JOURNAL OF GEOSCIENCE EDUCATION **64**, 259–269 (2016)

Engaging Undergraduates in Soil Sustainability Decision-Making Through an InTeGrate Module

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ABSTRACT

Continued agricultural productivity hinges on understanding how to manage soil resources. A 2-week undergraduate introductory-level module: *A Growing Concern: Sustaining Soil Resources Through Local Decision Making* was collaboratively developed through the InTeGrate Project. InTeGrate modules and courses engage students in grand challenges of sustainability (e.g., agriculture, water, and climate) using active learning strategies. In *A Growing Concern,* students examine physical and chemical distinctions between intensively managed agricultural landscapes (e.g., conventional tillage) and natural vegetative types. They analyze geospatial and soil profile data to identify how intensive land management threatens soil sustainability. After exploring land practice and climate impacts on soil, they create extension-style fact sheets that provide recommended practices to reduce soil erosion. To maximize accessibility, we piloted the module in three settings: (1) an interdisciplinary Ecological Agriculture course at a Land Grant Institution, (2) a Geology of the Critical Zone course at a 4- y college, and (3) an Introduction to Environmental Science course at a 2- y community college. Classroom observations using the reformed teaching observation protocol revealed that the instructors used reformed teaching practices. Students also commented favorably on the hands-on nature of the module within focus group sessions. All students passed the culminating fact sheet, which was aligned with the rubric used in module development. Students had some difficulty interpreting site-specific geologic data and applying systems thinking. Revisions to instructional materials emphasized local data and greater systems diagramming. © *2016 National Association of Geoscience Teachers*. [DOI: 10.5408/15-106.1]

Key words: undergraduate, InTeGrate, soil, climate change

INTRODUCTION

More than one-third of Earth's land is covered with crops that support food, fiber, and fuel needs (Hooke et al., 2012). Globally, agricultural intensification has generated erosion rates that exceed geologic rates of erosion by more than eight orders of magnitude (Hooke, 2000). Not only is soil destroyed faster than it is created (Montgomery, 2007), but the physical and chemical properties of the soil have been altered dramatically by conventional agricultural practices (e.g., Linn and Doran, 1984; Bayer et al., 2006). Intensification with attention to soil conservation may be the only long-term solution, with limited land area available for agricultural expansion (Ramankutty and Rhemtulla, 2012). Climate change exacerbates soil erosion via increased flooding or loss of biomass in response to drought (Nearing et al., 2004). We must develop adaptation strategies for sustainable agriculture, especially at local scales (Rosenzweig et al., 2007). Addressing soil sustainability into the future calls for educating students about the "skin of the earth" that supports us (Montgomery, 2007).

To educate and inspire the next generation to address issues of agricultural sustainability, agricultural curriculum is needed outside of traditional agricultural programs (NRC, 2009). A recent survey of programs in the United States reveals that this trend is well under way and that more total geology, geography, and environmental science programs include soils content than there are total soil science programs (Brevik, 2009). Robust undergraduate soils curriculum should incorporate central habits of soils professionals, including fieldwork, communication, jargon, systems thinking, authentic problems, and making connections by revisiting concepts in new situations (Field et al., 2011). To achieve this, we developed *A Growing Concern: Sustaining Soil Resources Through Local Decision Making* through the InTeGrate Project (Fortner et al., 2015). This module includes six 50-min units for independent or sequential implementation. Only the culminating unit requires that students synthesize knowledge from previous units to generate an agricultural extension-style fact sheet. Our goal is to describe the pilot of *A Growing Concern* and evidence for its impact on student learning and engagement. This features details about the 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 *A Growing Concern*.

MODULE DESCRIPTION

A Growing Concern and other modules and courses developed through the InTeGrate Project provide students with opportunities to explore the nexus between geosciences and sustainability (O'Connell et al., 2016). Modules were designed by authors from three institutional settings, with the goal of expanding accessibility to students (Egger et al., 2013); the authors of this paper developed *A Growing Concern*. Modules are aligned with measurable learning

Received 23 June 2015; revised 11 March 2016 and 23 July 2016; accepted 20 August 2016; published online 02 November 2016.

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goals. Specifically, the *A Growing Concern* module supports mastery of two learning goals:

- Students will use geologic data to develop a plan for sustainable soil management in one or more agricultural settings.
- Students will predict, using systems thinking, agricultural challenges that might result from climate change.

Guiding principles for all InTeGrate modules and courses include addressing a geoscience-related grand challenge to sustainability (e.g., soil erosion and climate change), engaging students in interdisciplinary thinking, incorporating the methods and habits of geoscientists, analysis of credible geoscience data, and incorporating systems thinking. These elements are detailed fully in the materials development and refinement rubric available online (InTeGrate Project, 2015). Topics, unit learning goals, and activities during the pilot are summarized in Table I; the entire module, including all instructor and student resources needed for implementation, is freely available online (Fortner et al., 2015). Throughout the module pilot, students explored the differences between intensively managed agricultural landscapes (e.g., grazelands and conventional tillage) and forested or natural vegetative types. Unit 1, for example, highlighted landscape differences between physiographic regions in agricultural and nonagricultural settings. Students examined landscape photos and records and reflected on observations. Unit 2 engaged students in the direct exploration of soil properties, including porosity and permeability. Experimental results informed their ideas for behavior in agricultural settings. Units 3 and 4 helped students develop an understanding of the spatial distribution of soil erosion associated with land use and soil properties with depth. Students worked with spatial figures and soil profile data, respectively, and considered implications for soil sustainability. Unit 5 engaged students in a jigsaw activity exploring factors that drive erosion, including climate change. Mixed pedagogical approaches provided students with opportunities to explore soil and implications for agricultural sustainability from distinct angles. During the pilot, units were completed sequentially. But they may also be completed independently to achieve unit-level learning outcomes.

Student mastery of all units was measured through a summative assessment project in Unit 6. In this culminating unit, students were situated in the role of agricultural manager. After viewing examples of effective and ineffective fact sheets from multiple environmental agencies, students synthesized lessons learned from previous units to produce an agricultural fact sheet. Fact sheets required the following: an argument for the significance of soil sustainability, a description of links between land management practices and erosivity, the predicted impacts of climate change on erosion rates, recommendations to minimize erosion, a call to action, and a description of the feasibility of recommendations for farmers. Format expectations included a 2-page limit, a balance of text and whitespace, an awareness of audience, and attention to grammar. These content and format expectations appear in the rubric handed out with the assignment and include exemplary, basic, and nonperformance categories. The fact sheet rubric used during the pilot was similar to the final version in the published module (Fortner et al., 2015), with minor modifications described in the discussion.

PILOT SETTING

The pilot of *A Growing Concern* occurred at each of our respective institutions. Our classes were small (<16 students), with a total of 40 students in all three courses. The InTeGrate Project collected demographic information through an external server not associated with the pilot schools (Egger et al., 2013; Kastens et al., 2014; McConnell et al., 2014). In total, 35 students responded to the demographic survey, but responding students did not always answer all questions. Survey responses have been reported in aggregate to respect confidentiality concerns associated with small numbers at each institution. Of 35 students, 11 were taking a required course, and 21 reporting students were in their third or fourth year of college. Students were mostly female ($n = 22$), with eight reporting males.

At Santa Rosa Junior College, a 2-y college, Murphy piloted the module in Introduction to Environmental Science (ENVS12), a general education science course. The course introduced environmental issues from a scientific perspective, focusing on physical, chemical, and biologic processes within the Earth system; the interaction between humans and these processes; and the role of science in finding sustainable solutions. The course served primarily nonscience majors, and labs were not a required component. Soils and climate change were part of the curricula for this course, and the module replaced direct instruction on these topics in the lecture portion of the course.

At Wittenberg University, a 4-y liberal arts program, Fortner piloted the module in an introductory course, Geology of the Critical Zone (Geol 170). The students in this course were all declared nonscience majors completing general education requirements with the exception of one undeclared student who subsequently declared a geology major. The Geology of the Critical Zone course seeks to have students understand how changes in anthropogenic, tectonic, and climate conditions force critical zone responses observed in soil, water, and biogeochemical response (e.g., see ideas from Brantley et al., 2007). The module was linked to the impact of two of these forcings (anthropogenic and climate) on agricultural sustainability and the role of tectonic forcing in soil production and erosion rates.

At Virginia Tech, a land grant research institution, Scherer piloted the module in the intermediate-level Ecological Agriculture course, which was required for an interdisciplinary minor in Civic Agriculture and Food Systems within a college of agriculture and life sciences. The course examined the ecologic foundations of sustainable agriculture practice and surveyed the principles of ecology and evolutionary biology in the context of civic agriculture and food systems. It also included an overview of both historic and modern sustainable agriculture practices. Students in this course typically do not have strong science backgrounds, and this module provided them the opportunity to work with real-world data and learn concepts that provide support for sustainable agriculture practices. It also incorporated geoscience concepts into a course that currently focuses on biology content.

METHODS

Our pilot was part of the larger InTeGrate project. The broad scope of the entire project evaluation is not described here. Rather, this study details the evaluation of *A Growing Concern* as it relates to understanding student outcomes associated with this introductory-level module. A detailed explanation for each method used to evaluate the impact of the module on students follows.

Review of the *A Growing Concern* Summative Assessment and Student Work

Two members of the InTeGrate Project assessment team (subsequently referred to as the materials reviewers), who were not involved in module development, examined the module summative assessment (i.e., the fact sheet assignment) and student work completed during the pilot. Both the assessment and the student work were scored for alignment with *A Growing Concern* module learning goals and InTeGrate guiding principles (i.e., addresses a grand challenge, addresses interdisciplinary problem, incorporates methods and habits of geoscientists, includes analyses of authentic data, and incorporates systems thinking). Each element (two module learning goals and five InTeGrate guiding principles) was rated on a rubric with a scale of 0–3. A score of 3 meant the element was explicitly and/or pervasively addressed by students, a 2 meant it was addressed in most of the materials, a 1 meant it was somewhat addressed, and a 0 meant the element was not addressed. Using this rubric, the materials reviewers separately rated the strength of the summative assessment assignment (Unit 6 materials provided to students) and actual student work. All fact sheets completed during the pilot were reviewed; these included individual or small-team submissions, depending on instructor preference. In our Results section, scores from reviewers are presented as averages as they were reported to the module authors and their feedback is summarized. In addition to reporting reviewer scores and feedback, we include examples from student work that illustrate the concepts discussed in the feedback and the percentage of student responses for which this concept was true. To determine these percentages, we systematically coded each fact sheet for evidence of this concept (i.e., present or absent).

Student Performance on Fact Sheet Assignment

In addition to the review of the fact sheets for alignment with the overall module and InTeGrate goals described earlier, student submissions of the fact sheet ($n = 31$) were graded. These summative assessment grades were determined by the individual instructors using the grading rubric that is included in Unit 6 of *A Growing Concern*. This rubric assesses student mastery of specific content and formatting expectations for the fact sheet as explained in the assignment. The grade range for these summative assessments across the three pilot settings and medians for each pilot setting are reported.

Module Author Reflections on Pilot

Module authors submitted a required postpilot reflection following teaching *A Growing Concern* in their class. We individually reflected on what went well, considered what was challenging, and determined strengths and weaknesses of the materials from our perspective as instructors. After submission of our reflections, we compared individual postpilot reflections to determine areas of agreement. We focus our description here on these shared impressions that contributed to decisions about final revisions of the module.

Classroom Observations and Student Feedback

During the *A Growing Concern* pilot, members of the InTeGrate Project who were not involved in module development observed two of our courses. During these multiple-day site visits, classroom observations of Units 2, 3, 5, and 6 were conducted using an InTeGrate observation protocol and the reformed teaching observation protocol (RTOP) (McConnell et al., 2014), with the goal of providing feedback to the module authors. The RTOP measures evidence for reformed teaching, as indicated by student construction of knowledge in class (Sawada et al., 2002). The RTOP is a tool used to evaluate reformed classroom dynamics using a rubric (0, never occurred, to 4, very descriptive) to collect data on five subscales: lesson design and implementation, propositional knowledge (what the teacher knows and presents), procedural knowledge (what the students do), student–student interaction, and student–faculty interaction (Budd et al., 2013). This tool has helped establish the relation between reformed teaching practices and student learning (Falconer et al., 2001; Budd et al., 2010). RTOP analysis yields a number between 0 and 100, with three categories of instruction: teacher centered (scores < 30), transitional, and student centered (scores ≥ 50) (Budd et al., 2013). RTOP scores (when collected) and written observer feedback were reported to the module authors.

Observers also conducted focus groups, which allow for solicitation of opinions in a social setting in which participants can hear and respond to the ideas expressed by others (Patton, 2002). Members of the InTeGrate Project conducted focus groups with students who participated in the pilot of the module in two courses. They lasted approximately 30 min and involved around five students each. One focus group was conducted following the pilot of Units 2 and 3, and the second followed the pilot of Units 5 and 6. Questions solicited student opinions of the strengths and weaknesses of the units as they experienced them in the classroom. Feedback was provided to the module developers in narrative form with no identifying information to protect the confidentiality of individual students. The limitations of both the RTOP and the focus group interviews in this study are their short temporal duration (i.e., a single class).

Assessment of Interdisciplinary Problem Solving

During the last week of class, students from two pilot classes ($n = 22$) responded to an interdisciplinary thinking essay prompt: "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." Student responses were coded for the challenges described (e.g., water, soil, and climate) by members of the InTeGrate Project for the entire InTeGrate cohort (e.g., this module and other modules developed in the same time frame) ($n = 180$). We examined student responses in our

TABLE I: Overview of units piloted in *A Growing Concern,* including learning goals and key activities for each of the six units (modified from Fortner et al., 2015).

Unit	Learning Goals	Key Activities
Unit 1: Impacts of Land Use	1. Use objective language to discuss and record the physical features of various landscapes presented in photographs. 2. Use their observations to compare and contrast agricultural with nonagricultural landscapes. 3. Discuss how components of Earth's systems (e.g., slope, rainfall, climate, soil type) can impact agricultural landscapes and soil sustainability.	• Identified physiographic regions from an image of the United States from space. • Made independent observations of both agricultural and natural landscapes in photographs, discussed these observations, and then interpreted impacts of agriculture on landscape. • Diagramed relevant systems interaction–associated images.
Unit 2: Soil Characteristics and Their Relationship to Land Use Practices	1. Describe the soil properties of porosity and permeability. 2. Characterize the porosity and permeability of a soil sample. 3. Interpret and assess the effects of land use practices on the porosity, permeability, and erosivity of the soil. 4. Make recommendations for sustainable agricultural practices in a hypothetical scenario.	• Completed a hands-on activity exploring soil properties of porosity and permeability of soil samples representative of both agricultural and natural environments. • Used experimental results to compare and contrast soils from varying environments while modeling the role of a soil assessment expert.
Unit 3: Exploring Natural and Agricultural Erosion Rates	1. Interpret data from geospatial figures, and analyze erosion rates. 2. Discuss the influence of agricultural erosion on soil sustainability. 3. Confront preconceived ideas, reframe these ideas given new data, and reflect on that process.	• Examined and discussed perceptions of erosion from images of mountain and agricultural landscapes. • Used geospatial figures to compare erosion rates associated with natural and agricultural landscapes in the United States (involves converting units). • Reflected on the negative implications of agricultural erosion on soil sustainability.
Unit 4: Using SoilWeb to Investigate the Soil Beneath You	1. Use the SoilWeb smartphone app or website to identify the most common soil in their area and sketch its soil profile (California Soil Resource Lab, 2015). 2. Explain how the physical and chemical properties of soil relate to soil horizons. 3. Identify which soil horizon is most important to fertility and how that fertility is affected by erosion.	• Retrieved soil information for the soil beneath the students using SoilWeb. • Using retrieved information, drew soil horizons and percent soil organic matter to scale, and discussed implications for the depth of soil fertility. • Completed a jigsaw activity comparing local soil erosion rates, soil horizons, and soil organic matter to other sites. • Discussed how the speed of implementing soil solutions impacts society and the economy.
Unit 5: Predicting the Effects of Climate Change on Soil Loss	1. Explain how rainfall and runoff erosivity, soil properties, landscape characteristics, and agricultural practices contribute to soil erosion. 2. Differentiate between natural and human influences on soil sustainability. 3. Analyze, using systems thinking, how changes in precipitation predicted in climate change models for their region will impact erosion rates.	• Completed a jigsaw activity exploring factors that drive erosion (i.e., revised universal soil loss equation variables). • Participated in a kinesthetic activity about influences on soil sustainability. • Watched a short video on climate change and agriculture. • Engaged in a guided lecture introducing systems diagrams and impacts of climate change on soil sustainability in their local region.
Unit 6: Creating an Agricultural Fact Sheet	1. Synthesize information about soil erosion, climate, management practices, and sustainability. 2. Make recommendations for agricultural practices that can minimize erosion and address feasibility of these actions from the perspectives of key stakeholders. 3. Use evidence to show what actions are needed to mitigate soil erosion, thereby increasing sustainability of soils. 4. Apply the characteristics of good science communication to the public by creating user-friendly fact sheets.	• Reviewed criteria for the summative fact sheet assignment. • Recalled what was learned in Units 1–5 that aligns with criteria for the summative fact sheet in a brain dump activity. • Shared brain dump with small groups. • Discussed both good and bad fact sheets examples and reflected on audience. • Crafted audience-friendly fact sheets that synthesize evidence about soil sustainability, climate change, and relevant management solutions.

TABLE II: Average scores of the alignment of the summative fact sheet assignment and student work with module learning goals and InTeGrate guiding principles. Possible scores range from 0 to 3; full alignment is equal to a 3. Scores of 2 and above reflect substantial alignment. Two external evaluators conducted scoring.

	Fact Sheet Assignment	Student Work
Module Learning Goals		
Degree to which assessment reflects ability to use geologic data to develop a plan for sustainable soil management in one or more agricultural settings	2.5	2
Degree to which assessment reflects ability to predict agricultural challenges that might result from climate change using systems thinking	2.5	2
InTeGrate Guiding Principles		
Degree to which assessment reflects competence explaining one or more geoscience-related grand challenges facing society	3	3
Degree to which assessment reflects ability to address interdisciplinary problems	2.5	2.5
Degree to which assessment reflects the nature and methods of geoscience and developing geoscientific habits of mind	2.5	2
Degree to which assessment reflects use of authentic and credible geoscience data to learn central concepts in the context of geoscience methods of inquiry	3	2
Degree to which assessment reflects ability to incorporate systems thinking	2.5	1.5

pilot courses for further evidence of alignment with topics considered within the module.

RESULTS

Review of the *A Growing Concern* Summative Assessment and Student Work

The results of the InTeGrate assessment team members' review of the module summative assessment (fact sheet) assignment and associated student work for alignment with module and InTeGrate goals are presented in Table II. Fact sheet assignment materials (what the students were asked to do) received scores of 2.5 or higher out of 3 on all components of the rubric, suggesting that the materials were highly aligned with the InTeGrate materials development and refinement rubric and module learning goals. When describing how well the fact sheet addresses module learning goal 1 (i.e., using geologic data to develop a management plan), reviewers noted "the 'fact sheet' provides opportunities for students to 'use geologic data' if students focus on interpreting data for their region." Similarly, in their feedback describing the alignment of the final fact sheet with Learning Goal 2, they stated that overall, "this was a great assignment because it asks students to predict what will happen in their region by using regional climate data, climate change predictions, data on soils," etc.

Materials reviewers determined that fact sheet materials mostly incorporated InTeGrate guiding principles. Both reviewers described fact sheet prompts as explicitly referencing grand challenges of climate and soil sustainability and making interdisciplinary connections. Each of these criteria received a 3 in the materials review. However, both reviewers felt that fact sheet materials could better emphasize the nature and methods of science. This category received a 2, and reviewers described the fact sheet as focusing more on analyses than other methodology, stating that the materials "do emphasize that students should be interpreting data for the region in which they live" but that other connections among analyses could be made more explicit. They reiterated this point in their evaluation of the InTeGrate Guiding Principle of authentic data. Finally, the fact sheet assignment received a 2.5 for addressing systems thinking, because it largely addressed this criterion by asking students to specifically address three or more variables affecting soil sustainability.

Materials reviewers scored student performance on fact sheets related to the module learning goals and InTeGrate guiding principles between 1.5 and 3. Student attainment of Module Learning Goals 1 and 2 received scores of 2. Learning Goal 1 emphasized the use of data, which students needed to incorporate to describe local soils. Materials reviewers noted that students often used generic geologic data, rather than site-specific data important to management decisions. To illustrate, one submission described a generic soil profile as follows: "The most fertile layers of soil are the top layers, O Horizon and A Horizon. Once these layers are eroded, harder, less fertile, clay-like soils then become the immediate topsoil." Another said, "Soil removed by erosion contains about 3 times more nutrients and 1.5 to 5 times more organic matter than the soil that remains behind." Only three fact sheets (10%) incorporated local soil data from the SoilWeb exercise. For learning goal 2 (i.e., using systems thinking to predict challenges to soil erosion resulting from climate change), materials reviewers suggested that students tended to cut and paste information on soil and climate change from multiple sources that may or may not be locally relevant. For example, multiple fact sheets included images of soil erosion that were not tailored to the location their fact sheet considered. Three examples included maps with climate or soil information of large areas that were described generally, rather than highlighting a region of interest. Another included a graph showing change in global average temperatures through time, which was beyond the scope of a regional evaluation. Despite these limitations, all fact sheets contained at least some place-specific information, including images of crops grown in the region. This is important because module learning goals implicitly consider place as a framework for evaluating soil data and climate trends for management decisions.

Materials reviewers provided detailed feedback discussing alignment of student materials with overarching InTeGrate guiding principles. Reviewers commented that all students addressed one or more grand challenges (e.g., soil, climate, and water) in their fact sheet assignment. Of these grand challenges, they were most able to discuss the limitations of natural resources (soil). For example, one fact sheet summarized, "The quality of our soil is degrading at an alarming rate because of the use of the role humans play. The use and abuse of our croplands has left our future to be undesirable." It went on to identify additional causes of soil loss associated with human activity. Another stated that "soil sustainability is much more important than people think and it has an effect on a larger group of people than most think. Soil erosion is a very real event that is affecting more and more landowners and if the proper precautions aren't taken to slow it down it can be very detrimental."

Materials reviewers also assigned student work an average score of 2.5 on the InTeGrate principle of addressing interdisciplinary problems. Among fact sheet assignment submissions, 90% discussed at least two of the three spheres of sustainability. Comments from the reviewer who assigned a 3 noted that the best examples were able to make links between scientific, economic, and political issues. The reviewer who assigned a 2 said that although the fact sheets contained interdisciplinary topics, many students didn't truly consider the feasibility of their recommendations from the stakeholder perspective. When discussing feasibility, one example stated, "A deeper rooting system will also be important to combating climate change.... If plants are in place with deep root systems to help soak up the moisture, less rain wouldn't be a problem. The lessened rate of rain will also help the erosion rate to decrease. When these deep rooting plants are harvested, their roots will help to break up the soil and make tilling for the next growing system easier. This would help the soil sustainability or, the maintenance of soil productivity for future generations." This example and several other examples don't reflect on what management strategies might mean for the farmers using them in terms of cost or barriers to implement.

Materials reviewers scored the student attainment of an understanding of the nature and methods of geoscience as a 2 (mostly addressed). They noted that students explicitly made comparisons between agricultural practices that reflected an integrated understanding of soil decision making. All fact sheets included descriptions of the causes of soil erosion and the importance of sustaining soil. Students described key practices needed to sustain soil, e.g., "Crop cover can include numerous different practices. One way to use crop cover to eliminate the erosion is by planting seasonal crops, like soybeans, earlier in the spring so when the rain season begins there is less erosion (Nearing et al., 2004)." However, a reviewer wrote, "student work focuses largely on spatial and temporal comparisons, but less so on other methods," reiterating an earlier point about how scale was central to meeting our learning goals, and hence, a key habit.

Both materials reviewers noted that materials clearly called for the analysis of authentic and credible geoscience data to learn central concepts in the context of inquiry. But they rated student work as a 2, saying "students were given latitude" in terms of the data they brought into their fact sheet. For example, only 40% of fact sheets included climate change forecasts specific to the region the fact sheet was targeting. However, two-thirds of the fact sheets described solutions that were specific to the region, and all examples correctly identified soil erosion responses associated with specific climate conditions.

The lowest student work score, 1.5, was for the incorporation of systems thinking skills. One reviewer reported that this criterion was somewhat addressed, and the other determined that it was mostly addressed. One wrote, "Half of the submissions include 3 or more causally linked variables that explain soil erosion." For example, one fact sheet stated: "rainfall in many highly productive areas like the Midwestern US is predicted to decrease due to climate change. Although less rainfall means less water washing away soil, less moisture compromises soil integrity and decreases crop yields, decreasing the ability to absorb water [and] increasing erosion rates." Another said, "Less rain and hotter temperatures generally means there will be a drought. Dry soils allow soil to be held together less tightly. In this case, a major factor will be wind erosion." Yet neither the fact sheet assignment nor the student work included systems language like flux, reservoir, or feedback.

Student Performance on Fact Sheet Assignment

Summative assessment grades for fact sheets submitted in all three pilots ($n = 31$) ranged from 60% to 98% of the points available. Two pilot sites had the students complete the fact sheet assignment individually; median scores at these sites were 81% and 80%. The third site had students complete the fact sheet in groups of three or four, because this was consistent with other major assignments in the course; the median score at this site was 90%.

Module Author Reflections on Pilot

After completing our module pilot, we collectively identified strengths and weaknesses from our individual postpilot reflections (Table III). Throughout the module, we observed evidence of students building from foundational practices, like observation, into hands-on exploration of soil and authentic data. Overall, we felt that students successfully worked through the module and were able to address soil science within the context of agricultural sustainability. We agreed that students performed well on the summative fact sheet assignment and felt that their work aligned with our module learning goals and InTeGrate guiding principles. We also felt that students completed most activities successfully and made connections between units. On a unit-by-unit basis, we were happy that central learning goals and all listed strengths that tie back to those goals were met.

Some weaknesses stood out to us. We all noticed the difference between the workflow of the module and our normal teaching style. We all chose either prework or homework in our normal workflow, and moving between both was new to us. We felt that this might also challenge other instructors and identified a need organize the delivery of prework and homework exercises upfront. We all noticed places where students struggled with technical language that could easily be clarified in revision. Independent of the materials review by InTeGrate team members, we determined that fact sheets would have been more successful if

TABLE III: Summary of primary strengths and weaknesses of the pilot module from faculty postpilot reflection.

Element	Strengths	Weaknesses
Unit 1	• Inclusion of foundational scientific practices (observation and interpretation) • Systems thinking introduced in homework	• Take-home exercise on Earth systems vague and confusing
Unit 2	• Hands-on exploration of soil properties • Student designed investigations and predictions	• Activity extended beyond 50 min • Students struggled to connect soil properties to land management practices
Unit 3	• Discussion promoted among all students • Preconceptions confronted students by (metacognition)	• Students struggled with unit conversions, which extended instructional time
Unit 4	• Examination of authentic, local soil data	• Students challenged with drawing to scale • Resources lacked level of detail necessary for student success
Unit 5	• Modeling of complex processes • Practice with systems thinking • Substantial student interactions or discussions	• Technical level of background reading challenging • Systems thinking not emphasized • Low student engagement with prescriptive worksheets
Module overall	• Soil science addressed in the context of agricultural sustainability • Promotion of reformed teaching practices • Promotion of scaffolding • Alignment with InTeGrate guiding principles	• Clarity and consistency of learning goals • Workflow tracking • Not personally relevant to all students

we better related systems thinking activities to climate change and erosion response and if we better emphasized the use and interpretation of local data throughout the module.

Classroom Observations and Focus Group-Identified Strengths and Weaknesses

Classroom observation records and focus group results from the pilot of module Units 2 and 3 (Class 1) and Units 5 and 6 (Class 2) were provided to the module authors. RTOP scores were reported for two of the four observation periods and were 68 and 59 for Units 2 and 3, respectively. These both are in the student-centered range of Budd et al. (2013). Observers reported that all four units promoted student-initiated discussions and questions. The observer for Class 1 said that during the pilot of Unit 2, students generated a general definition and effectively synthesized information from previous classes. Similarly, the observer for Class 2 noted that students relied on knowledge from earlier work to improve their knowledge or synthesis of new material. During the Class 1 pilot, the observer noted that students altered their experimental design to explore various properties of soil permeability and porosity. This observer also said that students were involved in "discussion to make predictions, observations, or estimations." This included students describing how humans and climate can impact erosion. Observations from classes also highlight strengths across units, with observer feedback noting that "both units are designed to effective (sic) foster active student participation in the transmission and discussion of material," "This activity fostered good group discussion," and the activity provided "opportunities for students to take charge of the discussion and to shift the focus of the lecture."

Similarly in the focus group interviews conducted in both classes at the end of the observation period, students generally said that they were learning content and appreciated having some flexibility to pursue open-ended inquiry. Student focus group feedback is summarized in Table IV. A student also commented on the complexity of the topic of climate change, exhibiting higher-order thinking as that student sought clarity. Several organizational and delivery issues were also described by students in focus group interviews. A few students expressed confusion over assignment workflow and wanted to have greater clarification of expectations. Worksheets may have been part of the confusion because they varied in delivery timing (prework, in-class, and homework). Several students also felt that worksheets could be reduced or better organized. The observer also suggested that during module revision, expectations could be clarified by providing learning goals for each unit up front using a standard format for each unit. During the Class 1 focus group, several students commented that it had been awhile since they had taken math, and one

TABLE IV: Summary of student perceptions of strengths and weaknesses of the module determined from student focus group feedback. 2,3 = focus group following teaching of Units 2 and 3. 5,6 = focus group following teaching of Units 5 and 6.

Strengths
Interactivity/hands on (2,3; 5,6)
Learned content (2,3; 5,6)
Open-ended inquiry (5,6)
Quantifying the complex process of erosion (5,6)
Weaknesses
Ambiguity of learning objectives (2,3; 5,6)
Unclear about structure (2,3)
Unprepared for math (2,3)
Lack of personal relevance (2,3)
Fast pace/overwhelmed (5,6)
Prescriptive worksheets (5,6)
Lack of concrete solutions (5,6)

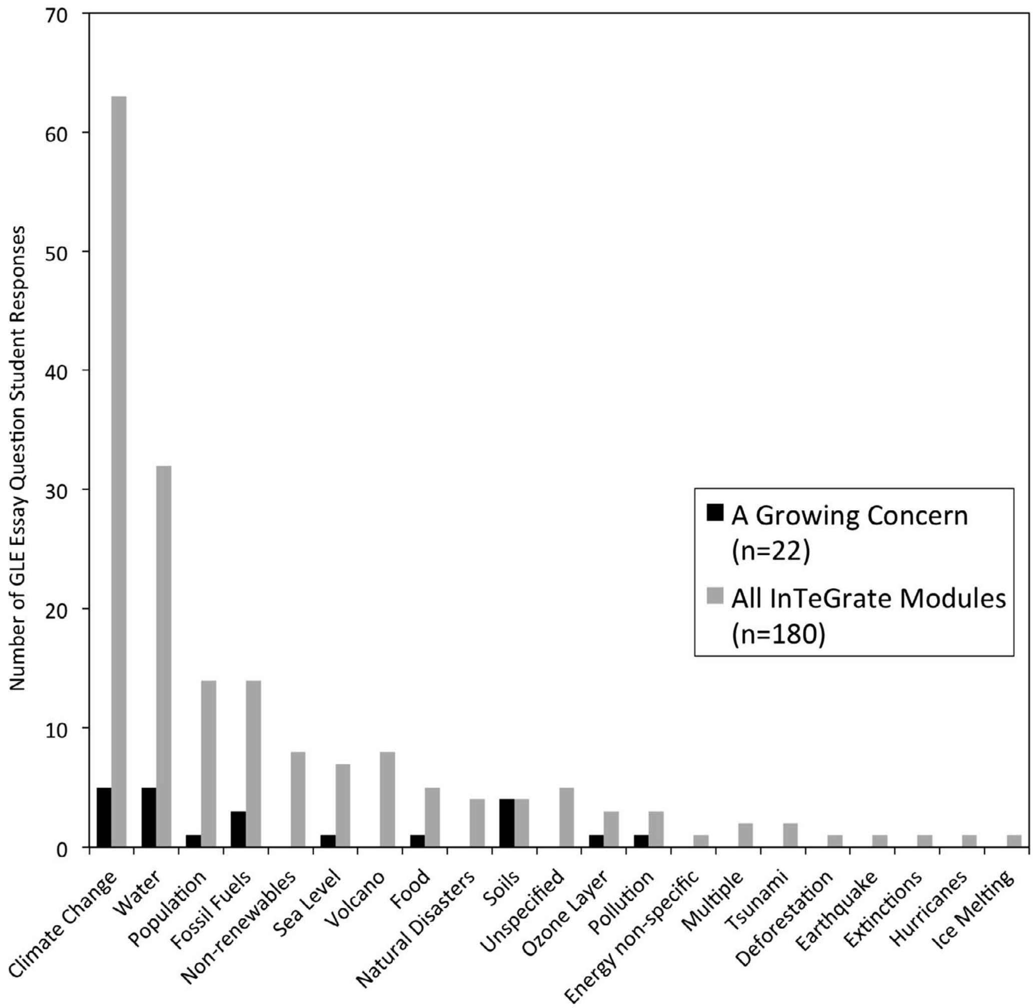

FIGURE 1: Student choice of "global challenge" topics for interdisciplinary geoscience literacy exam essay question student responses. When compared with responses for across InTeGrate modules during their pilot, only students who participated in *A Growing Concern* identified soils as a central topic.

stated that they were "stumbling blindly" with erosion rate conversions and calculations. The observer suggested providing students with additional practice time or a cheat sheet. Another student commented that they would be more interested in learning about their hometown than about the town their college was in. The observer suggested including additional societal connections to increase relevance.

Postcourse Interdisciplinary Essay

As a final assessment of knowledge and scientific thinking skills gained from InTeGrate modules, students across the project completed a postcourse interdisciplinary problem-solving essay. They were charged to "Identify and describe a global challenge that society will likely face in the next 50 years." Essay topics for the entire InTeGrate cohort are compared with those for students completing the *A Growing Concern* module in two of the pilot classes are presented in Fig. 1. Students completing our module were the only students who included soil sustainability in their response ($n = 4$). This was the second most frequent response. Our students most frequently discussed climate change ($n = 5$) and water ($n = 5$). Climate was also central to the *A Growing Concern* module. In addition to the topical alignment of student responses to their participation in our module, we highlight other areas of alignment. One student wrote: "A global challenge we will face in the next 50 years is soil sustainability. Soil is responsible for feeding the global population and the threats to soil sustainability make the outlook grim. Erosion and nutrient loss are a big factor in failing soil sustainability." These concepts came directly from *A Growing Concern*. Several students considered agricultural sustainability but moved away from content considered in the module. One noted that soil sustainability challenges "will effectively crash our global economy if the political rulers do not make funding for farmers more readily available and benefits for using organic farming measures." Another stated: "Our soil affects so many different aspects of life and life cycles, such as farming, carbon cycle, and wildlife management." Another student connected the relationship between the soil and the phosphorus cycle, writing, "Two components of the Earth System that interact with one another include soil and the phosphorus cycle. The way we treat our soil could prevent the phosphorus cycle from flowing, which can affect soils and animals involved in the cycle. These systems interact on a daily basis."

One student accurately wrote that a grand challenge "is the amount of land that is eroding at fast rates due to human interaction" but incorrectly speculated that "the largest of these interactions is grazing." However, this inference may be derived from incorrectly linking unit topics (e.g., Unit 2 involved building a model for soil compaction, and subsequent units explored the spatial extent of erosion and the factors driving erosion rates). The author of this response exhibited a complex systems understanding of the responses to grazing, noting that "grazing leads to compacted soil, which can lead to flooding." Other answers showed similar understanding of systems interactions and topical intersections (e.g., climate and agriculture) that are derived directly from material present within the module.

DISCUSSION

Module Success and Refinement

Student summative fact sheets and interdisciplinary essay responses exhibit central elements of the rubric used to create pilot materials. Materials reviewers emphasized that the fact sheet assignment was largely aligned with central learning goals and InTeGrate guiding principles, and scoring supports this. In addition, all students passed the fact sheet assignment, and median scores of 80% or higher across courses suggest substantive mastery is possible in varied class settings. Furthermore, many student responses to the interdisciplinary essay were aligned with the focus of the module. Topically, more than one-third of the reporting students focused on soil or climate. Furthermore, many incorporated ideas directly from the module or connected knowledge attained in the module with other knowledge from their experiences. Even an essay response that incorrectly linked module ideas showed knowledge of systems thinking. This evidence suggests that the *A Growing Concern* module was successful at meeting intended learning outcomes. In addition, observations and focus group sessions highlight that the module successfully engaged students in student-centered soil exploration.

Revisions made from pilot to publication on the InTeGrate website (Fortner et al., 2015) addressed shortfalls observed in the module summative assignment and critiques made during observation periods and in focus group interviews. The following described revisions passed the final rubric review by InTeGrate Project members and an external soils content expert before publication. The impact of these revisions on student learning will eventually be considered as part of project-wide evaluation across additional implementation settings.

Published units have a similar emphasis to those described in Table I, but some revisions were made to reduce weaknesses. While only a few edits were made to Unit 1 to address areas of student confusion in worksheet materials, we separated the last learning goal into two new learning goals to better align with separate activities. New learning goals focus on inferring how agricultural practices impact landscapes and soil sustainability and explaining the interaction of Earth's spheres within the context of agricultural systems. No changes were made to learning goals in Units 2 or 3, but the porosity and permeability activity in Unit 2 was revised to emphasize connections with land management. As part of the activity worksheet, students must now reflect on how compaction associated with tillage might impact soil porosity and permeability. In addition, instructional tips were added to Unit 3 to encourage practice with rate calculations through *The Math You Need When You Need It* (Wenner and Baer, 2015). The last two learning goals were revised in Unit 4. They now state, "Explain how a chemical property of soil, percent soil organic matter, is distributed with depth" and "Compare local erosion rates, soil horizons, and percent soil organic matter with other sites and estimate differences in sustainability" (Fortner et al., 2015). Unit 4 activities and associated materials now emphasize comparing local soil conditions with other sites. We shifted revised materials away from having students examine several soil properties; instead, they now examine soil organic carbon in more detail. The greater local emphasis and comparison with other sites give students opportunities to examine sites of their choice. Local sites are included because research suggests that place-based investigations improve student understanding of the role of science in problem solving (Surpless et al., 2014).

Learning goals for Units 5 remain the same, but activities and associated materials were edited to better set up the systems thinking skills that specifically link climate to soil response. In the revised unit, students diagram the impacts of climate change on soil response instead of spending the bulk of their time focusing on erosion variables. This revision directly addresses student confusion over technical language and prescriptive worksheets noted in the focus group interview. It also addresses the need to better connect climate conditions to soil response noticed by the fact sheet materials reviewers. Actively diagramming systems is associated with improved learning beyond narrative instruction alone (Wheat, 2010). The student who said they would rather think about their hometown than campus might benefit from allowing this option.

While learning goals for Unit 6 remained the same, the final fact sheet rubric and associated chunking activity (i.e., students recall lessons from previous units needed in the fact sheet) were revised to better instruct students in areas of weaker performance. Original rubric categories were retained, but new elements better articulate the scope of authentic data that students were expected to use. New elements include describing the physiographic region and describing local soil properties. The climate-related rubric element is now separated into two categories, one that asks students to describe the impact of climate on precipitation and another that that asks them to predict how changes in precipitation impacts erosion rates in their region. To solidify both personal relevance and systems thinking, we added a reflection assignment after completion of the final fact sheet assignment. Students are asked to reflect on their knowledge of soil sustainability and identify aspects of the module that were challenging or interesting to them. They reflect on gained systems thinking skills: "How did I use systems thinking to understand impacts on soil sustainability?" Finally, minor edits related to providing workflow support and adopting standard learning goal language were made before publication in response to the student focus group concerns and our struggles during the pilot. Students are now able to track prework and homework expectations in a single document outlining all activities and the inclusion of student material pages. Tracking is now a standard feature of published InTeGrate modules. Clear expectations such as these are associated with improved student learning outcomes (Kuh et al., 2011).

Recommendations for Adaptation and Adoption

Even though this study is limited to our pilot results, high-quality fact sheets suggest that adaptations of *A Growing Concern* and other InTeGrate materials should consider retaining alignment with the InTeGrate materials design and development rubric. The perspectives of professionals solving sustainability challenges are complex, and curriculum needs to incorporate that complexity (McKeown, 2011). Our module delves into the complexity of soil management throughout units by engaging students in different approaches to soil sustainability and by asking them to provide solutions in their final fact sheet assignment. This approach was used in a similar fashion by Balgopol et al. (2014); they engaged students in the complexity of agroecologic management by having students participating in a solution-oriented case designed to have each small team present evidence and perspectives from a single stakeholder and then work across teams to identify a consensus land management decision. A comparison of pre- and postresponses to an essay on land management decisions showed significant gains in their ability to describe systems and complexity (Balgopal et al., 2014). Using the interdisciplinary essay before a course begins, as well as after, might help instructors attain rapid insight into the learning gains of their students.

Finally, we noticed the influence of the emphasis of our specific courses on how students engaged with the module. Water-related content was embedded in multiple learning activities included in all three pilot courses. Two courses included water-themed active learning units, and the third included an invited guest lecturer. Not surprisingly, our students emphasized water in their interdisciplinary essay responses. Some of the language from fact sheets and essays may relate to instructor emphasis. For example, Fortner described taking students on a field trip to a nearby organic farm, with this emphasis retained in some fact sheets and essay responses. Instructor stories that contain unique aspects of implementation are available as part of all InTeGrate modules. A link to these stories appears on the landing page for each module. We each intentionally designed our course to fit the module we implemented. Exploring fit may be useful to others considering implementing or adopting modules.

Acknowledgments

This work is supported by a National Science Foundation collaboration between the Directorates for Education and Human Resources and Geosciences under grant DUE-1125331. We appreciate the support we received from all involved in the creation and review of *A Growing Concern,* including Barbara Bekken, Stuart Birnbaum, LeAnna Chapman, David McConnell, Ellen Iverson, Molly Kent, Michael Pelch, and Mary Sevina, and to the anonymous reviewers of this manuscript who greatly improved its focus. Thanks also to Cathy Manduca for her vision.

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