Most was that it was student oriented • Most was predicting the conditions of La Niña. Least was that the last two questions seemed redundant
Do you think the level of the material is suitable for the courses you teach?	• Yes, most definitely • Yes • Yes, community college level • Level is OK but may be too much detail for the amount of time we have to spend on ENSO
How do you think your students would respond to using these modules?	• I think they would like them and even use them as a study guide • It will be slow at beginning. Requires analysis • They really seem to enjoy these hands-on activities and say they learn more than in lectures
What challenges do you foresee to implementing these modules in your courses?	• Having students read through the text and understand the questions • Students usually are at a fairly low level. They are used to being fed information • More open ended questions are difficult to evaluate in a large class
Please feel free to add any additional comments here:	• Thank you! I'll be using this with my labs • Good sessions. Thanks for inviting me
October 16, 2015 workshop (9 attendees)	
Have you used any InTeGrate materials yet? If so, which ones have you used? What challenges have you faced in using the materials?	No (2 responses)
If you have used the materials, how did you students like them?	NA (2 responses)

(continued)

Table 7 (continued)

Question	Response
If you have not used the materials do you think the level of the material we have presented thus far is suitable for the courses you teach? What challenges do you think you would have in using the materials?	• I think the level of the materials is proper for my class, but I think one of the challenges that I will have when I use the materials is time. I believe it is better to provide students materials before each class, so they will have time to study before coming to class, and when they are in class, they just discuss together and answer the questions. Not all students will have the same level of reading skills in class • Yes, the content is relevant to the course I teach. I will be able to use the materials in my class. I think one of the challenges I will have in using the materials is the length of the activities and how long it takes to finish them in class, especially with my short class (50 min long). I think I will go with the option to do part of the activity (if I want to do it in class) or to let them do some of the activities as a group assignment
What can we do to help you in implementing the modules?	• Change at the classroom does not occur all at once, when we pay attention to the stages of implementation we can. Therefore, we need to learn the modules step by step in different workshops • This workshop gave me further practice and feedback about how to use the InTeGrate materials and to become more familiar with it. I think we need to practice more on how to use it, to realize all applicable and relevant activities
February 19, 2016 workshop for teaching assistants feedback (3 attendees)	
Do you think an exercise such as the “jigsaw” activity you just did will facilitate your style of teaching? Explain	• Yes. An active environment engages students to utilize their thoughts and share it with others. They are more open to other ideas and views that can shape or refine the way they think about things and overall help improve their abilities as a student • Yes, it’ll force the students to actually think and have some input into the group work • Yes, the jigsaw method allows for the students to engage in the topic. Typically faster students take over the group, and everyone follows. This technique allows the students to work at the same pace and come together at the end to discuss
What was the most interesting aspect of the activity? The least exciting aspect?	• Colorful imagery is the incentive to really look at the pictures and allow the student to express their ideas. I cannot really reply on a least exciting aspect. One thought is that a student may be reluctant to share due to their level of comfort • When we collaborated to see what other environments other people had. The ideas and just the overall thought processes. The least exciting was doing our own observations, but it’s good to get that done first to motivate to get to the next step • How quickly the jigsaw topic discussion comes together with everybody contributing

(continued)

Table 7 (continued)

Question	Response
Do you think the level of the material is suitable for the courses you teach?	• Yes. The level is suitable for engaging students of an intro course and hopefully engage each and every one to do the activity • I think so; even if there are some students that don't understand, it still introduces them to a new way of learning • Yes, because the method can be applied to any situation and a range of topics at different technical levels
How do you think your students would respond to using an activity like this?	• From what I have witnessed, many of the students like to talk and converse, and if it isn't too technical and rather visual, they can communicate openly and would respond well • I really can't say, some would enjoy it, but I know there are those that wouldn't because they would actually have to do their own work. But then there are also those that wouldn't even care to try • I think they would react positively if the jigsaw topic was applicable to the current lab topic/lecture
What challenges would you foresee to implementing an activity like this in your course?	• Only limited to a student's character or attitude. But a key thing is to allow the student groups to introduce each other and work with a team for a few weeks to allow for a social comfort • Getting them to actually participate. There's a lot of "oh, let me see what you have," so with this I imagine they may either bite the bullet and do the work or not do it or at least just do a bare minimum • Different levels of contribution to the end discussion would be apparent as some students prefer to do minimal work compared to others. However, the discussion would be of higher quality using this method as everyone is expected to contribute something

Table 8 Questions asked in focus groups and one-on-one interviews (fall 2015, spring 2016)

Question	Asked in focus groups[a]	Asked in one-on-one interviews[b]
What classes did you use InTeGrate materials in?	x	x
How many students were in the classes?	x	x
What units of InTeGrate did you use?	x	x
Did you use them "as is" or modify them?	x	x
What specific challenges did you face in modifying the materials?	x	x
What was the students' reaction to the material?	x	x
Did you test pre or post to the activity? If so, what were the results?	x	x
Would you use these materials again? Would you consider using other materials?	x	x

(continued)

Table 8 (continued)

Question	Asked in focus groups[a]	Asked in one-on-one interviews[b]
If you have used these materials before what changes, if any, did you make?		x
Do you have any other comments?	x	

[a]Eight participants fall 2015, six participants spring 2016
[b]Six respondents fall 2015, four respondents spring 2016

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Creating Opportunities to Teach and Engage with Undergraduates and Faculty at 2-Year Colleges and Minority Serving Institutions

Angelina Sanderson Bellamy, Guadalupe Carrillo, and Tenea Watson Nelson

Abstract In an effort to advance diversity in the geosciences, the Stanford InTeGrate Implementation Program (SIIP) increased the academic geosciences exposure of underrepresented minority undergraduates and increased career satisfaction and retention of Stanford School of Earth, Energy, and Environmental Science (Stanford Earth) graduate and postdoctoral students. The program facilitated pedagogy training and geoscience teaching opportunities for Stanford Earth graduate and postdoctoral students in STEM disciplines at local 2-year colleges and minority serving collegiate institutes (2YC/MSI). This chapter provides details on how the program was implemented as well as outcomes with regard to undergraduate students, Stanford Earth graduate and postdoctoral students, and 2YC/MSI faculty mentors who partnered with SIIP. Finally, we highlight different program elements that were conducive for successful implementation, as well as recommendations for creating a more systemic approach to increasing diversity in geoscience education at all levels.

Keywords Minority serving institutions · 2-year colleges · Mentorship · Capacity building · Geoscience pedagogy

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Introduction

Diversity in the STEM disciplines is lacking at all levels of academia, undergraduates through to the faculty level (NSF 2017). Only 34 underrepresented minorities (URMs) graduated in 2014 with Earth, atmospheric, and ocean sciences doctorates, which amount to 5.8% of all new PhDs in this group (NSF 2017). While numerous funding programs have prioritized increased recruitment and retention of URMs to STEM disciplines, little progress has been achieved in the Earth, ocean, and atmospheric sciences over the last 40 years (Bernard and Cooperdock 2018).

Reasons for this gap include feelings of isolation (Blackwell et al. 2009; Dunn et al. 2012), lack of social capital (Callahan et al. 2015), lack of visible role models (Foor et al. 2007; Zeldin et al. 2008), negative racial stereotypes (Ream et al. 2014), and a cultural gap between personal identity and topic of study (Lewis and Baker 2010). While this list is not exhaustive, the role that mentoring can play in addressing the above-listed barriers has been well-documented (Stokes et al. 2015; Haacker 2015; Callahan et al. 2015; Zambrana et al. 2015). Not only does mentoring promote stronger social capital ties for student learners, but students who mentor experience building of "self-esteem and … a greater goal and perspective, making struggles with isolation and discouragement tolerable" (Haacker 2015). Haacker (2015) further found that the opportunity for URM graduate students to inspire other URM students retains them in academia.

The Stanford School of Earth, Energy, and Environmental Sciences (Stanford Earth) InTeGrate Implementation Program (SIIP) used teaching and mentoring relationships to increase exposure of URM undergraduate students to geosciences, connect it to their lives, and potentially recruit them to the major. The program also addressed gaps in opportunities for Stanford graduate students who desire a more teaching-intensive career but are unable to gain their desired experience due to the research intensity of the university. The intention was to increase career satisfaction and retention of Stanford Earth PhD students and postdoctoral researchers (postdocs). To achieve this, the program targeted three academic levels:

1. Undergraduates at 2-year colleges and minority serving institutions (2YC/MSI) established connections between geoscience concepts and their own life experience, through new module material developed by InTeGrate. Stanford PhD students and postdocs taught modules that incorporated experiential learning with relevance to current topics.
2. Stanford PhD students and postdocs attended a 2-day geoscience pedagogy workshop and then taught InTeGrate module material in 2YC/MSI classrooms. Each instructor was paired with a faculty mentor where they were teaching.
3. 2YC/MSI faculty were exposed to new teaching material and acted in an advisory capacity to Stanford PhD students and postdocs.

SIIP built relationships with 2YC/MSIs, which have an historically higher percentage of URM science enrollment compared to traditionally white 4-year colleges (Snyder and Dillow 2011). The specific program objectives were to:

1. Further integrate geoscience teaching into 2YC/MSI courses through the use of InTeGrate modules.
2. Provide teaching and professional development to Stanford PhD students and postdocs who may not otherwise have the opportunity to teach or teach at 2YC/MSI institutions.
3. Strengthen collaboration with local 2YC/MSIs and increase recruitment efforts of URMs to our graduate programs and retention of Stanford URM PhD students and postdocs in the professoriate.

This chapter will describe the implementation program activities, outcomes and impacts, lessons learned, and recommendations.

Program Implementation

SIIP ran for 3 years beginning with recruitment of program participants in the summer of 2014. It was initially funded by a 2-year NSF grant. The third year of the program was funded by Stanford University's School of Earth, Energy, and Environmental Sciences (Stanford Earth). Over 3 years, InTeGrate modules were taught in 15 courses, across 8 2YC/MSIs, and reached an estimated 75–300 undergraduate students each year (Table 1). At Stanford, 19 PhD students and postdocs participated in training and teaching. Stanford participants were expected to spend up to, but not more than, 120 h on training, preparation, meetings, and teaching. Participants were reimbursed with a stipend, equivalent for 120 h of work, for their participation in the program.

Stanford postgraduate students each had between 6 and 15 total contact hours with undergraduates, teaching module material in the classroom each spring semester. Each student modified the module material to meet the needs of the course, course timing, and class size, which varied from 10 to 160 students and 1 course section. Some of the module material was taught once a week for 6 weeks, at 2.5 h each, some were taught three times a week for 3 weeks at 3 h each session, and some taught for three 3-h sessions over the course of the semester.

Year 1, June 2014–June 2015

During the spring of 2014, a database was created of 2YC/MSIs within a 15-mile radius of Stanford. Following initial contact, our program staff met with deans, professors, and other administrators from interested institutions to describe the implementation program and its objectives. We discussed the level of faculty involvement and how Stanford PhD students and postdocs would work with them. We also gave a brief overview of the different InTeGrate teaching modules and how they could augment classroom learning in a variety of science courses. In the first year, we partnered with four institutions (Table 1): Evergreen Valley College, Mission College, San Jose State University, and CSU East Bay. Faculty mentors

Table 1 List of institutions participating in SIIP, 2015–2017

Institution	Faculty mentor	Year of participation	Course	Module
California State University, East Bay	Michael Massey Gita Dunhill	2015, 2016	Introduction to Environmental Science (60 students)	Humans' Dependence on Earth's Mineral Resources
Evergreen Valley College	Celso Batalho Jagruti Vedamati	2015, 2017	Introduction to Earth Sciences (30 students)	Climate of Change
Foothill College	Dave Sauter Anne Alderkamp	2016 2017	Environmental Horticulture (30 students) Intro to Biology (60 students)	Sustainable Soils Climate of Change
Mission College	Jean Replicon	2015	Introduction to Marine Biology (30 students)	Climate of Change
Notre Dame de Namur College	Sherri Gallipeau	2016	Contemporary Environmental Sciences Issues (15 students)	Environmental Justice
San Jose State University	Joe Petsche	2015, 2016, 2017	Introduction to Geology (180 students)	Climate of Change
Santa Clara University	Jonathan Lariviere	2016 2017	Introduction to Earth System (10 students in each lab section)	Sustainable Soils
Cañada College	Susan Mahoney	2017	Intro to Environmental Science (20 students)	Climate of Change
San Jose City College	Tony Lenci	2017	Geology: Earth Science (25 students) Geology: Physical geology (24 students)	Natural Hazards

decided which InTeGrate teaching module they wanted to include in their classroom. Included modules were Climate of Change (Shellito et al. 2014) and Humans' Dependence on Earth's Mineral Resources (Bhattacharyya et al. 2014).

Two Stanford PhD students and three postdocs were recruited through an email campaign during the summer and autumn of 2014. We interviewed each student and paired them with faculty mentors based on the modules that fit their research and career interests. The interview process ensured that Stanford participants understood what was required of them for participating and that they were in support of program objectives, which were the primary factors for consideration in the program. Faculty mentors and Stanford participants both signed a document demonstrating understanding of participation and feedback expectations for the program. Graduate student and postdoc supervisors also provided their signed consent for up to 120 h of Stanford student participation in SIIP over the following two terms. This demonstrated the supervisor's commitment to developing their student's teaching skills, at times when research is the predominant priority. Students were provided alternative funding for their teaching and participation commitment, as not to conflict with their research funding.

Table 2 Information about how the module material was taught in different classrooms for Year 1

What class did you teach?	The third quarter of 3-quarter Intro to Environmental Science course with 64 first-year students		Three sections of Introduction to Geology; each section had ~60 students	Introduction to Earth Sciences course; 35 students	Introduction to Marine Biology course; 30 students
What module did you teach?	Humans' Dependence on Earth's Mineral Resources		Climate of Change	Climate of Change	Climate of Change; Exploring Geoscience Methods; offshore wind or offshore oil (activity collection, not modules)
What units within the module did you teach?	Unit 1 and 2 with integration of components in Unit 4 and 5	Unit 3 and 6 with integration of components in 4 and 5	Units 1 and 2 (the first activity in the unit, not the extension)	Units 1–5	Climate of Change Unit 2; Exploring Geoscience Methods Unit 1 and 2
How much time did you spend in the classroom?	4 sessions of 110 min each (440 min total)		3 sections for 75 min each, for 2 days (450 min total)	15½ h in total over a span of 6 weeks (930 min total)	About 3 h on each of three visits (540 min total)

Following the selection process, PhD students and postdocs were required to participate in a 2-day science pedagogy training workshop, held in December 2014. The training workshop consisted of a day of teaching pedagogy and a day of familiarizing students with the InTeGrate module material (InTeGrate 2018a). Stanford participants used the modules as a source of pedagogical information and professional development.

Stanford participants taught module material in the 2YC/MSI partner classrooms between February and May 2015. Before teaching in the classrooms, Stanford PhD students and postdocs met with their faculty mentors to discuss the classroom setting and challenges and how the InTeGrate module material would best compliment course learning objectives. Stanford participants attended one classroom session before teaching in order to get an idea of how their mentors handled the class.

During the autumn of 2014, Institutional Review Board (IRB) ethical approval was gained to administer pre- and post-module attitudinal and knowledge surveys for the 2YC/MSI undergraduate students attending classes participating in SIIP. Faculty partners administered both surveys to students in the first week of the course and in the final week of the course, per instructions from the central InTeGrate team (see Appendix 1 and 2 for questions). Faculty instructed students that their participation was voluntary and anonymous and provided an information sheet with further information about their survey participation, according to ethical guidelines.

Interview questions and surveys (see Table 2 and Appendix 3 and 4 for questions asked) were also administered to the Stanford participants in order to capture feedback about their experience as well as information about the courses in which they taught. Finally, interviews were conducted with faculty mentors at the end of the term to solicit feedback regarding their experience in the program (Appendix 5).

Year 2, June 2015–June 2016

During our second year, we partnered with three additional institutions: Foothill College, Notre Dame de Namur, and Santa Clara University (not a designated MSI but where 57% of the students identify themselves as "persons of color"). A new set of Stanford students was recruited over the summer, and they were matched with faculty and modules (Table 3). The central InTeGrate team released new module material, which was taught in the SIIP and included A Growing Concern: Sustaining Soil Resources Through Local Decision Making (Fortner et al. 2014) and Environmental Justice and Freshwater Resources modules (Perez et al. 2015). Students once again participated in science pedagogy and InTeGrate module training. They met with faculty host mentors in advance of their teaching sessions and facilitated the pre- and post-attitudinal and knowledge surveys for the undergraduate students. Unlike the first year, Stanford PhD students and postdocs also attended

Table 3 Information about how the module material was taught in different classrooms for Year 2

What class did you teach?	Introduction to Earth Systems (10 students in each lab section)	Environmental Horticulture (~30 students)	The third quarter of a 3-quarter Intro to Environmental Science with 82 first-year students	3 sections of Introduction to Geology; each section had ~60 students	Contemporary Environmental Sciences Issues, Summer term (14 students)
What module did you teach?	Sustainable Soils	Sustainable Soils	Humans' Dependence on Earth's Mineral Resources	Climate of Change	Environmental Justice
What units within the module did you teach?	Unit 1	Impacts of land use; soil characteristics and relationships; predicting the effect of climate change on soil loss	All of them	Unit 3—Anomalous Behavior (El Niño/La Niña)	All of them
How much time did you spend in the classroom?	4 lab sections, 2 h each (480 min total)	6 sessions, each 135 min (810 min total)	14 h (840 min total)	6 h divided between Tuesday and Thursday (360 min)	6 h (360 min)

a workshop on teaching for a diverse classroom setting, provided through Stanford University. At the end of the year, Stanford students and faculty mentors were interviewed to receive feedback on the program.

Year 3, June 2016–June 2017

In 2016–2017, the SIIP was conducted without funding from the NSF. Additionally, there was a change in program management with a new program director. Six PhD students and two postdocs were recruited to participate at six different academic institutions: Cañada College (new), San Jose City College (new), Evergreen College, Foothill College, Santa Clara University, and San Jose State University (Table 4). All PhD students and postdocs attended the program's 2-day training workshop. This was also the first time that former Stanford participants were involved in the program for a second time; one PhD student participated for the second time as an instructor at Foothill College, and one postdoc from Year 1 returned as a faculty mentor at Evergreen College. As for host universities, San Jose State University faculty participated in all 3 years of the program (Table 1). New modules taught included Living on the Edge: Building Resilient Societies on Active Plate Margins (Goodall et al. 2016), Natural Hazards and Risks: Hurricanes (Gilbert et al. 2014), and Earth's Thermostat (Dunn et al. 2016).

Also differing from years 1 and 2, the RTOP (Reform Teaching Observation Protocol) research team, which worked with the InTeGrate Implementation teams to understand the use of InTeGrate materials in the classroom, sent a researcher to observe how Stanford participants adapted and developed the materials. Once teaching was completed, PhD students, postdocs, and faculty mentors were asked to participate in an exit interview to gather information about their experience in the program and also to attain feedback and recommendations. The undergraduate students were surveyed regarding classroom experience with SIIP instructor. This survey information was different from what was used in Year 1 and 2; the pre- and post-survey tools used in Year 1 and Year 2 were difficult to administer, and owing to both the voluntary nature of the surveys and the poor correspondence between those taking the pre-survey and those taking the post-survey, the amount and quality of feedback were low (see Table 5).

Outcomes and Impact

Follow-up surveys were conducted with 2YC/MSI undergraduate students attending the modules, Stanford PhD students and postdoc teaching the module, and faculty host mentors (Table 5).

Table 4 Information about how the module material was taught in different classrooms for Year 3

What class did you teach?	Earth Science	Introduction to Biological Systems	Climate Change: Past to Future	3 sections of Intro to Geology	Intro to Environmental Science	Earth Science	Physical geology	Intermediate GIS
What module did you teach?	Humans' Dependence on Mineral Resources	Climate of Change; Systems Thinking; Earth's Temperature	Climate of Change	Living on the Edge	Climate of Change and Environmental Justice	Natural Hazards	Environmental Justice and Water, Agriculture, and Sustainability	Systems Thinking and Own Remote Sensing Material
Total Contact hours	8 h	9 h	6.5 h	5 h	6 h	3 h	3 h	8 h

Table 5 Participation and assessment tools used to evaluate program impact

	Year 1	Year 2	Year 3
2YC/MSI undergraduate students	Pre- and post-attitudinal assessment (n = 32 pairs; 17%) and knowledge surveys (n = 13 pairs; 7%)	Pre- and post-attitudinal assessment (n = 49 pairs; 22%) and knowledge surveys (n = 61 pairs; 27%)	Exit Evaluation Survey on classroom experience (n = 56)
Stanford PhD students and postdocs	Follow-up interview and survey (n = 5; 100%)	Follow-up interview and survey (n = 6; 100%)	Exit interview (n = 8; 100%)
2YC/MSI faculty mentors	Follow-up interview (n = 4; 100%)	Follow-up interview (n = 4; 80%)	Exit interview (n = 6; 100%)

Improved Integration of Geoscience into Courses at 2YC/MSIs

The first program objective was to work with 2YC/MSIs to build their capacity to integrate geoscience teaching into their courses through the use of InTeGrate modules. Improving capacity would lead to increased exposure to geosciences for undergraduate students and provide them with an opportunity to learn about specific concepts in this field. Approximately 1000 students attended the courses in which Stanford PhD students and postdocs taught InTeGrate module material. According to the pre- and post-knowledge surveys in 2015, 46% (n = 13) improved their scores in the post-knowledge survey, with an overall average increase of 0.08 points out of 10 possible points between pre- and post-knowledge surveys. In 2016, 42% of students (n = 61) received higher scores on their post-knowledge survey, with an overall average of 0.22 points improvement between the paired pre- and post-knowledge surveys.

Based on the results of paired pre- and post-attitudinal assessments for 2015 and 2016 (n = 81), more than half of 2YC/MSI undergraduate students reported that they had greater interest in increasing sustainability in their personal or professional lives after participating in the module. Approximately 40% expressed an increased interest in a career in Earth and Environmental Sciences.

However, it is important to point out that in both cases, fewer than a quarter of students who attended the courses are represented by the paired surveys. Since the Stanford participants were only present for some of the lectures, and not the first or the last, it was the sole responsibility of the faculty partners to administer the survey. In all cases, the faculty partners found it onerous to carve time out of their teaching schedule to administer the surveys and student response was mediocre, as participation was voluntary. In some cases, the instructors did not complete either the pre- or post-surveys, and likewise, students did not complete one of the two surveys, reducing the number of matched surveys completed.

In the third year, the pre- and post-surveys were replaced by an exit survey designed by the SIIP. The survey asked the following three questions:

1. What did you learn from the lectures? What concepts or body of knowledge did you find interesting or useful?
2. What aspects of this instructor's teaching were most helpful to you?
3. How can this instructor's teaching be improved?

The following reflections are taken from the 56 exit surveys collected from 2YC/MSI undergraduate students in Year 3 of SIIP. In response to the first two questions of the evaluation sheet which asked for topics learned and what worked in class, the students reported learning about foundational topics such as the hydrological cycle, El Niño, agricultural industry's use of water, safety during hurricanes, and climate change. They also reported learning about tools or techniques that facilitate research in the Earth sciences such as Google Earth, remote sensing, and computer programming languages. Themes were captured by carefully reviewing each survey and identifying key words that were repeated. Some students reported having difficulty with the Google Earth tutorial and understanding the remote sensing software. One student stated, "I thought it was really cool to see how remote sensing could be used in so many ways like tracking income or monitoring deforestation. I thought the Google Earth engine part was confusing, but mainly because we were crunched for time." Overall, the students' evaluation stated that they felt it was valuable to learn these tools and how they are applied to answering scientific questions. For example, 30% of the students (n = 17) reported recognizing the value of remote sensing and other GIS tools in examining Earth events.

Collectively, student feedback expressed satisfaction with their SIIP instructor for adding a new perspective to the classroom and showing them how research creates useful information about our world. Of the students who answered the evaluation, 86% expressed being satisfied with SIIP and learning new concepts related to the Earth sciences. One student commented that it was interesting how a SIIP instructor's research was connected to current events such as climate change. "It was useful to learn about hurricanes because they are caused by warm sea water along with other things and our temperatures are rising so this will affect us." Another student expressed enjoying the opportunity to connect concepts, namely, how climate change influences hurricane patterns. Fourteen students (25%) wrote that they found the SIIP activities useful and enjoyable, since they allowed them to ask questions, explain the concepts in their own words, and share information within their own groups and class. They also appreciated seeing data and graphs on El Niño since it not only reflected real data over a 10-year period but was also relevant to the students' geography and place in the world (California). A student from Santa Clara University stated, "I learned a lot about the relationship between different factors such as temperature, precipitation, and pressure during El Niño events. I found the data exercise very interesting."

Students recognized presentation style as a big area for improvement for the Stanford instructors. One student critiqued the pace of the lecture, suggesting that the instructor "slow down a bit on the slides so that [they] can take notes and absorb all the info." While another student commented on the instructor's voice level, writing, "a loud projection is needed to keep everyone attentive." Similarly, a student in

San Jose City College enjoyed the module on hurricanes but also noted the instructors' inexperience in speaking in front of a larger class: "His overall teachings are good but if he could just speak a little louder." Finally, students suggested that the instructor "improve visuals," while another recommended that the instructor "write clear slides so that when we miss your speech we can reference the slides."

Teaching Experience for Stanford PhD Students and Postdocs

SIIP provided teaching and professional development to postdocs and graduate students who may not otherwise have had the opportunity to teach or teach at 2YC/MSI institutions while enrolled or working at Stanford. We hypothesized that teaching and professional development activities would increase career satisfaction and improve retention of Stanford Earth graduate and postdoctoral students.

At the end of 3 years, a total of 19 PhD students and postdocs participated in training related to the InTeGrate modules and geoscience pedagogy and implemented the lessons they learned in the classroom. All of the Stanford participants reported that the program was beneficial, that their expectations were exceeded, and that they enjoyed working and teaching with their faculty mentors.

Attending a top-tier research institution, PhD students and postdocs at Stanford Earth do not have as many opportunities to teach undergraduate courses or introductory-level curriculum. There is also a smaller undergraduate population compared to the PhD student and postdoc community, leading to a relatively small number of teaching opportunities at Stanford Earth. SIIP appealed to PhD students and postdocs who were seeking opportunities to engage in Earth sciences diversity initiatives that would have an impact in their field. This desire is mirrored in research on this topic in STEM fields; URM PhD students are more likely to be motivated by altruistic values and a desire to give back to their communities than their majority peers (Thoman et al. 2015; McGee et al. 2016; Gibbs and Griffin 2013). Furthermore, Haacker (2015) states that many of the participants in their mentoring program were interested in "inspiring other minority students, and often decide to pursue an academic career to serve as faculty and mentors to lead by example."

SIIP provided a much-needed opportunity for our research community to teach and engage a multicultural undergraduate student population. Based on exit interviews, we identified at least four ways in which SIIP impacted the teaching and academic goals of the PhD students and postdocs. SIIP:

1. Created teaching experience for those interested in teaching at comprehensive colleges or for teaching introductory-level courses
2. Provided opportunity to fulfill outreach goals for Earth sciences
3. Provided experience teaching a multicultural student community and learning different pedagogical techniques
4. Allowed for graduate and postdoctoral students to evolve their teaching philosophy based on various levels of interest in the geological sciences

Based on responses from the follow-up interviews conducted with Stanford participants, we found that the students gained confidence in teaching and increased satisfaction with their PhD program or postdoctoral fellowship. "Being paired with an instructor who focused on teaching helped give me a lot more feedback specifically on teaching. I have taught and TA'ed before, but that was always on the side, but this experience was focusing on teaching and being in an institution that was not Stanford was really helpful for me. I've only been in Ivy League institutions, so this was a different type of student, so it was great to have a different kind of experience. It was really useful.'—PhD Student Instructor, Climate of Change module.

The program also allowed PhD students and postdocs to confirm or renew their interest in pursuing a career in a teaching-focused institution. A PhD student who taught at San Jose State University learned what constituted teaching an introductory course for a range of Earth sciences majors to non-majors. She reported teaching foundational concepts in tectonics as an invaluable experience. It gave her the opportunity to gain more teaching experience and also helped her consider being a professor in a liberal arts college or at other institutions where teaching is the predominant component of their work. It was a very different outcome for the PhD student who taught at Evergreen Valley College, for whom teaching the introductory course did not steer her path toward pursuing a career in teaching-focused institutions. Instead, as someone who loves research and is also committed to diversity outreach, the graduate student appreciated her SIIP experience for providing the opportunity to think further about how teaching can be valued in universities where the focus is primarily on research. Furthermore, a Stanford postdoc parlayed their positive SIIP experience at Evergreen Valley College into a faculty position.

The faculty mentorship was invaluable for Stanford PhD students and postdocs to plan and execute teaching plans for each session. "I think the [undergraduate] students enjoyed it, and I think they learned quite a bit and [Faculty mentor] seemed happy. I have a lot of criticisms for myself, but that's good. For example, I had never taught a multiple section course before, and I hadn't realized how hard it can be to keep things consistent among the classes. In one class, students asked about ocean acidification, so we talked about that. Then, in the second section, we talked more about drought and adaptation strategies. When I came back on Thursday, I tried to address both issues so both classes would get a taste – but I could see it would be a real challenge if I were testing them, to be sure I had covered exactly the same material. My classes would need to be more scripted, I think. Also, I am still learning how to pitch material at the right level and how to gauge how long an activity will take. [Faculty Member] was great about giving advice on that, and I really appreciated his help."—PhD Student Instructor, Climate of Change.

Stanford participants reported that the program helped them to fulfill their desire to engage in outreach in the Earth sciences and to share information on educational opportunities. One postdoc used his prior teaching and mentoring experience and his expertise in the marine sciences to plan an educational field trip to Santa Cruz. The postdoc used SIIP to relay opportunities at Stanford, including research and work opportunities in his lab and the Summer Undergraduate Research in Geoscience and Engineering (SURGE) program offered by the Stanford Earth Office of

Multicultural Affairs (OMA). Students approached him about these opportunities after class. “I’m really glad that I participated and got the opportunity to get outside the Stanford bubble,” he said, “especially since I don’t have a lot of opportunities to make an impact through teaching.” A PhD student who taught at San Jose City College also enjoyed incorporating experiences about being a researcher at Stanford and shared information about the SURGE program with interested students. In both of these cases, the SIIP instructors provided a sense of familiarity and encouraged students to examine opportunities within a research-intensive university.

SIIP also introduced PhD students and postdocs to a different teaching context from Stanford. Students at 2YC/MSIs had varying levels of academic preparation and engagement with the learning materials in the classroom. They also had a wide spread in age and professional backgrounds and aspirations. At Cañada College in Redwood City, the instructor—who taught the carbon cycle and environmental policy—was struck by the different levels of academic preparation and background found within a community college classroom. She found that these students balanced multiple priorities related to school, work and family, stating, “there’s a lot more real life going on and they are a lot more grounded in their own communities.” The different levels of academic preparation found in the classroom presented an opportunity for the instructor to re-calibrate teaching goals. She “learned how to not change expectations for the student but just to change the way that you teach the material.” One PhD student, who taught 8 h on Earth’s resources over the course of a week at Evergreen Valley College in San Jose, was challenged to teach to the different levels of the course. She first addressed foundational knowledge, assisting undergraduate students with reading graphs and the periodic table. She reported, “the biggest thing I learned is the different levels of preparedness--the first day was challenging but then it got better once you know what you needed to do.”

The new classroom context, in combination with InTeGrate resources, presented Stanford participants with the opportunity to develop their pedagogy and to reflect on teaching Earth sciences research for a multicultural undergraduate population. The majority of the PhD students and postdocs conveyed a newfound understanding of learning how to adapt materials and using various teaching tools to fit the needs of each classroom based on students’ age, major, preparation, and interest. The Latino postdoc who taught Natural Hazards at San Jose City College found that he shared an ethnic background with many of his students, who were also Latino. While his goal and focus were on teaching the science of hurricanes, he also succeeded in connecting the lesson with the students’ cultural heritage when explaining the origins of the word “hurricane” and how it stemmed from Mesoamerican mythology and the Maya word for god of storms, Hurakan. The Stanford participant at a similarly diverse institution in San Jose, Evergreen Valley College, reported changing her teaching philosophy and statement because of her SIIP experience. As a future professor interested in mentoring as much as research, she would like students to participate in the process of creating knowledge. “What I care about in teaching,” she says, “is giving students ownership over the knowledge, having them feel empowered to make decisions, and having them understand that true knowledge can be discovered.”

Strengthen Collaborative Associations with Local 2YC/MSIs

One pathway to improving URM recruitment in Stanford Earth is to strengthen collaborative associations with local 2YC/MSIs. We did this by pairing up Stanford PhD students and postdocs with faculty mentors at local 2YC/MSIs and arranging for these postgraduates to teach module material in their mentors' undergraduate course. Faculty host mentors enjoyed their time working with the Stanford participants whom they deemed well-prepared. They also enjoyed learning new material that they could incorporate into their classrooms.

Faculty mentors were interested in using InTeGrate module material to fulfill specific curriculum needs and thus had program instructors cover topics that were not regularly taught in their science classes. The material covered by module topics had not previously been taught, owing to a lack of familiarity with such topics or not having time to further develop their curriculum. Some topics that were added to course syllabi or were further explored by faculty due to SIIP include microbiology, remote sensing, and oceanography. Faculty reported that Stanford instructors not only filled gaps in the curriculum but also brought a new style of teaching and perspective into the classroom. They worked with faculty mentors on successful teaching strategies, such as teaching at the appropriate academic level and keeping undergraduates engaged during class. Follow-up meetings were held after each teaching session to review what was successful about the teaching experience and what could be improved.

Faculty mentors were satisfied with their participation in SIIP and listed the following benefits:

1. Fulfilling curriculum needs on Earth and environmental sciences topics that are not covered in class
2. Learning InTeGrate geoscience module activities, teaching techniques, and tools
3. Exposing undergraduate students to career path in Earth sciences, research, and academia
4. Inspiring undergraduates to consider universities such as Stanford or maintain their interest in STEM by seeing women and minority SIIP instructors
5. Increasing undergraduate literacy in Earth and environmental sciences, as evidenced by undergraduate student exit surveys

Even in institutions where there is an environmental science department and offerings on various Earth sciences topics, the Stanford postgraduates contributed to the curriculum and teaching goals in significant ways. An Evergreen Valley College faculty member commented, "I think that one of the strengths of the module material is the relevancy of it. The module material we covered was about El Nino and this was an El Nino year. It gave students the opportunity to ask things that had been on their mind about climate change and that they didn't understand. It really piqued their interest; they hadn't had this before. It is always good to have experts come in and talk about climate change. I am not an expert on this, so it was really helpful." Another noted, "In our department we don't have a lot of geology and earth systems."

According to the faculty, the PhD student who taught a week of his GIS class used materials from the InTeGrate Earth systems module and her own research to teach remote sensing. She helped set up the computer lab with the latest software and introduced students to Google Earth. "She contributed in pretty substantial ways… Remote sensing was new and the students loved it since it opened up the possibilities for careers." A SIIP postdoc instructor similarly brought in his own expertise in marine science and adapted the climate change module for an environmental science class. In addition to using the jigsaw exercise and teaching El Niño/La Niña, he helped design an ocean's sampling lab for the department. "He helped us figure out what equipment we needed to build a good lab." The participating faculty was not the only one to take notice of both of these instructors' initiative since other faculty and department chair were also interested in learning the new topics and teaching techniques introduced through SIIP.

Stanford PhD students and postdocs were role models and helped bring research to life in their classroom. Undergraduate students appreciated when Stanford instructors spoke about their own research, especially when women and/or minorities shared their path to pursuing science. Many participating faculty saw SIIP not only as an opportunity to bring in another instructor, but one who by virtue of being earlier in their career path, and a visitor, could connect with and open up to the classroom in a different way. One female PhD student was inspiring to the undergraduates, and they described her as a "rad woman scientist." Another PhD student reported: "They were really surprised to hear my story that I had an awful GPA in college and eventually ended up at Stanford." The San Jose City College participating faculty saw how the students connected with both of his SIIP instructors. "A lot of students wanted to talk to them after the class and learn about internships and Stanford" adding, "not only did they connect what they are doing to an average person's life, they also reinforced the idea that anyone can do it." An additional faculty commented, "Another positive aspect of the partnership is that community college students in general don't have a lot of contact with the universities like Stanford. Our students' goal is to transfer to San Jose State University, so to talk about Stanford is a different ballgame and it perks their interest. To have someone from Stanford to come into the classroom and treat the students with respect gives the students confidence."

Overall, by fulfilling curriculum needs and connecting with students through successful teaching moments, the SIIP instructors helped increase interest in Earth and environmental sciences. The most successful teaching moments in the program surfaced when the instructors connected the Earth science topic to a familiar or known community or to students' lives. A Stanford instructor at San Jose City College illustrated water supply and foot print by explaining the nearby San Joaquin Valley water supply (a region south of Silicon Valley). Similarly, when teaching Earth's resources in Evergreen Valley College, the Stanford instructor discussed the use of Earth's minerals in cosmetics and how it is important for students to be aware of what they are using.

While it remains undetermined if SIIP had a long-term influence on undergraduates pursuing academic and research paths in Earth sciences, immediate outcomes included increased interest in Earth sciences and a better understanding of Earth's current and future challenges. According to faculty from Foothill College, most of her students were not exploring new careers in the Earth sciences but in the health sciences. She noted that it was nonetheless beneficial for them to have an understanding of the environment and Earth sciences. "It's important for them to learn climate change" and how "as someone living California they can lessen its effects." They can incorporate this knowledge in their lives or in their respective careers.

Lessons Learned and Recommendations

SIIP was a new endeavor, and as such, there were important lessons learned, which we highlight here so that other programs seeking similar outcomes can appreciate elements critical for success.

Relationship Building as a Key Determinate of Effective Partnering

As was stated on the SIIP website (InTeGrate 2018b): "A key process in implementing the InTeGrate program at Stanford is establishing and building strong relationships with departments and faculty mentors from the different partnering institutions; with postdocs/grad students at Stanford; between postdocs/grad students and their faculty mentors; and between postdoc/grad students and the undergraduate students they teach. Key determinants of effective partnering include identifying a dedicated program director to initiate these relationships through in-person planning meetings, pedagogy training of postdocs and graduate students, and ensuring evaluation and feedback to measure student impact and postdoc/grad student/faculty learning and satisfaction. The feedback received at the end of each year provided an opportunity for participants to discuss aspects of the program that were particularly effective and ways in which we could improve the program."

Garner Faculty Support of PhD and Postdoctoral Student's Supervisor

One of the most delicate aspects of the program is the balance between spending enough time learning pedagogy and developing relationships between Stanford participants and their faculty mentor, without taking away too much time from participants' research schedule. In response, we made it clear to student's supervisors that their involvement in the program would be no more than 120 h. There were some students whose time conducting research was deemed too critical to allow participation in the program at that time.

Time Commitment of Host Faculty Member

While host faculty members at the partner institutions were incredibly interested and supportive of the program, there were concerns regarding their ability to dedicate the appropriate amount of time to mentor a Stanford PhD student or postdoc. They were also concerned with how they could best incorporate the InTeGrate module materials into their classroom. Finally, some faculty were unsure about the logistics of an external visiting lecturer teaching the course. It was important to communicate with faculty and also with those involved with staffing, the ways in which the program could adapt teaching material to incorporate it within content and timing constraints. In each case, fears were allayed by talking through module material with faculty, having them decide what material could complement classroom learning objectives, and then discussing what material it could replace and how much time could be made available for teaching module material. This varied from course to course and illustrated the flexibility of the program.

Updating/Modifying InTeGrate Module Material

As the module material was used, it became apparent that it needed to be modified to fit the subject matter and timing within the classroom. One faculty noted that the Climate of Change module and assignments were too theoretical in parts. A Stanford instructor recommended that modules should be updated regularly to reflect current research. Some instructors also expressed wanting more guidance on how much of the InTeGrate modules they needed to adapt and how much of their own research they could incorporate into their lesson. Each PhD student and postdoc handled the module material differently, making adaptations as appropriate to the course and to their own expertise.

Specific and Focused Program Evaluation and Data Collection

In all 3 years, SIIP instructors were asked to give their students the opportunity to fill out an evaluation sheet regarding their experiences with the SIIP instructor and InTeGrate modules. We found that clear communication with faculty, PhD students, and postdocs about the importance of the evaluations as a metric of measuring success was key, as the pre- and post-evaluations were not always distributed and a stack of completed evaluations was even lost once. Feedback from Years 1 and 2 prompted the discontinuation of the InTeGrate-wide pre- and post-knowledge and attitudinal assessments to a Year 3 evaluation that was more concise and more specific to addressing questions within SIIP. Based upon templates from Stanford University's Vice Provost for Teaching and Learning office, we devised three questions for undergraduate students to answer in an exit survey (see above section "Improved Integration of Geoscience into Courses at 2YC/MSIs").

Conclusion

SIIP program objectives were to increase exposure to geosciences for undergraduate students and to increase career satisfaction and retention for Stanford Earth PhD students and postdocs. Exit surveys capturing undergraduates' responses to module material indicate that the combination of having early career researchers from Stanford and using material that is relevant to their cultural and spatial context created a more engaging learning environment for undergraduate students. Faculty and Stanford PhD students and postdocs worked together to integrate the new learning material into the course syllabus, resulting in the possibility for longer-term impact on geoscience education. While it is not possible to evaluate the long-term impact, the opportunity to engage in teaching activities in 2YC/MSI was a valuable experience for all Stanford participants.

Inform Undergraduates About Geoscience Summer Programs and Other Undergraduate Programs at Research Universities

Teaching InTeGrate modules at 2YC/MSIs exposed students to opportunities for furthering their interest in geoscience. The SURGE program at Stanford Earth is tailored to broaden the diversity of future geosciences and engineers who pursue graduate studies as part of their career path. It was important that we utilize our time with the students to inform them of additional programs that may be of benefit to them. Now that the professors and students are knowledgeable about SURGE, Stanford Earth will continue to publicize these undergraduate research opportunities by sharing flyers and program information with the schools that participated in SIIP. Additionally, we plan to encourage professors to recommend specific students to the SURGE program. In this manner, the SIIP could also serve as a recruitment tool not only for our summer undergraduate research program, but also for Stanford Earth's graduate programs.

Develop MOUs with Host Institutions for Program Sustainability

In some cases, the relationship built between Stanford and the partner 2YC/MSI is based on the participation of one faculty member. This results in a vulnerable partnership in cases where the faculty changes teaching loads or is no longer able to participate in the SIIP. A memorandum of understanding (MOU) would institutionalize the partnership between Stanford and participating 2YC/MSI so that the partnership is not dependent on the just the faculty. An MOU would involve department heads in supporting the continuing partnership. Finally, establishing MOUs between Stanford and host institutions will hopefully not only sustain SIIP but also increase the number of courses and faculty and students involved between the schools.

Synergize Teaching Opportunities for PhD Students and Postdocs Across the Stanford Campus

As there are more students graduating with PhDs than faculty positions available nationwide, the need to provide teaching experience and opportunities to explore alternative pathways in academia becomes more apparent. This also meets the needs of those students who desire a teaching career. SIIP is not the only program at Stanford designed to create more varied teaching opportunities for students. Our Implementation Program activities spurred a meeting with the Stanford Vice Provost for Graduate Education (VPGE) office that brought together these collective programs on campus in an effort to determine how we can combine and institutionalize our efforts. An immediate outcome of SIIP was the incorporation of a Teaching for Diversity seminar into our training curriculum, which was taught through the Stanford Vice Provost for Teaching and Learning office. The next step will be to institutionalize a training program at Stanford across disciplines that offer teaching and pedagogy opportunities for PhD students and postdocs looking to develop their teaching portfolio.

Garner Institutional Programmatic, Financial, and Financial Management Support

SIIP was designed and executed through Stanford Earth OMA. It was critical for OMA to garner the operational and financial support of the Stanford Earth Dean's Office, along with the University Vice Provost for Graduate Education. It was critical to engage and communicate with grant management and financial units to familiarize them with utilization of a programmatic (non-research) grant. In our case, a senior academic staff administrator designed the program, wrote the subcontract grant application, and had majority input and control over the program. We recommend that such individuals are granted co-Principal Investigator status, making the managerial, programmatic, and financial responsibilities clear to all units involved. Having a staff member focused on this program allowed appropriate dedication of time and strategy building for implementation of this program, as it is non-research focused. In addition, the program required a part-time program manager focused on the daily activities, ensuring that the program ran smoothly and as designed. In our case this individual was a postdoc, enabling the scholar to gain experience in student outreach as desired for their academic career path.

Moving Diversity Up the Agenda in Earth and Environmental Sciences

Over the course of 3 years, seven academic institutions worked with Stanford to address the topics of increasing exposure to and interest in geosciences and advancing diversity in geosciences and geosciences education. "Overall, [Stanford] InTeGrate's model of encouraging PhD students and postdocs to teach at local 2YC/MSI institutions brings attention to the crucial role that young researchers who are beginning careers in academia and higher education have in shaping geosciences education. As young researchers, they are in key positions to identify and teach the geosciences topics that engage today's students and they will most likely have influence in bringing visibility to the topic of how shaping the future of the geosciences must take into consideration an increasingly diverse undergraduate student population" (InTeGrate 2018b). SIIP also, "helps to bring visibility to how the expansion and sustainability of geosciences education in our country must also take into consideration the changing demographics of the student population" (InTeGrate 2018b). We look forward to the implementation of even more programs that work with PhD students and postdocs (future faculty) to develop geosciences pedagogy that amplifies the recruitment and retention of URM undergraduates to the field of study.

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Appendix 1: Knowledge Survey Questions

1. Natural hazards can be put into two major categories. Some natural hazards can be made worse by humans; others are largely independent of human activities. Select the natural hazard least likely to be affected by human activity.
   (a) Forest fires
   (b) Tsunami
   (c) Landslides
   (d) Coastal erosion
2. Which of the following geologic processes are most likely caused by the interactions between the tectonic plates at their boundaries? Select all that apply.
   (a) Earthquakes
   (b) Continental glaciation
   (c) Floods
   (d) Volcanic eruptions
   (e) Mountains
3. Which of the following statements about the distribution of life in the oceans is most correct?
   (a) Life is more abundant and diverse in some parts of the ocean than in others.
   (b) Life is abundant and diverse throughout the ocean.
   (c) Life is less abundant and diverse in the oceans than it is on land.
4. Which of the following ways do humans affect oceans? Select all that apply.
   (a) Humans alter ocean ecosystems through fishing.
   (b) Humans alter shorelines through development.
   (c) Humans mine mid-ocean ridges.
   (d) Humans change overall ocean composition by desalination.
   (e) Humans alter tidal cycles.
5. Which of the following processes primarily involves the atmosphere and the biosphere?
   (a) The formation of limestone
   (b) The photosynthetic cycle
   (c) The hydrological cycle
6. Which of the following processes are sources of carbon to the atmosphere? Select all that apply.
   (a) Plant decay
   (b) Limestone formation
   (c) Cattle ranching
   (d) Fossil fuel use

7. There are several climate models used to research future change. Which climate modeling statement about twenty-first century temperature change projections is most accurate?
   (a) Climate model projections do not agree on future likely outcomes.
   (b) Climate model projections show similar trends for future outcomes.
   (c) Climate model projections show the same results for future outcomes.
8. The first reasonably accurate mercury thermometers were invented in 1724, almost 300 years ago. What kinds of processes and/or data are used by scientists to determine temperatures more than 10,000 years in the past? Select all that apply.
   (a) Written records
   (b) Ice cores
   (c) Tree rings
   (d) Sedimentary layers
   (e) Oxygen isotopes

Appendix 2: Pre-attitudinal Survey

1. What is your reason for taking this course? Check all that apply:
   (a) Personal interest.
   (b) General education or distribution requirement.
   (c) It counts toward my major.
   (d) I think it will be useful in my career.
   (e) Others (please explain).
2. Have you formally declared a major yet?
   (a) Yes
   (b) No
3. Please indicate whether you have or intend to declare a major in each of the following areas of study:
   (a) Arts
      i. Will not choose
      ii. Might choose
      iii. Will definitely or have chosen
   (b) Biology/life sciences/ecology
      i. Will not choose
      ii. Might choose
      iii. Will definitely or have chosen

(c) Business
   i. Will not choose
   ii. Might choose
   iii. Will definitely or have chosen
(d) Chemistry or physics
   i. Will not choose
   ii. Might choose
   iii. Will definitely or have chosen
(e) Economics
   i. Will not choose
   ii. Might choose
   iii. Will definitely or have chosen
(f) Education
   i. Will not choose
   ii. Might choose
   iii. Will definitely or have chosen
(g) Engineering or computer science
   i. Will not choose
   ii. Might choose
   iii. Will definitely or have chosen
(h) Environmental sciences/environmental studies
   i. Will not choose
   ii. Might choose
   iii. Will definitely or have chosen
(i) Geosciences (atmospheric sciences, meteorology, ocean sciences, geology, geophysics)
   i. Will not choose
   ii. Might choose
   iii. Will definitely or have chosen
(j) Humanities (English, foreign languages, history, philosophy)
   i. Will not choose
   ii. Might choose
   iii. Will definitely or have chosen
(k) Social sciences (psychology, sociology, anthropology, archeology, political science)
   i. Will not choose

    ii. Might choose
    iii. Will definitely or have chosen

  (l) A major that is not on the list (please specify)

4. How interested are you in the following professions?

   (a) Engineering

      i. Very interested
      ii. A little bit interested
      iii. Definitely *not* interested
      iv. Don't know enough to judge

   (b) Environmental consulting

      i. Very interested
      ii. A little bit interested
      iii. Definitely *not* interested
      iv. Don't know enough to judge

   (c) Environmental journalism

      i. Very interested
      ii. A little bit interested
      iii. Definitely *not* interested
      iv. Don't know enough to judge

   (d) Environmental law

      i. Very interested
      ii. A little bit interested
      iii. Definitely *not* interested
      iv. Don't know enough to judge

   (e) Government agency (e.g., NOAA, NASA, EPA, USGS)

      i. Very interested
      ii. A little bit interested
      iii. Definitely *not* interested
      iv. Don't know enough to judge

   (f) Health/medicine

      i. Very interested
      ii. A little bit interested
      iii. Definitely *not* interested
      iv. Don't know enough to judge

   (g) Hydrology or water resources

      i. Very interested
      ii. A little bit interested

   iii. Definitely *not* interested
   iv. Don't know enough to judge

(h) Land-use planning

   i. Very interested
   ii. A little bit interested
   iii. Definitely *not* interested
   iv. Don't know enough to judge

(i) Mining industry

   i. Very interested
   ii. A little bit interested
   iii. Definitely *not* interested
   iv. Don't know enough to judge

(j) Oil and gas industry

   i. Very interested
   ii. A little bit interested
   iii. Definitely *not* interested
   iv. Don't know enough to judge

(k) Professor in college or university

   i. Very interested
   ii. A little bit interested
   iii. Definitely *not* interested
   iv. Don't know enough to judge

(l) Public policy

   i. Very interested
   ii. A little bit interested
   iii. Definitely *not* interested
   iv. Don't know enough to judge

(m) Sustainability officer

   i. Very interested
   ii. A little bit interested
   iii. Definitely *not* interested
   iv. Don't know enough to judge

(n) Science teacher in primary or secondary school

   i. Very interested
   ii. A little bit interested
   iii. Definitely *not* interested
   iv. Don't know enough to judge

5. As you consider career directions after graduation, how important is it to you to do work in which you use your knowledge of the earth and environment? Please select one number: 1 (not important) 2 3 4 5 6 7 (very important)
6. As you consider employment after graduation, how important is it to you to work in an organization committed to environmentally sustainable practices (independent of the field)? Examples of environmentally sustainable practices would include minimizing energy and water use in the workplace. Please select one number: 1 (not important) 2 3 4 5 6 7 (very important)
7. Please indicate your level of concern about each of the following potential developments on the Earth. Focus on the impact on your region in your lifetime.

   (a) Global climate change

      i. Not a problem
      ii. Somewhat of a problem
      iii. Major problem

   (b) Population growth

      i. Not a problem
      ii. Somewhat of a problem
      iii. Major problem

   (c) Meteor impact

      i. Not a problem
      ii. Somewhat of a problem
      iii. Major problem

   (d) Loss of biodiversity

      i. Not a problem
      ii. Somewhat of a problem
      iii. Major problem

   (e) Energy resource limitations

      i. Not a problem
      ii. Somewhat of a problem
      iii. Major problem

   (f) Water resource limitations

      i. Not a problem
      ii. Somewhat of a problem
      iii. Major problem

   (g) Mineral resource limitations

      i. Not a problem
      ii. Somewhat of a problem
      iii. Major problem

8. Please indicate the extent to which you engaged in each of the following activities during the past week (mark all that apply):

   (a) Turned off the water while brushing teeth

      i. Not at all
      ii. Once per week
      iii. 2–3 times per week
      iv. Daily

   (b) Recycled paper, glass, or aluminum

      i. Not at all
      ii. Once per week
      iii. 2–3 times per week
      iv. Daily

   (c) Washed clothes in cold water

      i. Not at all
      ii. Once per week
      iii. 2–3 times per week
      iv. Daily

   (d) Unplugged appliances to eliminate "ghost" power use

      i. Not at all
      ii. Once per week
      iii. 2–3 times per week
      iv. Daily

   (e) Walked or biked instead of using a car

      i. Not at all
      ii. Once per week
      iii. 2–3 times per week
      iv. Daily

   (f) Turned off lights when leaving a room

      i. Not at all
      ii. Once per week
      iii. 2–3 times per week
      iv. Daily

   (g) Used public transportation instead of a car

      i. Not at all
      ii. Once per week
      iii. 2–3 times per week
      iv. Daily

(h) Used a "power saver" scheme for your computer

   i. Not at all
   ii. Once per week
   iii. 2–3 times per week
   iv. Daily

(i) Purchased locally grown food

   i. Not at all
   ii. Once per week
   iii. 2–3 times per week
   iv. Daily

(j) Brought a reusable bag to the store

   i. Not at all
   ii. Once per week
   iii. 2–3 times per week
   iv. Daily

(k) Talked to your friends and family about the ways that human action affect the environment

   i. Not at all
   ii. Once per week
   iii. 2–3 times per week
   iv. Daily

(l) Refrained from making a purchase in order to reduce impact on the environment

   i. Not at all
   ii. Once per week
   iii. 2–3 times per week
   iv. Daily

Appendix 3: Follow-Up Interview Questions for Stanford Participants

1. What did you feel were the strongest parts of the InTeGrate program at Stanford?
2. What aspect of the program can we improve?
3. Did you feel that you received enough support from the program director to facilitate your participation?
4. Did you feel that you received enough support from your faculty mentor to teach the module?
5. Did you feel like you had enough interaction with your faculty mentor?
6. How was your relationship with your faculty mentor?

7. Were you able to communicate well with your faculty mentor?
8. Were your expectations of the program met?
9. Were your expectations of your faculty mentor met?
10. Did the InTeGrate Agreement help make expectations of you as a participant clear?
11. Would you feel comfortable approaching your faculty mentor for a recommendation or for career advice?
12. Was the 2-day workshop in December useful in preparing you to teach the module?
13. How would you improve it?
14. What were the most useful aspects of the workshop?
15. Is there any part of the workshop that you would exclude?
16. Did you feel like the module material was well-prepared for use in the classroom?
17. Overall, how do you feel about your experience in the InTeGrate program at Stanford?
18. Would you recommend the program to other postdocs/grad students?
19. Do you feel like you achieved your objectives from the program?

Appendix 4: Follow-Up Survey with Stanford Participants

1. What module did you teach?
2. What units within the module did you teach?
3. Why did you choose these units?
4. Within each unit, which activities did you use?
5. Why did you choose these activities?
6. How much time did you spend in the classroom with students?
7. How much time did each of the activities/units take?
8. Which activities worked best with the students, and in what way did it work best?
9. Was there any material that was difficult to use or you would choose to modify?
10. In what way would you modify it?
11. If you were to do it again, how would you teach the module differently?

Appendix 5: Follow-Up Interview with Faculty Participants

1. Were you satisfied with the quality of teaching provided by the Stanford postdoc/grad student?
2. Were you satisfied with the quality of the material presented in the module?
3. What do you feel were the strong aspects of the program?

4. What do you feel could be improved in the program?
5. Did you feel like you were able to communicate effectively with your postdoc/grad student about what to expect from the students in the course?
6. Did you feel that the expectations of you as a faculty advisor were clear?
7. How would you characterize the relationship with the postdoc/grad student?
8. Would you recommend the InTeGrate program at Stanford to other faculty?
9. Are you interested in participating in the InTeGrate program again next year?
10. Why or why not?

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HBCUs Broadening Participation in Geosciences (A Journey Through InTeGrate)

Reginald S. Archer, Felicia Davis, Sue C. Ebanks, and Richard D. Schulterbrandt Gragg III

Abstract Historically black colleges and universities (HBCUs) play a unique role in addressing the low numbers of African Americans entering and persisting through undergraduate and graduate geoscience programs. In a strategic effort to increase HBCU participation in geoscience curriculum and faculty development opportunities, InTeGrate conducted targeted outreach to HBCU faculty to facilitate through the establishment of the HBCU Geosciences Working Group (GWG). The overarching goal of the HBCU GWG is to increase Earth Science literacy among Black students. The GWG successfully developed and executed three HBCU geoscience workshops for a growing network of educators and researchers at HBCUs. These workshops addressed (1) the gap between K-12 educators and Earth Science education, (2) culturally relevant pedagogy, and (3) environmental sustainability. The HBCU GWG advocates for culturally relevant content and the use of Pan-African pedagogy to significantly alter the current educational paradigm. This pedagogy directly benefits African-American students, the African diaspora, and the efforts to build a more diverse geoscience workforce. The HBCU GWG is leading the development of a critical mass of faculty and K-12 teachers prepared to serve as mentors and role models, working to increase early exposure to geosciences, making them more relevant to HBCU students, and connect underrepresented students to geoscience careers.

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Introduction

The American Geosciences Institute (AGI) forecasts a deficiency of approximately 135,000 geoscientists by 2020 (Sherman-Morris and McNeal 2016), when nearly 48% of the current workforce will be at or near retirement, indicating an urgent need in the geoscience workforce of the United States, and opportunities of future workforce demands necessitate innovative strategies for recruitment, retention, and graduation of an increasingly more diverse population (Wolfe and Riggs 2017; Gragg III et al. 2013). The convergence of a shortage of skilled geoscientists and growth in geoscience and related workforce sectors indicates a bright future for graduates in these fields in the coming decades (Gonzales and Keane 2010). However, the long-term challenge for the geosciences is recruitment and production of earth-literate professionals, yet the concern over workforce needs is often coupled with the persistent lack of diversity, geoscience literacy, participation and training at primary, secondary, and postsecondary levels in the science, technology, engineering, and mathematics (STEM) disciplines (Callahan et al. 2015). In an earlier review, Tsui (2007) provided a distilled list of 10 best practices of successful, documented intervention approaches to increasing minority participation in the STEM fields. Furthermore, in the Ocean Sciences, there is a growing body of literature addressing the growing demographic trend of underrepresented minorities (URM) (Gilligan et al. 2007). Most recently, these observations have been developed into a list of action items in the form of a charge to the Ocean Sciences community to take the necessary steps to reach, attract, and support URM to greater success in the geosciences (Gilligan and Ebanks 2016). These populations offer a talented pool of potential geoscience professionals equipped to work in traditional and nontraditional careers (Huntoon and Lane 2007).

While the number of African American STEM students has increased, the overall increase is relatively low compared with other racial and cultural groups in the country. This is especially evident for those students entering and persisting through undergraduate geoscience programs, which rank among the least ethnically diverse STEM fields (Kaba 2013; O'Connell et al. 2017; Sherman-Morris and McNeal 2016; Wolfe and Riggs 2017). In addition, demographic changes in academia, particularly in the faculty and administrative ranks, have been much slower than anticipated, highlighting the need for innovation in promoting retention and advancement at and beyond the student level (Whittaker and Montgomery 2014). Bernard and Cooperdock (2018) clearly indicate that, taken collectively, the previous 40 years of working on diversity in the geosciences has not resulted in remarkable improvement.

This problem of disproportionate underrepresentation of ethnic and racial minorities and women, especially in the geosciences, is linked to the deficits in both the number of educators and number of scholars able to develop and communicate this knowledge (O'Connell et al. 2017; Whittaker and Montgomery 2014). Sherman-Morris and McNeal (2016) revealed that fewer minority geoscience graduates leads to a reduced number of minority geoscientists available to serve as role models, decreasing exposure to science, and further exacerbating a leaky career pipeline. Lack of exposure and limited interest in science as a career choice in early years (K-12) narrows opportunities for recruitment (ACAD 2007). While early exposure is an issue at the pre-college levels, once in college, students who lack role models and mentors, hands-on research experiences, or even international experiences are less likely to be interested in majoring in STEM fields. Despite targeted efforts across funding agencies and educational organizations, many barriers limit the efforts to recruit talented URM college students to the geosciences and reduce the chances for success (Sherman-Morris and McNeal 2016).

Faculty play a major role in addressing this gap by being actively involved in connecting potential students and careers in the Earth Sciences, through recruitment, retention, and advancement of underrepresented minorities. However, low faculty representation and progression, as well as a shortage of senior role models and mentors to support success of students, exacerbate the problem. Fewer resources are allocated to support URM faculty in the early career phases, and less attention has been given to consideration of the specific roles of STEM faculty members in the day-to-day training of students (Johnson and Okoro 2016; Whittaker and Montgomery 2014).

Many programs achieve success at broadening participation at the local level, and in institution-specific approaches in the geosciences, which include curricular innovations or recruitment and retention strategies (Callahan et al. 2017; Wolfe and Riggs 2017). InTeGrate enables a systems approach to address factors associated with stimulating interest in the geosciences through faculty development and curriculum enhancement, including K-12 outreach and teacher preparation. The Manual of Best Practices for Recruiting and Retaining Underrepresented Groups in Ecology and the Environmental Sciences (ACAD 2007) recommended improving and extending partnerships, building relevant multi/interdisciplinary curricula and courses, and creating faculty development programs to build a critical mass of URM mentors and role models. In addition, faculty resources should support a network of peers and senior researchers as well as culturally relevant, hands-on education and research opportunities throughout a student's science education (Johnson and Okoro 2016).

Successful STEM intervention programs for underrepresented students integrate teaching, mentoring, and research activities at various academic levels and across institutions and networks. Research has shown that an integrated approach works effectively to maximize efforts to increase diversity (Tsui 2007; Whittaker and Montgomery 2014; Wolfe and Riggs 2017). It is also recommended that interventions do not treat geosciences as a single entity when informing students, at all educational levels, about pathways to geoscience careers (Huntoon and Lane 2007; Sherman-Morris and McNeal 2016).

The Center for Interdisciplinary Teaching of Geoscience for a Sustainable Future (InTeGrate), funded by National Science Foundation (NSF): Science, Technology, Engineering, and Mathematics Talent Expansion Program (STEP), supports the teaching of geoscience in the context of societal issues both within geoscience courses and across the undergraduate curriculum. One of the major goals of InTeGrate is to increase the number of majors in the geosciences and related fields, and also address the challenge of broadening participation by developing an understanding of the potential barriers, and characteristics of successful programs that help overcome these barriers.

Historically black colleges and universities (HBCUs) are uniquely situated to address the challenges of building a diverse geoscience workforce, as they are experienced in engaging underrepresented minority students in STEM disciplines and careers including geosciences. In an effort to increase the number of majors in the geosciences and related fields and address the challenge of broadening participation, InTeGrate facilitated connections of geoscience educators, at HBCUs, with resources to collaborate across academic levels and disciplines. This led to the development of the HBCU Geosciences Working Group (HBCU GWG), a community of practice that shares a passion for promoting geoscience literacy, education, and research among historically black colleges and universities and the communities they serve.

Since its founding at the 2015 Earth Educators' Rendezvous in Madison, Wisconsin, the HBCU GWG embarked on a multifaceted inclusion and diversity approach to the geosciences. The following three sections, HBCU pathways, HBCU geosciences working group, and HBCU geoscience workshop series, discuss three of those integrated approaches to connect educators and researchers at HBCUs and the communities they serve to geosciences, to promote the use of InTeGrate teaching modules at HBCUs, and to support the development of a diverse geoscience workforce.

HBCU Pathways

Midway into the InTeGrate project, HBCU participation was lacking, and InTeGrate Principal Investigator Cathy Manduca recruited Felicia Davis, sustainability coordinator at the Clark Atlanta University, to the InTeGrate leadership team, to enhance HBCU outreach and engagement. This has resulted in the participation of over 150 HBCU faculty to date and impacted over 1000 HBCU students directly and at least 1500 students indirectly. Since many HBCUs have an interdisciplinary approach to the geosciences and sustainability, STEM and social sciences faculty were invited to participate in InTeGrate-related activities, beginning with the Coastal Hazards, Risk, and Environmental Justice Workshop in May, 2015. Several themes emerged in the final workshop synthesis that also informed further HBCU InTeGrate engagement and the establishment of the HBCU Geosciences Working Group (InTeGrate 2015).

- There is a need for continued education of educators to help understand and teach about the connections among hazards, risk, and justice. Many educators steeped in single-disciplinary approaches are not well-equipped to help students understand transdisciplinary, socio-environmental issues, such as environmental hazards, which may result in disproportionate environmental, social, and economic impacts, based on ethnicity, gender, culture, and socioeconomic status.
- Environmental justice is a good lens for engaging all students and all disciplines in addressing environmental and resource issues. Including introducing the Earth to those who may not be as interested in STEM education.
- Educators should develop and deliver transdisciplinary content about the connections among hazards, risk, and justice and the multidisciplinary approaches to understand issues related to environmental hazards.
- Coastal Hazards, Risk, and Environmental Justice is a culturally relevant topic for transdisciplinary learning that connects science, policy, universities, and local communities to understand the relationship between natural conditions, human activities, risk, and resilience.
- Networking opportunities among minority serving institutions and between minority serving institutions and predominantly white institutions allowed sharing of effective practices, challenges, and opportunities to plan for collective action.

Following the Coastal Hazards Workshop, HBCU participants remained engaged. Claflin and Savannah State Universities each completed InTeGrate Implementation Projects (Kantor et al. 2017; Ebanks et al. 2017). Morehouse College and Florida Agricultural and Mechanical University (FAMU) also successfully developed and contributed to two InTeGrate course modules: Food as the Foundation for Healthy Communities (Gragg et al. 2017) and Lead in the Environment (Waggett et al. 2017).

With the addition of HBCU representation on the leadership team, InTeGrate was more successful in pairing HBCU faculty and researchers with resources to collaborate across academic levels and disciplines and to further increase STEM pathways and participation, specifically in the geosciences. HBCUs make up just 3% of America's colleges and universities yet graduate approximately 20% of all African American BS degrees, 25% in STEM fields (Lomax 2015). The importance of HBCUs in broadening participation is evident by the number of African American science and engineering doctorate recipients who also received their bachelor's degree from HBCUs (Fiegener and Proudfoot 2013; Upton and Tanenbaum 2014). "Black S&E doctorate recipients from U.S. universities complete their undergraduate degrees at many kinds of institutions. Nearly 30% earned a bachelor's degree from an HBCU, one of the most common types of baccalaureate institutions for black S&E doctorate recipients. HBCUs are especially important baccalaureate-origin institutions of black doctorate recipients in agricultural sciences; earth, atmospheric, and ocean sciences; mathematics; biological sciences; and physical sciences" (National Science Foundation 2017). Additionally, HBCUs graduate a significant number of Black teachers (US Department of Education 2016). Thus, this distinct community of higher-education institutions is uniquely situated to address the challenges and opportunities of building an inclusive and diverse geoscience workforce, developing and delivering culturally relevant pedagogy, preparing geoscience literate pre-service teachers, and engaging students in issues of economic, environmental, and social sustainability, all in a stable and nurturing environment.

HBCU Geosciences Working Group

In 2016, at University of Wisconsin, Madison, the second Annual Earth Educators' Rendezvous (EER) convened instructors, experienced STEM educators, researchers, and administrators to discuss new approaches to teaching and learning, opportunities to get involved in research programs, and academic career preparation. Felicia Davis and Richard Schulterbrandt Gragg led the founding and development of the HBCU Geosciences Working Group (GWG) to promote geosciences on HBCU campuses and in the communities that they serve. Eight collaborators representing seven different HBCUs attended the initial meeting and laid the foundation for a community of practice working to formulate effective strategies to broaden pathways and advance participation in the geosciences (see Fig. 1).

The HBCU GWG provides a familiar home for HBCU faculty within the broader InTeGrate community of practice network. Each faculty member/collaborator brings a unique perspective and set of challenges and opportunities. Collectively the group contributes to research and activities involved in recruiting, retaining, progressing, and graduating African American and other URM geoscientists. The GWG has been instrumental in reaching and engaging underrepresented faculty within the InTeGrate community.

With a shared mission to promote geoscience literacy, education, and research among HBCUs and the communities they serve, the GWG places the advancement of black students and relevancy to the African diaspora as priorities, driving participation in activities broadly designed to support strengthening geoscience pipelines. Since its founding in 2016, the HBCU GWG membership has grown to represent 24 institutions across 10 states (see Table 1).

Ongoing and intentional outreach has resulted in a significant increase in HBCU attendance and conference engagement, evidenced by the increased number of oral, workshop, and poster presentations by HBCU faculty in the third Annual Rendezvous, at the University of New Mexico, Albuquerque in 2017.

In the last 2 years plus the extension period of the InTeGrate project, two GWG member institutions: Claflin University (CU)—a private HBCU in Orangeburg, South Carolina and Savannah State University (SSU)—a public HBCU in Savannah, Georgia, were awarded Implementation Program (IP) sub-awards. In support of their campus sustainability initiative, Claflin implemented *CU InTeGrated*. They utilized the InTeGrate module entitled *Map Your Hazards*, for curricular and outreach integration, to improve regionally relevant Earth literacy among their students

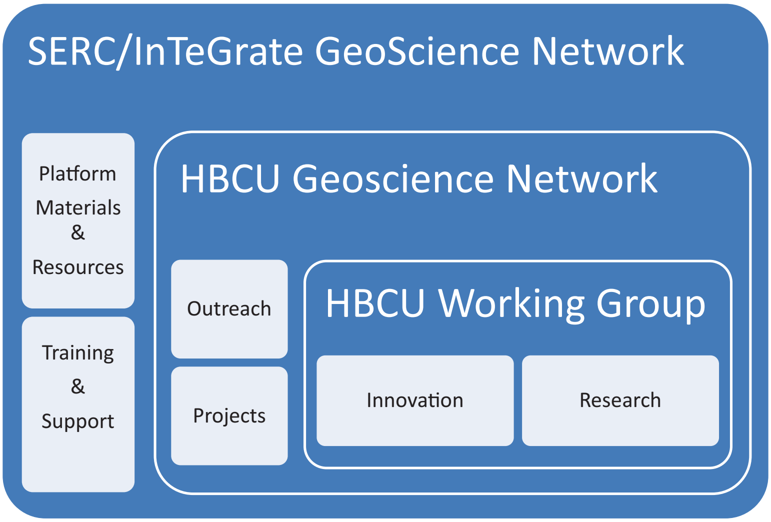

Fig. 1 Conceptual model of the nested working group linkages. External outreach and support resources include but are not limited to the National Association of Geoscience Teachers (NAGT), National Society of Black Engineers (NSBE), National Technical Association (NTA), National Association of Black Geoscientists (NABG), American Geophysical Union (AGU), and Association of American Geographers (AAG)

Table 1 HBCU Geosciences Working Group institutional members

States	Institutions
Alabama	Alabama Agricultural and Mechanical University; Oakwood College; Tuskegee University
District of Columbia	Howard University
Florida	Bethune Cookman University; Edward Waters College; Florida Agricultural and Mechanical University
Georgia	Clark Atlanta University; Claflin University; Fort Valley University; Morehouse College; Savannah State University; Spelman College
Maryland	Coppin State University; Morgan State University; University of Maryland Eastern
North Carolina	Elizabeth City State University; North Carolina Agricultural and Technical University
South Carolina	Claflin University
Tennessee	Tennessee State University
Texas	Texas Southern University
Virginia	Hampton University; Norfolk State University; Virginia State University

and surrounding community and to enhance and increase their, on- and off-campus, green policies and initiatives, as well as faculty capacity to incorporate learning about the Earth across the curriculum at Claflin University.

The Savannah State IP implemented *Collaborate to Heighten Awareness*, *Rejuvenate*, *and Train* (*CHART*ing). The SSU project established a certificate program in Coastal Hazards and Risks Management, improved the use of service-learning in InTeGrate modules, and developed the key partnerships necessary for a lasting impact beyond the InTeGrate sub-award. The service-learning definition is established by the National Academies of Sciences, Engineering, and Medicine (2017) *Service-Learning in Undergraduate Geosciences: Proceedings of a Workshop*. This definition, "projects planned as components of academic coursework in which students use knowledge and skills taught in the course to address real needs in their communities," served as the basis for the certificate program. SSU infused components of Coastal Hazards and Risk Management and other relevant modules into nine courses across Africana Studies, Environmental Science, Global Logistics & International Business, Homeland Security & Emergency Management, Marine Science, and Political Science. In addition, two new classes were designed and approved, increasing the potential impact on students at different levels of undergraduate study: COST 1140 Coastal Hazards & Environmental Risk and COST 4140K Environmental Justice & Coastal Risk Management.

Under the leadership of Sue Ebanks, GWG members Savannah State University, Tennessee State University, and Florida A&M University collaboratively developed and submitted the 2017 GeoPaths IMPACT: Expanding HBCU pathways for Geoscience Education to the National Science Foundation Improving Undergraduate STEM Education (I USE) Program. The application proposes to develop and deploy the HBCU Deep Dive Process that will deliver institution-specific assessments, outcomes, and recommendations for enhancing and/or building geoscience content and delivery capacities in pre-service teacher preparation programs and curricula. This assessment tool will be designed to systematically assess the pathways through which our institutions attract minority students to the geosciences and support them through graduation and entry into the workforce. Working collaboratively with at least five additional member institutions, comprising different characteristics (e.g., metropolitan campus, public/private, undergraduate only, undergraduate and graduate, etc.), the assessment tool will be tested for scalability. To address K-12 outreach and preparation, this process will also examine participant training of future and in-service teachers in the geosciences, with a particular focus on the middle grades because sixth grade is generally the first level at which students are exposed to the geosciences as per the Next Generation Science Standards. We anticipate that the Deep Dive development and deployment will reveal ways in which students can be better reached and served by expanding HBCU geoscience pathways from K-12 education to the workforce. Mintesinot Jiru, Coppin State University represented the GWG on the team led by Anne Eggers to align the contents of the InTeGrate teaching modules with the Next Generation Science Standards (NGSS). Lastly, Richard Schulterbrandt Gragg III is leading a collaborative InTeGrate/HBCU Research Team to test InTeGrate teaching modules in courses at their respective institutions. At the time of this publication, there are no results to report from this 2018 supplemental project.

HBCU Geoscience Workshop Series

In an effort to build a critical mass of mentors and role models, to address the lack of early exposure, and to make geosciences relevant to students, the GWG successfully developed and executed three geoscience workshops in 2017. The first workshop, entitled *Strengthening Geoscience Competency for HBCU Pre-Service Teachers*, convened at Tennessee State University to address the gap between K-12 educators and Earth Science education. The second workshop in the series, *Pan-African Approaches to Teaching Geoscience*, was hosted by Morehouse College and addressed culturally relevant pedagogy. The third workshop *Putting Sustainability into Action: New Strategies for Courses and Programs* was held at the Florida A&M University, and it focused on environmental sustainability (See Table 2).

The HBCU geoscience workshop series connected a network of university and community advocates, educators, and researchers. An immediate goal was to increase HBCU participation in the InTeGrate project and to support the teaching of geoscience in the context of societal issues both within geoscience courses and across the undergraduate curriculum with InTeGrate open access platform and materials. Each GWG workshop averaged 30 participants whom were encouraged and invited to become members of the HBCU Geosciences Working Group.

While many successful programs focus on student-centric factors (Wolfe and Riggs 2017), the HBCU GWG directed each workshop to specifically target educational, cultural, and institutional barriers, which have been identified as limiting factors in recruiting and graduating Earth Science literate URM into the geosciences workforce (Sherman-Morris and McNeal 2016). In considering new initiatives, Johnson and Okoro (2016) recommend supporting and expanding the number of young URM professionals, as well as professional programs aimed at early and mid-career scientists. Partnering HBCU faculty members and other stakeholders with the InTeGrate project encouraged relationship building and collaborations reinforcing the importance of Earth Science literacy and promoting effective strategies to increase diversity in STEM (ACAD 2007; Huntoon and Lane 2007; Pride and Olsen 2007; Serpa et al. 2007; Tsui 2007; Whittaker and Montgomery 2014). Mentoring supports professional success, increases the diversity of mentors and role models in the sciences, and increases retention (Huntoon and Lane 2007; Pride and Olsen 2007; Zaniewski and Reinholz 2016). The HBCU Workshop series extended the organized support network of the HBCU GWG to increase diversity and retention through development of relationships among geoscientists, educators, and students.

Table 2 HBCU geoscience workshop series

Name	Host	Location	Date	Conveners	Number of participants	Number of institutions represented	Potential # of students impacted per year
Strengthening geoscience competency for HBCU pre-service teachers	Tennessee State University	Nashville, TN	February 2–4, 2017	Reginald Archer, TSU; Mark Abolins, MTSU; James Ebert, SUNY Oneonta; Cathy Manduca, Carleton; David Padgett, TSU; Cheryl Young, Heritage	24	13	>2400
Pan-African approaches to teaching geoscience	Morehouse College	Atlanta, GA	March 23–25, 2017	Cynthia Hewitt, Morehouse; Barb Tewksbury, Hamilton	35	22	>3500
Putting sustainability into action: new strategies for courses and programs	Florida A&M University	Tallahassee, FL	October 26–28, 2017	Richard Schulterbrandt Gragg and John Warford, FAMU; Hannah Scherer, Virginia Tech; Gary Weissmann, UNM; Catherine Manduca, Carleton	27	9	>2700

Strengthening Geoscience Competency for HBCU Pre-Service Teachers

The Tennessee State University (TSU) hosted the first in the series of HBCU geoscience workshops, February 2–4, 2017. The workshop was open to multidisciplinary HBCU teams comprising at least two faculty members from both education and STEM departments who train pre-service teachers. Building on current practices and successful models from established programs, HBCU teams developed new methods and practices for infusing Earth Science topics in teacher preparation classes and enhance collaborations between Earth Science and teacher education programs. The workshop synthesis and summary of key ideas can be found on the InTeGrate website (InTeGrate 2017c).

Overview

Teaching about the Earth in a societal context broadens the interest and cultural relevance of the Earth sciences to all students. Nationwide, many K-12 science teachers lack an undergraduate geoscience or related degree and are teaching out-of-field (Pride and Olsen 2007). The critical need for teachers who are adept at science education, particularly extends to schools serving low-income and urban minority populations. Many HBCUs are located in proximity to these schools and educate a large share of public school teachers. Strengthening geoscience curricula and exposing HBCU pre-service teachers to Earth Science learning modules during the early stages of their college programs will improve their ability to cultivate Earth literacy among elementary and secondary school students (ACAD 2007; Johnson and Okoro 2016). Workshop discussions and activities focused on the challenges and opportunities of enhancing capacity and program curricula, using the InTeGrate open access platform and materials. The workshop culminated with a synthesis of the discussions and proposed program changes, as a resource to support others in the design and integration of Earth Science content in teacher preparation program curricula.

Goals

The goals included building a community of people involved in Earth Science and teacher preparation at the HBCUs, strengthening collaborations between STEM and education faculty, documentation of programs and strategies for preparing geoscience literate K-12 teachers, and exploring the use and adaptation of InTeGrate materials and processes to strengthen the role of Earth Science in teacher preparation at participant institutions.

Participant Feedback and Outcomes

The HBCU GWG and the InTeGrate modules and implementation program models can help infuse Earth education across the curriculum. The participants agreed that teacher preparation programs at HBCUs that address Earth Science need to be strengthened to increase the number of Earth literate people. Identifying some of the common challenges and strengths at many HBCUs and the role InTeGrate and the HBCU GWG could play provided insight in addressing these issues. Participants also found value in discussions around InTeGrate modules that have been implemented at different programs, and some plan to use them in the future. The InTeGrate teacher preparation resources can be used to increase Earth Science knowledge for the licensure exams. The attendees also stressed the importance of inviting dean level administrators to future workshops. Administrative buy-in of Geoscience recruitment and retention activities demonstrates institutional commitment to diversity and inclusion and action to advance accountability at all levels (Wolfe and Riggs 2017).

Actions were proposed that included talking across institutions, developing partnerships and collaborations and connecting other initiatives and programs, such as the Global Learning and Observations to Benefit the Environment (GLOBE) Program (https://www.globe.gov/). Additionally, the workshop encouraged promoting various pathways for students to become Earth Science literate, either through existing coursework or by assessing workforce education needs from current teachers who have degrees from a geoscience program. The HBCU GWG was empowered and looking forward to continue this workshop series with the next workshop at Morehouse College on Pan-African pedagogy and geosciences.

Pan-African Approaches to Teaching Geoscience

This, March 23–25, 2017, workshop was a joint effort of the InTeGrate HBCU GWG and the Morehouse College Faculty Development Pan-African Pedagogy Institute. The Morehouse program and activities focused on developing opportunities for students to learn geoscience in the context of culturally relevant questions, using Pan-African pedagogical approaches. Faculty from diverse disciplines were invited to attend. The workshop synthesis and Pan-African approaches for materials developed in association with the workshop can be found on the InTeGrate website (InTeGrate 2017a).

Overview

Africa holds a logical interest or fascination for Black students indoctrinated by the standard “from slavery to freedom” educational narrative. The Pan-African Geoscience Workshop focused on developing opportunities for students to learn geoscience in the context of culturally relevant questions using Pan-African pedagogical approaches. Africa is integrally linked to the United States through the impact of Africans in America and Africa as a source of minerals, other materials and intellectual resources. Geosciences provide a framework for the comprehension of humanity's evolution and interaction with the material world of earth, an important counterpart to the African consciousness of one-ness. Equally, the Pan-African approach includes a narrative of humans from their beginnings as homo-sapiens in Africa, providing a spiritual, intellectual, and social meaningfulness and relevance upon which to ground study of sustainable ecological one-ness. Successful strategies to recruit and retain African American students include making sure that geosciences are relevant (Huntoon and Lane 2007).

The Pan-African pedagogical strategy strives to incorporate a broad and inclusive sampling of African history, context, and culture, including unearthing and making visible and clear the link of contemporary knowledge to roots in Africa. It is the method and practice of teaching any and all subjects, or areas of knowledge, based on the full history of people and Africa, which we share as branches of a common root. The workshop participants were encouraged to explore ways to deeply connect African American students to learning about the Earth by framing instruction around important questions in Pan-African studies. Johnson and Okoro (2016) emphasize that culturally relevant programming is missing for minorities, along with mentorship from senior colleagues who are from similar backgrounds. Good Pan-African pedagogy for geoscience instruction relies on instructors who strive to be culturally relevant and create lessons that begin with students' experiences, which are discussed and infused in the learning, so that students have the opportunity to learn by building on their personal background and academic strengths. Some potential intersections and questions explored at the workshop focused on: the geologic record and African roots of modern humans; understanding people, migration and relationships to geological processes; iron and metallurgy—origins, and innovation today; natural resource scarcity and international relations, culture and sustainability; human causes and natural processes of desertification and reforestation of the Sahel; culture, conflict, and geology; and the geography of gold—local and global ecological challenges and social impacts.

Goals

The goals of this workshop were to facilitate the exploration of the intersections between geoscience and the important, societally relevant questions that frame current teaching in Pan-African studies; define characteristics of Pan-African pedagogy; and develop a rubric for evaluating culturally relevant modules and course materials that support Pan-African geoscience teaching.

Outcomes

Participants posted a geoscience teaching activity or syllabus along with a brief essay to the workshop space on the InTeGrate platform, that other participants were invited to read prior to the workshop. The essays addressed approaches that participants developed and tried, or would like to try, such as African geoscience issues and examples that lend themselves teaching Geoscience concepts, and the nature of Pan-African (culturally relevant) pedagogy. Common themes emerged from the workshop, regarding the role of Pan-African pedagogy in the establishment of virtues and the values of geoscientists, including the ongoing practice of bringing awareness to the links between these concepts and the experiences and practice of preparing geoscience students with life supporting skills for incorporation into society.

This workshop culminated with the sharing of the ten core Pan-African Principles of Family, Oneness, Soul, Balance, Rhythm, African Humanism, Sankofa, Matrism, Maroon, and Know Thy Self each tied to fundamental aspects of identity. Pan-African Pedagogy may be understood as using these 10 specific culturally relevant principles to motivate, increase mutual understanding, and enrich learning. Next steps include assessing whether instructional plans include a comprehensive Pan-Africa approach to geoscience literacy, and if there is a need for more interaction with Pan-African youth as products of a neo-indigenous reality.

Putting Sustainability into Action: New Strategies for Courses and Programs

Sustainability has emerged as a central theme for teaching about the environment. Whether it is from the perspective of science, economics, or society, sustainability is of high interest to students, including those who are traditionally underrepresented in the geosciences (Gragg III et al. 2013). The workshop was hosted at Florida A&M University, October 26–28, 2017. The workshop summary can be found on the InTeGrate website (InTeGrate 2017b).

Overview

This workshop focused on strategies for infusing sustainability content into curricula, especially at HBCUs. Attendees, representing the natural and social sciences; geosciences; education; engineering; and arts and humanities, participated in presentations and dialogue on experiences, expectations, and outcomes and the approach to incorporate and strengthen sustainability in courses and programs. In advance of the workshop, all participants contributed a relevant teaching activity, course syllabus, or program description that formed the foundation for discussion and exchange. Using these examples, participants identified and discussed common strategies for putting sustainability into action. Over the course of the workshop, multidisciplinary working groups of faculty, administrators, and sustainability officers developed culturally responsive methods and practices for putting environmental and social sustainability into action and strengthening courses and programs at their institutions.

Goals

The goals of this workshop comprised identifying existing programs that integrate geoscience and sustainability, the strengths and weaknesses of various program designs, and the challenges and opportunities that they address, especially on HBCU campuses. In addition, the workshop involved developing strategies to incorporate workshop resources and/or principles into courses and to support the design of interdisciplinary teaching activities that address infusing social and environmental sustainability into the curriculum.

Outcomes

This workshop design brought together multidisciplinary teams of at least two or three members, comprised of faculty, sustainability coordinators, and one community member, with interest in teaching sustainability in their courses or administering sustainability projects in their programs or activities at their institutions. Participants explored culturally responsive teaching methods and practices from HBCU programs and curricula, as well as from InTeGrate modules. Emphasis was placed on activities that enriched thoughts and attitudes and inspired action in the context of environmental sustainability. Proven examples and models provided participants with approaches for incorporating sustainability concepts into their courses and programs to better prepare students to solve current and emerging challenges and increase effective community engagement. Follow-up actions were proposed, such as promotion of geoscience courses/program offerings available to students and faculty in teacher education programs, requesting funding from legislature to help address science teacher shortages, and providing enhanced experiential learning related to environmental sustainability. Moreover, participants would focus on developing interdisciplinary programs, workshops, and webinars integrating STEM and environmental sustainability (Clark and Gragg III 2011).

HBCU Geosciences Working Group Broader Impacts and Future Implications

The HBCU GWG in collaboration with InTeGrate is committed to promoting culturally relevant geoscience curricula, increasing the number of underrepresented students entering the geoscience workforce and broadly increasing Earth Science literacy among HBCUs and the communities they serve. Initial connections between InTeGrate and HBCU educators launched multifaceted approaches and pathways to achieving inclusion and diversity in the geosciences. Three approach strategies, HBCU pathways, HBCU geosciences working group, and the HBCU geoscience workshop series, were effectively implemented, highlighting the opportunities for broadening participation in the geosciences through ongoing transdisciplinary emphasis and activities on HBCU pre-service teacher education programs and faculty, culturally relevant pedagogy, and social, economic, and environmental sustainability. One of the common themes emerging from each of the workshops was to explore ways to impact campus administration and leadership. Some examples include hosting undergraduate leadership conferences and campus-based listening sessions and encouraging deans to invest in interdisciplinary teaching and address challenges and opportunities associated with teaching across disciplines. There is also a need to develop networks with school superintendents to strengthen the bridge for in-service K-12 teachers to further our potential to build an Earth Science literate workforce. The GWG and the InTeGrate community of practice network have mutually benefited from collaborative participation, and the GWG has developed into an influential vehicle for broadening participation and advancing the geosciences among HBCUs and the communities they serve. The HBCU GWG is fostering important and new collaborations including an emerging relationship with the National Science Foundation Geosciences Directorate.

The HBCU GWG remains an advocate for culturally relevant content and Pan-African pedagogy, to significantly alter the current educational paradigm, benefitting African American students directly, the African diaspora more broadly, and contributing to a more diverse geoscience workforce. GWG members have developed and submitted joint proposals and articles for publication, following up on themes explored in workshops, conferences, meetings, and trainings. At the time of this writing, some members of the HBCU GWG are conducting a supplemental research project to investigate the impact of teaching InTeGrate geoscience modules on HBCU students and faculty. At the invitation of Ambrose Jearld, Jr., PhD, President of the National Technical Association (NTA), the HBCU GWG has participated in two previous workshops and will formally co-host its third geoscience workshop at the NTA 90th Annual Conference: *Full STEAM Ahead* in September 26–28, 2018, in Norfolk, Virginia. The National Technical Association (http://ntawebmaster28.wpengine.com/) is the oldest African American technical organization in the United States. Founded in 1925 the NTA was created to encourage and inspire women, minorities, and youth to enter and excel in the fields of math, science, and technology.

The HBCU GWG is committed to increasing participation of underrepresented groups in geosciences, eliminating performance gaps, particularly among African American students, and creating inclusive institutional environments. Through InTeGrate, the HBCU GWG continues to be engaged in planning of and participation in the Earth Educators' Rendezvous, future events, and activities. John Warford is a member of the Rendezvous planning committee, and Richard Schulterbrandt Gragg has joined the InTeGrate leadership team. This HBCU geoscience community of practice network was facilitated through Carleton College Science Education Research Center's InTeGrate Project, and collaborations and professional development toward increasing pathways and broadening participation in geosciences continue to grow.

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