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How Does Adding an Emphasis on Socioscientific Issues Influence Student Attitudes About Science, Its Relevance, and Their Interpretations of Sustainability?

Michael A. Pelch[1,a] and David A. McConnell[2]

ABSTRACT

A general consensus exists among the leaders of both developed and developing nations that their citizens should be scientifically literate. Therefore, it is important for educational systems to provide students with access to pertinent scientific knowledge, an appreciation for the scientific processes, and the ability to evaluate scientific claims. Students' attitudes toward science and its relevance can serve to nurture or impede the development of their science literacy. Some researchers have proposed that we can improve students' attitudes toward science and foster science literacy by emphasizing the connections between science and society. We sought to determine if the repeated and explicit exposure to socioscientific issues through the use of InTeGrate course materials would result in positive changes to students' attitudes about science and its relevance. We collected data on student attitudes using the revised Scientific Attitude Inventory and the Changes in Attitude about the Relevance of Science survey in a quasi-experimental design over four semesters of an introductory physical geology course. Results, although mixed, show that an emphasis of socioscientific issues can positively influence students' attitudes about science and their perceptions on the relevance of science. These findings have potential implications for the selection of content for introductory science courses, and demonstrate the utility of designing or adapting geoscience lessons based around socioscientific issues. © *2017 National Association of Geoscience Teachers*. [DOI: 10.5408/16-173.1]

Key words: undergraduates, sustainability, attitudes

INTRODUCTION

Anthropogenic influences on global life support systems have reached a magnitude unprecedented in human history and currently approach levels that have the potential to jeopardize our well-being as a species (Jerneck et al., 2011). Human beings are an integral part of the Earth system and since the Industrial Revolution our society has developed to a point where we have the capability of significantly impacting our environment (Vitousek et al., 1997; Barnosky et al., 2014). A stable future will require the sustainable and ethical use of our natural resources and environmental systems (American Geophysical Union, 1994; National Science Foundation, 1996; National Research Council [NRC], 2000). A science literate population is necessary to make thoughtful decisions that will sustain human beings and other species in an evolving earth system. Consequently, the United States must build robust educational pathways for its citizenry to develop the global perspective, cultural sensitivity, economic wisdom, and scientific acumen to inform decisions regarding this environmental challenge.

A general consensus exists among the United States and other nations that it is important for their citizens and leaders to be scientifically literate (Miller, 2004; Tewksbury et al., 2013). The proportion of U.S. adults who can be considered scientifically literate has steadily increased since the 1950s (Miller, 2004). However, this number remains low enough to be problematic for a democratic society that places value on its citizens' understanding of major national policies and that requires their participation in the resolution of important environmental debates (Miller, 2004). The term "science literacy" is generally accepted to have been first used in the late 1950s in an article entitled "Science Literacy: Its Meaning for American Schools" (Hurd, 1958; see reference in Roberts, 1983; DeBoer, 1991; Laugksch, 2000). A national interest in science emerged during the late 1950s in response to the launch of the Soviet *Sputnik* satellite (Laugksch, 2000). There have subsequently been multiple attempts to define and assess science literacy (DeBoer, 1991; Laugksch, 2000; Miller, 2004; Feinstein, 2011; Sadler, 2014; Shen, 2014).

Defining Science Literacy

A key challenge in defining science literacy is the evolving and iterative nature of science itself that contributes to a steady change in scientific information over time. Shen (1975) argued that science literacy should be viewed as a series of separate metrics and proposed different literacy standards for citizens with different roles (e.g., consumer, government representative, expert). Miller (2004) describes a science literate citizen as someone who can understand the science section of the *New York Times*. This definition of science literacy emphasizes the ability to read and comprehend scientific information written at a particular educational level. However, many would view science literacy as a more complex construct that goes beyond understanding content.

Roberts (2007) describes two predominant "visions" of science literacy that he suggested represent end members of a continuum. Vision I science literacy focuses on a student's comprehension of content and Vision II science literacy

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[1]University of Washington, Department of Biology, Box 351800, Seattle, Washington 98195, USA
[2]North Carolina State University, 2800 Faucette Drive, 1125 Jordan Hall, Campus Box 8208, Raleigh North Carolina 27695, USA
[a]Author to whom correspondence should be addressed. Electronic mail: pelchm@uw.edu.

focuses on a student's ability to use scientific information to understand and explore complex issues. The Program for International Student Assessment (PISA, 2006; Bybee and McCrae, 2011) outlined four interrelated characteristics that defined science literacy: (1) recognizing life situations involving science and technology, (2) understanding the natural world, (3) demonstrating competencies that include identifying scientific questions, and (4) responding with an interest in science, support for scientific inquiry and motivation to act responsibly towards natural resources and environments. The fourth item is clearly attitudinal in orientation (Bybee and McCrae, 2011).

Science Literacy and Education

Educational effort has historically focused on improving Vision I science literacy; however, recently there has been greater emphasis to promote Vision II science literacy (Romine et al., 2017). Vision II science literacy is closely aligned with characteristics defined by PISA 2006. This more holistic approach towards improving students' science literacy has become a crucial yet ill-defined goal of science education. We live in a republican society that constitutes an environment in which science interacts with other societal forces (Nowtony et al., 2001). In this view, it becomes important for the educational system to provide students with an understanding of the processes of science and the ability to evaluate scientific claims (Colucci-Gray et al., 2006).

Vision II science literacy in an educational setting often centers on topics labeled as socioscientific issues. Socioscientific issues are societal issues rooted in science and include topics such as climate change and diminishing natural resources (Zeidler et al., 2003). Dealing with socioscientific issues arising from the complex interactions of science and society represents an integral component of scientific literacy and citizenship education (Colucci-Gray et al., 2006). Sadler and Zeidler (2005) argued that students with a better understanding of the connections between content and society make more rational and informed decisions around issues involving scientific concepts. Limited research on the impact of socioscientific issues suggests that an emphasis on the connections between domain-specific knowledge and society can help students make more informed decisions related to socioscientific issues (Zo'bi, 2014). The objective of this study is to examine how revising an introductory geoscience course to explicitly focus on socioscientific issues influenced undergraduates' attitudes toward science and its relevance.

Conceptual Framework

Personal attitudes play a significant role in an individual's interest, attention, and response to science and technology and contributes to the development of students' scientific literacy (Bybee and McCrae, 2011). PISA 2006 primarily investigated the attitudes of younger adolescents (15-year-olds from over 50 countries). Relatively few studies have examined college students' attitudes toward geoscience. Nadelson and Viskupic (2010) investigated attitudes toward science of students in both lower division and upper division geoscience courses. They found that students' attitudes were similar at the beginning of both courses and that both study populations showed the development of more negative attitudes toward science during the course. Bezzi (1999) conducted a qualitative study of undergraduates' attitudes toward the physical sciences (which included geoscience). He found that students had negative perceptions and attitudes toward geoscience and that this did not change after taking an introductory geoscience course. Bezzi's conclusions were echoed in a study by Osborne, Simon, and Collins (2003) who also concluded that students showed negative attitudes toward the physical sciences. Although these analyses have characterized attitudes related to specific courses, none of these studies examined how students' attitudes about science and its relevance are potentially altered by the introduction of an explicit emphasis on socioscientific issues throughout a course.

Science literacy is connected to students' attitudes toward science, their perceptions of its relevance to their lives and their ability to evaluate and understand issues dealing with sustainability (Alsop and Watts, 2003; Zeidler et al., 2005; Holbrook and Rannikmae, 2009). For instance, in their review of the PISA 2006 results, Bybee and McCrae (2011) found that students were most interested in science issues related to health and safety. Topics that students found the least relevant centered on the physical sciences such as physics, chemistry, and geology. Teaching practices that seek to influence and potentially improve geoscience literacy among college students may need to adapt curricular materials to present content in a way that students find personally relevant.

Van der Leeuw, Wiek, Harlow, and Buizer (2012) noted that future generations will face myriad sustainability challenges at a range of scales. These challenges have contributed to the rise of the scientific cross-discipline of sustainability science. Sustainability science is an attempt to bridge the natural and social sciences with the intent on seeking creative solutions to complex problems such as, but not limited to; biodiversity loss, deforestation, climate change, land degradation, and water scarcity (Jerneck et al., 2011). Defining sustainability is challenging due to the complex and interdisciplinary nature of the concept. In our study, we choose to define sustainability as *development that meets the needs of society without compromising natural systems or the abilities of future generations to meet their own needs*. This interpretation is modified from the definition provided World Commission on Environment and Development (WECD; Brundtland, 1987).

InTeGrate Modules

Many of the issues related to science literacy and sustainability are deeply rooted within the geosciences (Kajikawa, 2008; Jerneck et al., 2011; van der Leeuw et al., 2012). Overlapping sustainability-related issues tied to the geosciences have recently gained greater prominence due in part to community sourced literacy documents (e.g., Wysession et al., 2012), published calls for discipline-wide action (e.g., Tewksbury et al., 2013), and through community-wide efforts such as the InTeGrate project (Interdisciplinary Teaching about Earth for a Sustainable Future, http://serc.carleton.edu/integrate/index.html), which seeks to improve geoscience literacy and sustainability education by developing new instructional materials. One element of the InTeGrate project was the development of a series of 11 modules to support introductory geoscience and environmental science courses. The modules are customizable and are each composed of six units equivalent to individual lectures or lessons. Each unit features several related activities, and the modules can be broken down and incorporated into a course at a variety of scales. For example, an instructor may choose entire modules, a selection of stand-alone units, or individual activities to assimilate into their classes. The introductory modules are designed to promote geoscience literacy in the context of socioscientific issues. This is accomplished by incorporating a systems thinking approach, grounded in the earth science literacy documents, and focused on highlighting the connections between geoscience and society (Egger et al., 2015; Manduca et al., 2015). InTeGrate materials are designed to include research-validated instructional strategies that have been demonstrated to improve student engagement and learning (e.g., Freeman et al., 2014). Each module and its subsequent units are designed around measurable learning objectives, a variety of formative and summative assessments, and student-centered classroom activities (McConnell et al., 2013).

Each InTeGrate module follows five key design principles: (1) It is designed around a particular grand challenge facing society (e.g., NRC, 2000); (2) It features interdisciplinary problems involving economic, societal, and policy issues; (3) It incorporates activities that have students use authentic geoscience data; (4) It synthesizes concepts across different components of Earth to support systems thinking; and, (5) It encourages students to use the methods of geoscience and develop geoscientific habits of mind (e.g., comparing modern processes with those in the geologic record).

Grand challenges are featured in modules addressing topics such as dealing with climate change (Climate of Change), assessing the exploitation of natural resources (Humans' Dependence on Natural Resources), managing freshwater resources (Environmental Justice and Freshwater Resources), and mitigating risks posed by natural hazards along plate boundaries (Living on the Edge). InTeGrate activities were designed to reduce the amount of time the instructor spends lecturing and increase the proportion of class time students spend working collaboratively on problems and participating in discussions. Each activity within a module was developed employing backward design (Wiggins and McTighe, 2005). This style of course content creation centers on first establishing the measurable tasks instructors want students to know (learning objectives), then designing the activities students will perform to meet those objectives, and finally focuses on creating formative and summative assessments to measure student learning.

It is important to understand what a typical class would *look* like that incorporated InTeGrate module activities. To provide this glimpse, we will describe the first activity performed in this study from the Humans' Dependence on Earth's Mineral Resources (HDEMR) module, which is designed around the socioscientific issue of the use of natural resources. The HDEMR module may represent a student's first interaction with minerals in an introductory geoscience course. Unit 1 (People, Products and Minerals), begins by presenting the following learning objectives to students: (1) label examples of mineral resources, the products that contain them, and the mineral properties that cause these resources to be used in these products, and (2) describe how elemental abundance relates to mineral abundance and resource availability. The lesson starts by dividing the class into groups of four to five students and presenting them with a worksheet of mineral names, chemical formulae of those minerals, and a mixture of pictures of products and or the actual products made from those minerals. The objective of the activity is for students to work together to match up the products with the minerals they contain. For example, one of the pictures provided to students was a spool of copper wire and the groups needed to match that with the mineral Bornite (Cu_5FeS_4). The only information students have to work with is their own knowledge and the knowledge of their peers, a basic understanding of chemistry and the periodic table of elements, and product labels. This activity has students making the connections between common everyday products and economic minerals. This explicit and student-driven connection between people and geology is done before any formal introduction to what a mineral is and how minerals can be combined to create rocks.

Introducing *why* minerals are important to society before discussing their geologic characteristics is one of the ways InTeGrate resources differ from a more traditional approach used in introductory geology courses. The HDEMR module continues with a class presentation on the characteristics that define a mineral and how elemental abundances in the different layers of the Earth constrain the distribution of rocks and minerals. After completing unit 1, students continue their investigation of mineral resources in the HDEMR module by looking at how population growth impacts mineral use, changes to the supply and demand of minerals over time (Unit 2), mineral mining and the environment (Unit 3), mineral resources created during rock formation (Units 4, 5), and the positive and negative impacts of mining on people and the environment (Unit 6).

Emphasizing the connections between geoscience and society has the potential to enhance students understanding of key environmental issues. Further, it provides an opportunity to influence student attitudes about science that may help promote learning and recruit majors. However, research on the links between teaching about socioscientific issues, science literacy, and students' attitudes is lacking. This study sought to determine if incorporating InTeGrate resources that provide an explicit emphasis on socioscientific issues would positively influence students' attitudes toward science, their perceptions on the relevance of science, and their understanding of sustainability in the geosciences. We investigated the following research questions:

1. How are students' attitudes about science and its relevance influenced by the repeated emphasis of socioscientific issues (through InTeGrate materials) in an introductory geology course?
2. Does an emphasis of socioscientific issues help students characterize sustainability in the geosciences?
3. Does an emphasis on socioscientific topics result in changes in student learning of course content?

We hypothesize that the repeated emphasis of socioscientific issues during an introductory geology course will result in positive changes in students' attitudes toward science and the relevance of science. Additionally, we posit that this

TABLE I: Study participants.

	Control Semester 1 (n = 79)	Control Semester 2 (n = 87)	Treatment Semester 1 (n = 74)	Treatment Semester 2 (n = 70)
Men	58	53	51	46
Women	21	34	23	24
Freshman	31	37	33	37
Sophomore	19	26	23	11
Junior	19	16	12	19
Senior	10	8	6	3
STEM[1]	20	9	20	17
Non-STEM	59	78	59	54

[1]STEM = science, technology, engineering, and mathematics.

explicit emphasis on socioscientific issues will better prepare students to identify concepts dealing with sustainability and to help them gain a more pragmatic understanding of the relationship between geoscience and sustainability.

TABLE II: Content modules for control and treatment semesters. Modules in bold during the treatment semester are InTeGrate modules.

Module	Control	Treatment
1	Introduction/Scientific Method	Introduction/Scientific Method
2	Plate Tectonics	Plate Tectonics
3	Rocks and Minerals	**Humans' Dependence on Earth Mineral Resources**
4	Earthquakes and Volcanoes	**Living on the Edge: Building Resilient Societies on Active Plate Margins**
5	Geologic Time	Geologic Time
6	Earths Past Climate	**Climate of Change**
7	Water and Society	**Environmental Justice and Freshwater Resources**
8	Energy Resources and Climate Change	Energy Resources and Climate Change

METHODS

We employed a quasi-experimental design (Anderson-Cook, 2005) consisting of two control semesters (CS1 and CS2) and two treatment semesters (TS1 and TS2). For the purposes of this analysis, a quasi-experiment is defined as a study seeking to determine causal explanation for an observation that lacks the random assignment of participants to experimental and control groups (Shadish et al., 2002). We sought to determine if the change in curricular materials during the treatment semesters resulted in any changes in student attitudes about science, its relevance, and student understanding of sustainability in the geosciences.

Study Context

We collected data across two control semesters and two treatment semesters. The character and numbers of participants was relatively consistent among semesters. The overall structure of the course, instructional strategies, and grading methods were also kept consistent whenever possible although there was unavoidable variation introduced by the change in course materials between control and treatment semesters. Finally, the corresponding author taught all four classes at similar times in the same classroom.

Participants

This study involved 310 students (Table I) enrolled in a physical geology course at North Carolina State University (NCSU). Each participant was over the age of 18 and provided their written consent to be included in this study. Our sample predominantly consisted of freshmen and sophomores most of whom were male non-STEM (science, technology, engineering, and mathematics) majors. STEM majors were identified using information from the university registrar system that is available to instructors. A STEM major is defined as any student who had declared their area of study in a STEM discipline (e.g., biology, chemistry, engineering, mathematics, physics, geology, computer science) at the time of course enrollment. The distribution of students among the four academic levels was similar for all four semesters (Table I). The academic and demographic distribution of students in this study is typical of introductory physical geology courses at NCSU. Ethnicity and race were not investigated in this study.

Course Content

The original (control) version of the course is subdivided into eight modules (Table II) and incorporates a selection of topics presented in almost every Physical Geology textbook. Treatment semesters replaced 60% of the standard course material with materials developed for the InTeGrate project (Table II). These materials typically involved the same content topic but focused on more socially relevant aspects of that topic. For example, in the control semesters students learned about the hazards associated with earthquakes and volcanoes and what impacts those phenomena have on people. In the treatment semesters students used that same knowledge combined with real-world data sets to assess the risks to real structures such as schools and businesses as well as whole cities.

Course Format

The course includes four exams, each testing students on material from two content modules. In addition, students completed online "learning journals" prior to each class meeting and answered questions on an online quiz for each module. The learning journal exercises consist of a series of multiple choice and open-ended questions answered on the basis of reading assignments or short videos that are linked to upcoming lecture topics. Student grades were calculated on the basis of exams (60%), in-class clicker questions (ConcepTests, 10%), online quizzes (10%), and learning journals (20%). Classes from all four semesters lasted 75 minutes and met twice per week. The room layout was auditorium style with nonmovable chairs arranged in rows facing the instructor.

TABLE III: List of course characteristics between the standard physical geology course at NCSU and the InTeGrate introductory modules.

	Standard Physical Geology Course at NCSU	InTeGrate Introductory Modules
Clicker Questions	X	X
Data Interpretation	X	X
Making Predictions and Hypotheses	X	X
Small Group Work (10%)	X	X
Think-pair-share questions	X	X
Preclass Assignments	X	X
Small Group Work (~50% or >)		X
Working with real data sets		X
Integrated In-Class Discussions		X
Postclass Assignments		X

Pedagogy

Instruction in the physical geology classes involved an active learning format where students frequently participated in collaborative activities with their peers (Table III). Both control and treatment classes employed clicker questions where students responded to confirmatory or conceptual questions presented by the instructor. Both versions of the course required that students make basic interpretations of data presented in figures and use that information to make simple predictions and hypotheses on several concepts presented to them over the course of the semester. Students regularly worked with their peers for at least 15% of the class period in the control classes. Time spent working in small groups was typically longer in the treatment classes. These interactions were generally presented in the form of small group activities or think-pair-share activities. Additionally, both course formats required students to complete short assignments before coming to class. During the standard physical geology course these assignments consisted of a series of "learning journals" in which students responded to questions about reading assignments or short videos. During the version of the course using the InTeGrate course materials much of the preclass work almost exclusively involved short videos covering basic geoscience concepts. The videos allowed the instructor to devote more in-class time to student-centered activities such as group work and planned in-class discussions. The InTeGrate materials are further differentiated from the standard course materials in that students typically work together for more of the class period and often work with real scientific data sets. InTeGrate course work also contains more planned, semi-structured in-class discussions (Table III). Although class discussion did occur during the control semesters, instructor-facilitated discussions were used more frequently in the treatment semesters to assess specific learning objectives.

Instructional Reliability

The corresponding author taught both control and treatment classes during all four semesters. The materials and techniques presented to students were identical during control semesters. Materials were also presented similarly during treatment semesters although there were some adjustments to the sequencing and organization of the presentations in the fall semester on the basis of feedback from the initial use of the materials in the spring semester (see Study Limitations for additional information). The instructor often utilized strategies described by the module authors that were built into each module and accessible via the InTeGrate website. Using the same instructor minimized variability in instructional practice and provided a greater degree of internal consistency and confidence. Controlling for instructional practice is especially important when measuring students' attitudes because research has shown that certain teaching strategies as well as the instructor's personality and interactions with students can have a significant influence on attitudes about a course (Osborne et al., 2003). Additionally, training an instructor (or several instructors) to use the InTeGrate teaching materials could have introduced myriad additional variables that would have been difficult to regulate.

A formally trained, independent observer employed the Reformed Teaching Observation Protocol (RTOP; Sawada et al., 2002; Budd et al., 2013) to score three nonconsecutive classes per semester in order to provide greater confidence in our fidelity of implementation. The RTOP instrument is designed to identify key dimensions of active learning, including the design and implementation of the lesson, the content (propositional) knowledge of the instructor, the nature of the tasks the students were asked to complete (procedural knowledge), communication among students, and the relationship between the instructor and students (Sawada et al., 2002). InTeGrate materials used in this study are designed to feature a higher degree of active learning; therefore, observations made during the treatment semesters were conducted during classes where only standard materials were taught to assess the consistency of instruction across all four study semesters. The total scores, as well the subcategory totals, for all 12 observations are shown in Table IV, and these scores did not significantly vary as a function of semester, $F(2, 9) = 2.294$, $p = 0.157$.

Data Collection

Attitudes toward Science

Students' attitudes about science were measured using the revised Scientific Attitude Inventory (SAI II). The SAI II is designed around 12 position statements (six positive statements and six negative statements) relating to an individual's attitude toward science. For example, the positive affirmation of the first position is "The laws and/or theories of science are approximations of truth and are subject to change," whereas the negative affirmation is "The laws and/or theories of science represent unchangeable truths discovered through science." Each position statement is represented by items on the SAI II. The original Student Attitude Inventory (SAI) was developed by Moore and Suntman (1970) and was subsequently the subject of a thorough reevaluation by Munby (1983), which highlighted several issues with the survey's validity. The review by Munby (1983) led to the revision of the SAI by Moore and Foy (1997), which addressed the validation issues and created an improved instrument named the SAI II. The SAI II is a 40-item survey featuring a five-point Likert scale

TABLE IV: Breakdown of RTOP observation scores.

Observation	CS1			CS2			TS1			TS2		
	1	2	3	1	2	3	1	2	3	1	2	3
Lesson Design	8	9	11	9	10	11	8	11	9	9	10	11
Propositional Knowledge	18	19	15	18	18	18	18	19	18	18	17	16
Procedural Knowledge	7	8	4	6	8	8	6	5	7	7	6	6
Communicative Interaction	12	9	11	10	11	13	9	11	9	10	9	9
Student/Teacher Relationships	7	8	9	8	10	7	8	7	10	9	10	9
Total	53	53	50	51	57	57	49	53	53	53	52	51
Semester Mean		52			55			52			52	

[1]RTOP = Reformed Teaching Observation Protocol; CS = Control Semester; TS = Treatment Semester.

where respondents choose an option between strongly agree, agree, neutral, disagree, and strongly disagree. The validity of the SAI II has also been questioned by Lichtenstein et al. (2008). In the reevaluation of the SAI II they found the instrument to be unreliable for a convenience sample of adolescents. However, despite this criticism, Nadelson and Viskupic (2010) found the instrument valid and reliable for use with college students, which they attributed to the greater maturity level of their study population. We administered the SAI II on the first day of class to all participants and then again near the end of the semester. The actual day for the postsurvey varied due to situational factors such available class time and scheduling around holidays. We chose not to analyze individual position statements (subcategories) because the low number of items resulted in reduced values of internal consistency.

Perceptions of the Relevance of Science

Attitudes about the relevance of science were measured using the Changes in Attitude about the Relevance of Science (CARS) survey. The CARS survey was developed by Siegel and Ranney (2003) and is composed of three 25-item surveys. Students respond to each item using a five-point Likert scale where respondents choose an option between strongly agree and strongly disagree. The CARS surveys allow the researcher to gain greater insight about how students' attitudes about the relevance of science changes overs time (Siegel and Ranney, 2003). Additionally, the CARS survey is designed to minimize the impacts of repeated testing bias by dividing 59 items among the three different versions, each version consisting of 25 items (17 version-unique items and eight repeated items). The first of the three versions was administered on the first day of class, the second version during the middle of the semester, and the third version was administered at the end of the semester with the postclass iteration of the SAI II. Several of the items from the original CARS survey have been reworded to make them more geology-specific. For example, item 17 on the first version of the CARS survey was initially worded as follows: "Science class will help prepare me for a career." The word "science" was replaced with "geology" and now reads as "Geology class will help me prepare for a career." Only minor wording changes were made to items in order to maintain the instrument's original validity and reliability. Similar changes have been made to other attitude instruments. For example, Adams, Wieman, Perkins, and Barbera (2008) modified the Colorado Learning Attitudes about Science Survey (CLASS) from a physics-focused instrument to one that could be used in a chemistry class. Their revisions were much more robust than the changes detailed here yet still maintained the instrument's original validity and reliability (Adams et al., 2008).

Sustainability

Measuring students' descriptions of sustainability was more difficult because there were neither quantitative instruments that adequately measured the construct nor were there any purely qualitative instruments that fit our study design. This led us to employ a short-answer question that students would respond to during their final exam. The design of this question was guided by sustainability science and earth science literacy documents and asked students to perform three tasks: (1) define sustainability in the geosciences, (2) identify topics that deal with sustainability, and (3) describe why one of those topics would be important to know to be scientifically literate.

The first part of the students' response is intended to gauge whether students recognize that sustainability in the geosciences has important implications for future generations and that it requires a balance between human society and the earth system. The field of sustainability science has commonly framed sustainability within a three pillar model, with the pillars represented by the economy, environment, and society (Kajikawa, 2008; Kastenhofer and Rammel, 2005). The three-pillar model stresses balance between human and natural components, and the idea of balance is crucial when attempting to achieve and define sustainability. Hay and Mimura (2006) argued that sustainability can only be achieved by conserving both resources and the capacity of the environment to absorb the multiple stresses induced by human activities. The temporal aspect of resource use and ecosystem viability (Kajikawa, 2008) is also important in defining sustainability. Sustainability is also frequently characterized as a social choice about what to develop, what to sustain, and for how long (Parris and Kates, 2003). This temporal aspect also forces consideration of the tradeoffs and implications between short- and long-term processes (Kajikawa, 2008). The third part of the question was designed to elucidate why and how the topic of their choice is an important socioscientific issue, and we wanted students to link socioscientific issues with evidence from their class.

TABLE V: Pearson correlation matrix for all post-semester instruments from all four study semesters.

	1	2	3	4
CS1				
1. Post-SAI II[1]				
2. CARS C	0.53			
3. Sust. Quest.	0.33	0.20		
4. Exam Total	0.04	0.02	0.13	
5. Final Grade	0.05	0.07*	0.41*	0.49*
CS2				
1. Post-SAI II				
2. CARS C	0.71			
3. Sust. Quest.	0.11	0.18		
4. Exam Total	−0.19	−0.14	0.08	
5. Final Grade	0.35*	0.31*	0.17*	−0.12
TS1				
1. Post-SAI II				
2. CARS C	0.20*			
3. Sust. Quest.	0.27	0.19		
4. Exam Total	−0.15	0.03	−0.01	
5. Final Grade	0.36*	0.16	0.19	−0.06
TS2				
1. Post-SAI II				
2. CARS C	0.72*			
3. Sust. Quest.	0.14	0.21		
4. Exam Total	−0.11	−0.23	−0.08	
5. Final Grade	0.15*	−0.01	0.21	−0.32

[1]SAI = Scientific Attitude Inventory; CARS = Changes in Attitude about the Relevance of Science; Sust. Quest. = Sustainability Question.
*$p < 0.05$.

Data Analysis

Survey scores from the SAI II and the CARS surveys were converted to person measures using Rasch modeling and analysis. Rasch analysis was developed by George Rasch (1960) and represents a one-way probabilistic approach based on Item Response Theory (IRT). The application of Rasch analysis and measurement in the social sciences has been most notably discussed in the 1967 Invitational ETS conference and in a wide variety of subsequent publications (e.g., Wright, 1977; Andrich, 1978; Wright and Stone, 1979; Wright, 1984; Choppin, 1985; Wilson and Adams, 1995; Linacre, 1998; Libarkin and Anderson, 2005; Linacre, 2006; Linacre, 2010; Miyake et al., 2010; Boone et al., 2011; Tong, 2013). Rasch modeling is both norm-referenced (comparing individuals with the group) and criterion-referenced (measured according to specific standards; Siegel and Ranney, 2003). This is accomplished by considering the difficulty of the item on a continuum, the participant's response to that item (ability), and the probability that a participant will choose a response (Boone et al., 2014). Winsteps software (Linacre and Wright, 2000) was used to compute person measures. Person measures are expressed in logistical units (logits), which are equal-interval units that can be applied to parametric statistical tests because they avoid many of the issues of the nonlinearity of rating scales as well as the nonlinearity of raw survey data (Boone et al., 2014). In order to preserve the distinction between the two instruments the logit values on the SAI II were scaled to a 0–100 scoring system whereas the CARS survey results are shown with their unmodified logit values. Person measures were compared within quasi-experimental groups by employing dependent *t* tests and repeated-measures analyses of variance (ANOVA) where appropriate. To compare person measures among different quasi-experimental groups we employed one-way ANOVA and independent *t* tests. Normal distributions of data were evaluated through visual analysis of Q–Q plots.

Participants' responses to the open-ended questions about sustainability were investigated through a qualitative content analysis. Coding of individual responses and subsequent data analyses were performed using Atlas.ti software. The coding process began by first reading through every student's response and identifying key quotations (using the Atlas.ti software) where students were discussing topics that aligned with "three-pillar model" described by Kajikawa (2008). Next, all the highlighted quotations were sorted by quasi-experimental group and analyzed a second time in order to identify common phrases and patterns in students' responses. These patterns were used to develop a series of coding algorithms consisting of series of words or phrases linked to the "three-pillar model" of sustainability. Next, these coding algorithms were used to auto-code statements in Atlas.ti. Individual codes were then grouped to develop themes. The number of codes for each theme were calculated and then converted into a percent for each quasi-experimental group. Code co-occurrences were also determined using the Atlas.ti software, and provide insight into the context with which participants describe items or processes. A code co-occurrence value quantitatively describes how often two codes are found within the same coded segment. For our study, a coded segment was a sentence.

RESULTS

A Pearson correlation matrix among instruments administered at the end of all four study semesters is shown in Table V. This table provides insight into how much of the variability in one instrument is explained by a participant's score on another instrument. A significant portion of a student's attitude toward science (SAI II score) can be explained by their CARS survey score at the end of the semester.

CARS Survey Results

CARS data (Fig. 1) show no significant change over time during the first control semester (CS1) whereas results for the second control semester (CS2) show a significant improvement in students' attitudes toward the relevance of science over time, $F(2, 128) = 7.913$, $p = 0.001$, $\eta^2 = 0.11$. Students' attitudes toward the relevance of science show a significant improvement over time for both treatment semesters, TS1, $F(2, 52) = 10.189$, $p = 0.001$, $\eta^2 = 0.28$, and TS2, $F(2, 84) = 3.399$, $p = 0.038$, $\eta^2 = 0.07$. Data from the CARS C (version administered at the end of the semester) can provide insight into the absolute change observed between control and treatment groups. CARS C means for CS1 and CS2 do not significantly vary and neither do the

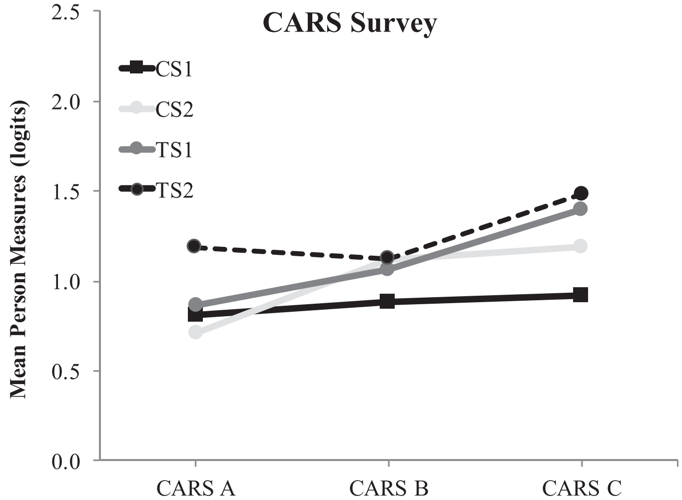

FIGURE 1: CARS survey results for all four study semesters.

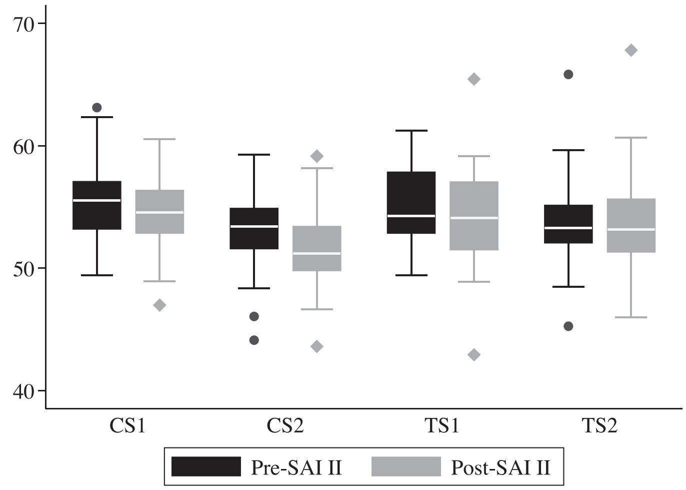

FIGURE 2: Results from the SAI II for all four study semesters.

scores from TS1 and TS2. Investigating differences grouped by spring and fall semester between CARS C scores show that the mean CARS C score for TS1 (Spring) was significantly higher than in CS1, [Spring; $t(99) = 1.982$, $p = 0.05$, $d = 0.40$]. TS2 (Fall) and CS2 (Fall) did not significantly vary. The internal consistency of the CARS survey was investigated to determine its reliability for use with our study sample. We calculated Cronbach alpha values ranging from 0.71–0.92, and this range included all four quasi-experimental groups and all iterations of the CARS survey.

SAI II Results

SAI II scores (Fig. 2) show statistically significant decreases in both CS1, $t(62) = 3.04$, $p = 0.004$, $d = 0.34$; CS2, $t(76) = 5.73$, $p = 0.000$, $d = 0.56$; and in TS1, $t(40) = 2.85$, $p = 0.007$, $d = 0.36$. TS2 showed no change between pre- and postclass SAI II surveys. Additionally, there was no difference among all four study groups in their attitudes toward science at the beginning of each semester. We calculated Cronbach alpha values ranging from 0.81–0.91, and this range included all four quasi-experimental groups and both pre- and postcourse iterations of the survey.

Sustainability Question Results

Two conceptual themes emerged from students' attempts to define sustainability in the geosciences: (1) Sustainability (Future), which encompasses occurrences where students explicitly describe the importance of conservation resources for future generations; and (2) Sustainability (Balance), which encompasses occurrences where students explicitly describe the importance of a balance between humanity and natural systems. For example, a student can refer to the need to conserve resources stating "Sustainability involves both limiting use and using more efficient ways so that future generations can use those same resources." An example of how students refer to the need for balance can be perceived through the following quote: "Sustainability is the use of nonrenewable and renewable resources to the extent that the use of these does not have an adverse effect on earth's natural balance…" The other four content themes identified occurrences where students discussed one of the following major topics tied to both the geosciences and sustainability science: (1) Climate change, (2) Energy Resources, (3) Water, and (4) Mining and Minerals. For example, students could state "Climate change is important for someone to understand…", "Sustainability is in regard to our use and depletion of oil, natural gas and water…" or "We have talked about how in mining we need to as a society be more concerned with the amount of waste we produce and what we do with it." Results of the coding show differences between the control and treatment groups' percentage of coded statements (Table VI) and the co-occurrence values (Table VII), and show differences in the frequency of coded statements describing a balance between humans and natural systems between control and treatment semesters. There is also a large discrepancy in the number of coded statements for Mining and Minerals between control and treatment groups (Table VI).

Class Performance Results

Average final grades and exam totals (mean score of the four course exams) for all four semesters are shown in Fig. 3 and are used as a way to measure students' learning gains and are collectively referred to as class performance. There is

TABLE VI: Percent of coded statements by theme from Control and Treatment groups.

	Def. of Sust.-Balance[1]	Def. of Sust.-Future	Climate Change	Energy Resources	Water	Mining and Minerals
Control	2%	7%	21%	29%	38%	4%
Treatment	0.4%	6%	24%	24%	26%	19%

[1]Sust. = sustainability.

TABLE VII: Code co-occurrences for combined Control and Treatment groups.

	Climate Change	Energy Resources	Mining and Minerals
CONTROL			
Energy Resources	0.23		
Mining and Minerals	0.07	0.06	
Water Resources	0.16	0.16	0.05
TREATMENT			
Energy Resources	0.30		
Mining and Minerals	0.21	0.23	
Water Resources	0.17	0.18	0.22

no statistically significant variation in exam total among students across the four semesters. An analysis of variance among final grade does show a significant difference between semesters, $F(3, 305) = 8.61$, $p = 0.001$, and a Bonferroni post-hoc analysis indicated that much of that variation is attributed to higher grades during TS2.

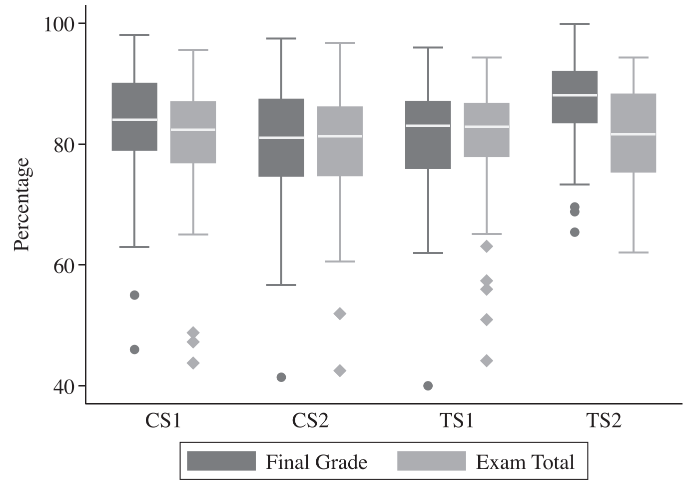

FIGURE 3: Final grade and exam totals for all four study semesters. Exam total is the average score for all four of the course exams.

DISCUSSION

The impact of an explicit and repeated emphasis of socioscientific issues in a physical geology class show some positive changes between control and treatment semesters. Both treatment semesters (TS1 and TS2) showed improvements in students' attitudes about the relevance of science over time, but the second control semester (CS2) also showed a significant improvement in their attitudes about the relevance of science with a larger effect size than TS2 (Fig. 1). This could suggest that something other than the InTeGrate materials may be influencing attitudes about relevance that was not incorporated in this study. However, it is important to note that students in TS2 started out the semester with the highest CARS survey scores measured in this study, suggesting some degree of diminishing returns on the possible changes to students' attitudes over the course of a 15-week semester.

Students' Attitudes

Emphasis on socioscientific issues reduced the negative impact of physical geology on students' attitudes toward science that has been observed in previous studies. During treatment semesters, these data show that many students' attitudes do not significantly decrease after taking a physical geology course (Fig. 2). When looked at collectively these results suggest that InTeGrate course materials were effective at creating a class-wide shift toward more positive attitudes about science. Students with more negative attitudes shift toward more neutral attitudes and students with more neutral to positive attitudes shifted even more towards the positive end of the scale. These data can then be inferred to suggest that an explicit emphasis on socioscientific issues in class may result in positive shifts in students' attitudes.

Our results reiterate some of the findings of Zo'bi (2014) and Sadler and Zeidler (2005) who noted that explicitly displaying the connections between science and society will have positive impacts on students' perceptions of science. Our data show a significant correlation between CARS C scores and SAI II scores during treatment semesters (Table V). Consequently, we propose a potential connection between student perceptions of course relevance with attitudes about science. A student's perception of the relevance of science is closely tied to the emotional domain (Keller, 1983; Holbrook and Rannikmae, 2009) and there is a portion of a student's attitudes toward science derived from an emotional perspective (Moore and Foy, 1997). These "emotional" attitudes are related to how a student feels about certain topics or a whole course (Moore and Foy, 1997). Therefore, the emotional part of a student's attitude about science closely parallels their attitudes about the relevance of science. This overlap among the emotional domain for both students' attitudes about science and their perceptions of the relevance of science could be inferred to suggest that class content designed to influence the relevance of science may also be an effective method of altering attitudes toward science.

The emphasis of socioscientific issues did not have a significant negative or positive impact on students' class performance. Relevance has been connected to learner empowerment and motivation to study (Keller, 1983). However, our data do not show a simple correlation with this statement because our results show nonsignificant to negative correlations between CARS C scores and students' final grades and exam totals (Table V). Instead, our results parallel the findings of Warren (2011) who showed no connection between content relevance and student cognitive learning. Warren suggested that the lack of correlation between relevance and performance could be due to the fact that multiple instructors were used to teach classes. Our data provides evidence contrary to that hypothesis because we employed the same instructor for all four study groups and still found no statistically significant link between students' exam performance and how relevant they found scientific information. In TS2 students CARS C scores had no significant correlation with either final grade or exam total. These mixed findings may suggest that other factors influence the relationship between achievement and students' perceptions of the relevance of science or the relationship could be more complex than suggested in Keller (1983). Although performance is not strongly linked with a student's perception of course relevance, retention and persistence in STEM are significantly correlated with perceived relevance (Hanauer et al., 2016; Schinske et al., 2016). Consequently, it may be important for educators to consider how their content choices and teaching strategies impact students' perceptions of course relevance in addition to making choices based on learning outcomes.

Sustainability

Students from both control and treatment groups do not typically define sustainability by referring to both the need for balance between humans and natural systems and its importance for ensuring the prosperity of future generations (Table VI). Students' definitions of sustainability primarily discuss its importance in the context of ensuring the prosperity of future generations. Students' tendency to not describe sustainability in terms of balance between humans and Earth could be due to the idea that they may view sustainability as a competing force to progress. Kagawa (2007) carried out an investigation on students' conceptualization of sustainability and found that students viewed sustainability as being at odds against economic progress. This discrepancy between students' definitions involving a balance between humanity and the earth systems in our data supports this conclusion. These data could also indicate a need for physical geology courses to find more effective strategies to emphasize the importance of a balance between society and the earth system.

Co-occurrence values provide insight into how often individual codes are found within the same coded segments. For example, a code co-occurrence value of 1 would indicate that two codes were always found in the same statements. Code co-occurrence values (Table VII) for the four content themes (climate change, water, energy resources, mining and minerals) were higher in the treatment semesters than in the control semesters. These data are interpreted to suggest that students in the treatment semesters are discussing sustainability in a more integrated manner than students from control semesters.

The frequency of coded statements and co-occurrence values for Mining and Minerals are significantly higher during treatment semesters. During the control semesters minerals were covered in a traditional manner, and mining and its impacts were rarely discussed explicitly. For example, the focus of minerals in a traditional geology course is on topics such as the definition of a mineral, classes of minerals, the rock cycle, and the three different types of rocks formed from one or more minerals. Mined natural resources' impact on society are a central component of the Humans' Dependence on Earth's Mineral Resources module used in the treatment semesters. Therefore, this contrast between content focus of the control and treatment semesters may explain the discrepancy in coded data.

Analyzing responses from the control semesters revealed that out of approximately 19,000 words from the responses of 166 students, the word ''minerals'' was mentioned four times. The way we use minerals and their rates of consumption are an important aspect of both earth science literacy (Wysession et al., 2012) and sustainability (Kajikawa, 2008; Jerneck et al., 2011). An introductory geology course that addresses the impact of minerals on society relatively briefly may not make a sufficient impression on students to have them recognize its role in a sustainable future. Introductory geoscience courses represent one of the few opportunities to convey the important role of mineral-based resources in modern societies. Student responses from the treatment semesters show a significant increase in the mention of minerals, mining, and the importance of those minerals. Not only were topics mentioned more frequently but the order of magnitude increase in code co-occurrence values with all three of the other themes suggests that students are at least thinking about minerals and mining in the context of a variety of sustainability-related topics, such as climate change and energy resources. This is evidence supporting the positive impact of InTeGrate materials to present geoscience information in a way that changes how students think about a complex topic such as sustainability in the geosciences.

STUDY LIMITATIONS

The quantitative focus of our research design limited the depth to which we could analyze differences in students' attitudes between control and treatment semesters. However, the use of qualitative methods could have substantially reduced the number of students included in our study and could have introduced a high level of volunteer bias. To qualitatively characterize how students' attitudes would change over the course of the semester would have required students to volunteer for multiple lengthy interviews outside of class. This would have been difficult because we did not have any method in place to incentivize participants. The corresponding author not only taught classes but also collected and analyzed data. We acknowledge that this is a potential source of bias. However, data were anonymized when entered in digital storage, and an undergraduate research assistant graded a significant portion of the SAI II and CARS surveys independent of the corresponding author.

Results during TS2 were more consistent than in TS1. This could be the result of unforeseen and unavoidable difficulties that accompany the first implementation of new course materials. TS1 was the first time the instructor had included so many InTeGrate units into the course. Consequently, this led to difficulties determining how to best adapt materials. The corresponding author noted that the initial version of the revised course had inconsistent pacing as represented by variations in the quantity and difficulty of work to be completed by students. This created a heightened level of frustration among some students during the semester and that was also evident in course evaluations. Throughout the first semester the corresponding author made careful notes about what worked and what did not work. These lessons learned, along with feedback provided by students during course evaluations, led to revisions regarding how the InTeGrate materials were incorporated into the course in subsequent semester. These revisions were piloted during a much smaller summer session and were again tuned to better fit the large class taught during the upcoming fall semester (TS2). The revised method of implementing the InTeGrate materials provided a much more organized and consistent experience for the students. Students' perceptions of a course do have an impact on their attitudes toward science and its relevance (Osborne et al., 2003). Therefore, it is reasonable to assume that the frustrations voiced by students in TS1 may have had some influence on their attitudes. Student feedback and evaluations for TS2 were more positive.

CONCLUSION

The repeated and explicit emphasis of socioscientific issues provided through the InTeGrate course materials reduced some of the negative influence of a standard physical geology class on students' attitudes about science, and it helped some students to perceive geoscience content to be more relevant. Emphasizing socioscientific issues provided some students with a more diverse view of how course topics are related to each other and how they fit within the context of sustainability in the geosciences. These findings have implications not only for introductory geosciences courses but for other introductory courses within the physical sciences that struggle to engage students. Additionally, students' attitudes are an important factor that influences their decision to pursue a particular career. Consequently, the incorporation of socioscientific issues in introductory courses to improve attitudes toward science may assist in recruiting and retaining STEM majors.

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