Integrating Geoscience and Sustainability: Examining Socio-Techno-Ecological Relationships Within Content Designed to Prepare Teachers

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ABSTRACT

Coupling the study of sustainability with geoscience may enable students to explore science in a more sophisticated way by examining the social–technological–ecological relationships that exist between human–nonhuman and flora–fauna–land interactions. Elementary educators are a population capable of making these issues come to life for today's youngest citizens, who will ultimately become tomorrow's changemakers. This study explores Sustainability Science for Teachers, a semester-long hybrid course designed to enable future teachers to engage in sustainability and science concepts while developing their understanding of science from the human perspective and in which an issues-based curriculum underpins social and biosphere responsibility. The course's Water unit is explored as a case study of the melding of sustainability and geoscience to engage teachers in a more nuanced understanding of science education. The unit's curriculum is presented and its design process is explained, followed by a cross-sectional analysis of student outcomes. Data from preservice teachers enrolled in the course, as well as course alumni, were collected over a 4-y period. A mixed methods evaluation of teachers' opinions and products indicate that the Water unit facilitated the development of new understanding and new ways of thinking about teaching their future students. Opportunities and challenges for fusing the geosciences, sustainability concepts, and preservice teacher education in a novel and impactful fashion are discussed. © *2017 National Association of Geoscience Teachers*. [DOI: 10.5408/16-177.1]

Key words: sustainability science, geoscience, teacher education, university course design, hybrid learning, digital storytelling

INTRODUCTION

Sustainability science and geoscience are intertwined disciplines. Geoscience integrates vast expertise in Earth-system behavior at the interfaces of the geosphere, atmosphere, hydrosphere, cryosphere, and biosphere. From locating and identifying fossil fuel resources to calculating underground aquifer capacities, the field of geoscience works to better understand and render legible the Earth processes that shape and reshape the world we live in and manipulate for human gain. Sustainability science concerns itself with people, the planet, and production systems in an overlapping fashion. Aiming to be future oriented, sustainability is guided by the goal of "meet[ing] the needs and aspirations of the present without compromising the ability to meet those of the future" (Our Common Future, 1987, 11). Sustainability science is concerned with improving human well-being and is ever mindful of the simultaneous need to minimize ecological damage and resource depletion, especially over longer timescales. It requires that we pay attention to Earth's natural limits as identified in geoscience when making decisions that affect people today and in the future (Our Common Future, 1987; Orr, 1992; Kates et al., 2001). When explicitly coupling geoscience and sustainability narratives, sustainability goals and concepts focus on the social–technological–ecological relationships that exist between human–nonhuman and flora–fauna–land interactions. For example, when studying water with these two domains, it is necessary to explore both the natural water cycle and the variety of human-managed water systems that are in place. These reinforce each other and illuminate various concepts, values, ideas, and questions that are necessary for a complete picture of the world we live in and the one we plan for.

The geoscience and sustainability science fields are also complementary, because both fields focus on holistically examining and understanding large and complex environmental systems. While the field of geoscience examines the ways that Earth's physical components are integrated, sustainability science explicitly brings in social and political components regarding the future of resource development and distribution on scales from the local to the global. These two fields support a critical need to plan and develop more sustainable, just, and equitable futures that are based on sound scientific and environmental principles, as well as long-term planning that recognizes durable and resilient human and environmental relationships as a common social goal. Geoscience education is a central component of achieving this goal, and "the Earth science community…needs to tackle the question of how best to inject scientific insights into the debate about a sustainable future" (Schlosser and Pfirman, 2012, p. 587). One of the most important arenas in which geoscience concepts should be brought to bear in discussions of sustainability is to teach future classroom and informal educators how basic scientific and environmental concepts are joined with sustainability concepts regarding values, sociopolitical action, economics,

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and development (Hodson, 2003). As Gosselin et al. (2013) have argued, "Incorporating sustainability topics into coursework can be a stimulating and powerful mechanism for linking course content to real-world issues" (p. 221). Students become excited about content that they can connect to the headlines they are reading online, as well as to their community or personal experience. Simultaneously incorporating geoscience concepts with sustainability concepts is one way to make both exciting and relevant for future educators and to create holistic approaches to educating students about environmental issues.

With these knowledge sets in mind, a key focus must be on preparing the next generation to make informed decisions, challenge the status quo, and identify solutions. Citizens need to be able to marshal new insights and understand overlapping spheres of knowledge in order to redesign society along socially just pathways and ensure biosphere processes are stable. As part of achieving this outcome, education is a central component of improving the human condition and mobilizing new knowledge into actionable items (Hodson, 2003). The field of education represents a critical mechanism to enact lasting and impactful change toward achieving the goals of environmentally and socially sustainable societies. As such, a key element is educating future classroom teachers in sustainability literacy (UNESCO, 2010) and the geoscience concepts that sustainable planning is based upon. According to Nolet (2013), "Teacher education institutions can play a critical role in the work of reorienting education systems at all levels to address sustainability" (p. 53). Working with classroom teachers to inculcate sustainability concepts will have a direct effect on students who will be future leaders, thinkers, and citizens—those who will mobilize new knowledge and ways of thinking to change the world for the better.

The current study describes how we have drawn on the knowledge, processes, and logic from the geosciences to inform a course on sustainability science designed for preservice teachers. We describe Sustainability Science for Teachers (SSFT), a semester-long hybrid course that is a requirement in the undergraduate education program at a large public university. We explore the course's Water unit, one of the most well-received units, as a case study of this educational approach. Details are presented regarding the curriculum and initial outcomes for this learning experience that intricately meld sustainability and geoscience concepts. A discussion follows regarding how the curricula for this course offer new ways to fuse the geosciences, sustainability concepts, and pedagogy in a novel and impactful fashion.

RATIONALE AND BACKGROUND

Challenges in Liberal Arts and Science Education

An integral part of liberal arts education in universities across the world is to animate science concepts for a lay audience of learners. An educated 21st century populous must challenge the traditional linear understanding of science and society exemplified at the 1933 Chicago World's Fair, where "Science discovers, genius invents, industry applies, and man adapts himself" (Chandler, 2010, p. 14). Rather than adhere to this reductionist role of the citizen in relation to scientific knowledge, we argue that citizens need a clear understanding of science and the societal implications of science and technology to gain intellectual independence (Gaon and Norris, 2001). Sustainability offers a lens through which to tackle this challenge, and geoscience topics such as the hydrosphere are a way to help university students understand the practical aspects and civic-related responsibilities of science, technology, engineering, and math (STEM) fields and their implications for the future of the planet (Shen, 1975; Liu, 2009).

Among colleges of education specifically, a challenge in preparing undergraduate preservice teachers is facilitating their ability to integrate the Next Generation Science Standards (NGSS Lead States, 2013) and Common Core Standards (National Governors Association Center for Best Practices and Council of Chief State School Officers, 2010) into classroom teaching. These standards for education demand that teachers engage students in learning across content areas while exploring real-world, relevant problems. Tomorrow's teachers need to be equipped with the pedagogical skills and background content knowledge to explore the scientific and humanistic realities of current issues, such as the 2016 water crisis in Flint, Michigan. The Flint case study exemplifies the need for a rich exploration of socio-techno-ecological relationships that highlight infrastructure, politics, and geosciences to better expose how thinking across the curriculum can highlight consequences that disproportionately affect poor and minority populations. Over the last decade, educational scholars have begun to suggest that sustainability may be one way to approach such topics with elementary students and offer the necessary ways of thinking to make these important connections (Nolet, 2009, 2013, 2016; Stibbe and Luna, 2009).

Preparing Teachers to Teach Science

Scholars of science education have identified two major challenges that elementary educators face when integrating science into their curriculum. First, kindergarten through 8th grade (K–8) classroom teachers lack self-efficacy in teaching science topics, and preparation for teaching science is lacking, particularly when it comes to pedagogical approaches that animate science topics to bolster teachers' confidence in relation to both understanding and translating scientific concepts for students (Appleton, 1995; Westerback, 2006; Howitt, 2007). Consequently, the National Research Council (NRC) Committee on Science Learning stated that an increased effort on science literacy is important for educators in the K–8 space (NRC, 2000). Second, sustainability issues are not formally addressed in most schools. Nolet (2009) reports that U.S. teachers are not prepared to meaningfully teach how current and future issues related to overconsumption of resources, human-caused environmental damage, and technological solutions affect the world we live and the one we plan. Meanwhile, the Intergovernmental Panel on Climate Change (2014) articulates a need for greater access to education that raises awareness about adaptation and resiliency strategies grounded in an understanding of scientific concepts and appropriate applications of technology (Brooks et al., 2005; Adger, 2006). Critically, as Paavola's (2008) international case study demonstrates, a lack of education about both environmental science and sustainability concepts is a constraint that contributes to systemic environmental vulnerability and insecurity.

The SSFT course was adopted to address these complex and interconnected issues by prompting preservice teachers to explore current issues related to geoscience, environmental science, biological science, physical science, history, social science, engineering, and technology to make sustainability science topics come to life. The course aims to facilitate teachers' ability to integrate these concepts in the K–8 curriculum by increasing both their confidence in understanding of environmental science concepts and their comfort in translating those for students in relation to sustainability concepts.

Sustainability Science for Teachers

Three main areas of literature are useful for conceptualizing sustainability for a teacher audience: environmental education (including geosciences), ecological literacy (Orr, 1989), and sustainability literacy (Sachs, 1997, 2004; Nolet, 2009; Stibbe and Luna, 2009; Wiek et al., 2011). Major definitions associated with science and sustainability (Our Common Future, 1987; Kates et al., 2001) are also valuable for integrating these three fields, which complementarily consider causality and complexity of scientific knowledge production, technological applications, and social concerns. For instance, sustainability seeks to question and unpack how topics of science, technology, and society are embedded in human relations with and decisions about Earth's natural and human-made systems (Solomon and Aikenhead, 1994). Similarly, emerging epistemologies associated with complexity (Bateson, 1991; Maturana, 1978) are a useful way to engage with complex thinking about various wicked sustainability problems and plausible solutions that are or could be responsibly implemented.

Sustainability Education Framework for Teachers

Warren et al. (2014) have argued that sustainability literacy can be developed in teachers via the Sustainability Education Framework for Teachers (SEFT). This framework was developed specifically for the SSFT course to scaffold preservice teachers' ability to engage in critical thinking about sustainability topics, and it has implications for other courses and teaching models. At the core of SEFT are four ways of thinking: futures, values, systems, and strategic. These are conceptualized as being bidirectional and interrelated (see the following link for supplemental content [Available in the online journal and at http:dx.doi.org/10.5408/16-177s1], including brief videos on SEFT).

Futures thinking includes "the ability to collectively analyze, evaluate, and craft rich 'pictures' of the future related to sustainability issues and sustainability problem-solving frameworks" (Wiek et al., 2011, p. 208–209), while values thinking means understanding concepts of justice, equity, social–ecological integrity, and ethics, along with how these concepts vary across and within cultures and how they can be integrated to contribute to addressing sustainability problems. Systems thinking includes the ability to analyze complex systems, both across the major areas of sustainability, including society, the environment, and the economy, and across different scales, from local to global, all while "considering possible cascading effects, inertia, feedback loops, and the other systemic features related to sustainability issues and sustainability problem-solving frameworks" (Wiek et al., 2011, p. 207). Finally, strategic thinking involves considering various pathways for addressing environmental problems, including identifying alternative solutions, and challenging existing cultural assumptions about wicked problems (Lawrence, 1999). This process may identify new solutions that may be more culturally and environmentally appropriate, especially when influenced by futures, values, and systems thinking.

SEFT's four ways of thinking are inherently interlinked, and combining them to address sustainability issues, especially resource allocation, aids in linking sustainability topics that are seemingly disparate and too complex for the novice teacher population to understand and teach about without specialized formal study. Instead, using these different ways of conceptualizing scientific concepts builds knowledge, skills, and attitudes necessary for addressing social and environmental problems with respect to complex sustainability challenges. As a conceptual framework, SEFT offers organizing principles for examining and considering sustainability problem–solution sets, like those explored in the SSFT course. It offers a logical framework for working in interpersonal, intragroup, and intergroup situations. Reconceptualized from existing sustainability literacy (Stibbe and Luna, 2009), sustainability competency (Wiek et al., 2011), and sustainability development literature (Sachs, 1997, 2004), the framework is streamlined for a teacher audience.

Course Overview

SSFT is a semester-long hybrid class that aims to develop preservice teachers' science content knowledge in the context of society's engagement with science and technology. See Archambault and Warren (2015) for a detailed overview of the course curriculum and structure. Additional information can also be found online via http://sse.asu.edu/courses/scn400/.

Connecting Sustainability and Geoscience

Over the semester, SSFT explores 13 weeklong units, or domains of sustainability knowledge: introduction to sustainability, population, poverty, food, water, fossil fuels, new energy, ecosystem services, biome stories, production, disposal, governance, and change. Many of the units draw inspiration from Earth systems and geoscience to teach sustainability concepts, especially in relation to natural cycles, resource limitations, and the effects of human–nature interactions on the environment. For instance, the Water unit explores the natural water cycle, as well as different ways that humans use and alter this cycle on different scales, from the community level to the national and international levels. As another example, the Ecosystem Services unit examines basic environmental and geosciences, focusing on how the carbon system functions, how fossil fuels are derived from geologic exploration, and how humans exploit basic ecosystem functions to further the success of the human species but often do not realize how much they are altering natural systems or affecting other species, humans, and organisms.

Across the units, preservice teachers learn about different aspects of core geosciences to understand what systems are in place and how human intervention has changed these systems, as well as an overview of the consequences of those changes. By combining geoscience, sustainability concepts, and new pedagogical resources and perspectives, the goal is for preservice teachers gain confidence in their grasp of basic geoscience and environmental science concepts, which may make them more effective at translating sustainability concepts to their future students.

Course Design Team and Instructors

An interdisciplinary design team of experts in sustainability, science education, pedagogy, and technology was brought together in 2011 to create the initial content for the SSFT course. The team included 20 individuals, composed of professors, postdoctoral fellows, graduate students, graphic designers, and administrative support. The team's specific disciplinary training ranged from scholars steeped in sustainability science and geoscience, with an emphasis on phosphorus recovery, water systems and governance, nanotechnology, genetics, food systems, justice, and urban landscapes, to those with training in educational technology, engineering, and the science of design. The team updates all course materials annually to reflect principled practices that satisfy both education and sustainability requirements. Instructors for the course vary by semester and come from a variety of disciplinary backgrounds, including sustainability science, science and technology studies, justice studies, and education.

Course Student Population

Approximately 125–200 preservice teachers enroll in SSFT each semester, divided into course sections of 20–35 teachers each. Although demographic data have not been formally collected since the course's inception, demographics were collected in the most recent semester, spring 2016 ($n = 99$). At that time, the SSFT student population was predominantly female (92%), identified as white or Caucasian (77%), and was interested in teaching grades 3–5 (65%). Most preservice teachers were under the age of 25 (86%) and were considered digital natives who have grown up using computers, the Internet, and mobile technologies (Lei, 2009). These population descriptors are consistent with informal observations of the student population since SSFT's inception in 2011.

Initial Evidence of Course Impact

Foley et al. (2015) provided initial evidence demonstrating that SSFT is an effective way to cultivate sustainability literacy among preservice teachers. In the study, preservice teachers enrolled in the first SSFT cohort (fall 2012) were asked to create sustainability concept maps at the beginning and conclusion of the course. Upon comparing the maps within subjects, results indicated that most preservice teachers entered the course with limited understanding of sustainability. By the end of the course, preservice teachers' understandings became more complex and interconnected, with concept maps that had significantly more nodes and levels of hierarchy, reflecting a greater depth of understanding. The study suggests that SSFT is a promising intervention for developing sustainability literacy but was limited because it used a limited sample size and only examined proximal outcomes of current students, as opposed to exploring lasting impacts over time, actual classroom impacts, or both.

The current study extends Foley et al.'s (2015) work, examining outcomes from a larger sample of SSFT preservice teachers across multiple data sources, while also examining impacts to classroom practice (distal outcomes) among course alumni. The current study focuses specifically on how the SSFT curriculum draws on the knowledge, processes, and logic from Earth systems to inform sustainability education for preservice teachers, using the Water unit as a case study.

METHOD

Design

A case study approach was used, because this supports the exploration and description of a rich and authentic course context (Yin, 2014). The Water unit was explored as a single case, addressing the following research questions:

1. How was the Water unit designed to reach the goals of developing new understandings of science, geoscience, and sustainability and new ways of teaching and thinking in preservice teacher-students?
2. How did the Water unit affect future teachers?

To address the first research question, we provide a narrative description of the structure, design, and content for the unit. To address the second research question, we evaluate evidence regarding preservice teachers' beliefs and products from the learning experience. We also explore course alumni reports about the lasting impacts of the learning experience. Regarding teachers' perspectives and practices, qualitative and quantitative data sources were analyzed together to consider the most robust evidence available (Creswell, 2015).

Case Selection

The Water unit was selected because it is an ideal example of connecting geoscience and sustainability within SSFT. In the unit, preservice teachers learn about hydrology systems, including human-produced systems and natural systems such as the water cycle, while considering the impacts of these systems on humans, the environment, and the economy. Preservice teachers evaluate and explore how to engage these concepts with K–8 students through hands-on activities and a lesson evaluation assignment. The Water unit is an example of the extent to which the study of Earth systems truly complements SSFT's approach to sustainability education.

Data Sources and Analysis

To address the first research question, we garnered evidence from a number of course materials, including the syllabus, online course resources, the instructors' collaborative online wiki site, and lesson plans for the face-to-face (FtF) class meetings. The authors also brought knowledge of their personal experiences as instructors and designers for the course.

To address the second research question, qualitative and quantitative data were collected from three sources (Table I). The two surveys were developed by the course design team using an iterative process (Czaja and Blair, 2005). Quantitative data were analyzed for descriptive frequencies, and qualitative data were open coded, drawing on a constant comparative approach (Strauss and Corbin, 1998). In coding open-ended responses, we identified several themes of interest in participants' responses regarding why they believed water was an important topic (course exit survey) and why course alumni chose to teach this topic (alumni survey). We also identified exemplars that embodied compelling examples of the observed themes in the participants' own words (Tracy, 2013).

TABLE I: Case study data sources.

Data Source	Quantity	Quality	Sample	*n*	Response Rate	Format
Course exit survey	Yes	Yes	Preservice teachers in the spring 2016 cohort	123	99%	•Web-based survey •15 minutes to complete •Administered at last course meeting of spring 2016
Alumni survey	Yes	Yes	Preservice teachers in the spring 2012–spring 2013 cohorts	99	31%	•Web-based survey •15 minutes to complete •Administered in summer 2014
Sustainability unit projects	Yes	No	Students in the fall 2012–spring 2015 cohorts	819	81%	•Students' digital artifacts (typically websites) showcasing an original sustainability unit they created for elementary students

Trustworthiness and Limitations

This case study presents limited and contextually bound evidence, so it is difficult to generalize findings (Yin, 2014). Nonetheless, it takes place in an authentic setting and, as a case study, aims to provide a rich description of a unique case, which may provide nascent ideas for applications to similar contexts. The concerns and proposals explored in SSFT are intended to be global, but the course was created by a group of scholars and designers situated in a Western industrialized society. The data presented in this paper rely primarily on self-report from preservice teacher-students and course alumni, which may not necessarily be reflective of participants' actions or observable experiences (Fowler, 2002). Future work may provide a more complete picture by investigating impacts via observational methods such as classroom observation and lesson plan artifact analysis.

In addition, as much as the course aims to address significant sustainability and geoscience content, as well as teaching strategies to incorporate this content into K–12 classrooms, there are constraints to what can be accomplished in a single semester. Although the course seeks to improve both content knowledge and pedagogical approaches to teaching, there is always potential to improve. One area for future advancement may include more directly addressing ways to help teachers be prepared to meet the needs of student populations that are directly and differently affected by sustainability challenges, specifically dealing with the equitable or inequitable distribution of impacts, in addition to brainstorming ways to tackle such challenges. Often this area is addressed through in-class activities and discussions that happen during the weekly FtF portion of the course. However, the main thrust and focus of the course remains centered on building future teachers' pedagogical content knowledge (Shulman, 1986) specific to sustainability science.

Finally, the authors have been involved in both the development and the instruction of the course. As a result, they have had intimate experience with it over time. While some may view this as a limitation to impartial evaluation, we view it as an advantage. Our truly immersive experience with the course, preservice teachers, and instructors over time allows us to provide a deeper, richer, and more accurate analysis of the context (Tracy, 2013).

RESULTS

Description of the Water Unit Design

The Water unit is presented during the fifth week of the SSFT course sequence. The essential question asks, "How can we provide water to meet human needs sustainably?" Activities for both online and FtF portions of the unit are presented in Table II. Consistent with the other weeks in the course, before attending the in-person class, preservice teachers watch online digital storytelling videos (Robin, 2008), complete an online quiz, and write a personal reflection submitted online. Then, in the FtF class, preservice teachers engage more deeply with the concepts in collaborative groups, concluding with a K–8 lesson plan evaluation completed online. Throughout the unit, preservice teachers employ SEFT's four ways of thinking (Warren et al., 2014), considering the water issues presented with a critical lens. Below, we describe the curricular components of the unit, organized by the two principal learning objectives for the course, which aim for preservice teachers to develop new

TABLE II: Water unit activities.

Goal	Process	Environment	Activity	Description
Developing new ways of thinking	1	Online	Digital stories	Watch seven digital storytelling video segments
	2	Online	Formative assessments	1. Complete a 10-item electronic quiz
				2. Write a two-paragraph personal reflection on the water topic
Developing new ways of teaching	3	Face-to-face	Hands-on activities	Participate in collaborative centers exploring water systems
	4	Online	Lesson plan evaluation	Write an evaluation of an authentic water lesson plan

TABLE III: Water unit video clips.

Video Clip	Title	Description
1	Introduction to H_2O	The scientific study of hydrology, including the hydrologic cycle, is presented.
2	Water as a System	Water sustainability is explored, including a focus on the balance between the demand for water and the natural supply.
3	Waste Water, Labor, and Energy	Where does our water go when it leaves our house, and how does it get clean?
4	Human Health and Water	According to the World Health Organization, poor water supply sanitation and hygiene causes water-related diseases such as enema, dehydration, and malnutrition.
5	Environmental Health and Water	The rapid increase of human population over the last century, from 2 billion people in 1910 to 7 billion people in 2010, has created pressure on many environments in which humans have transformed the water landscape.
6	Local Case Study: Phoenix, Arizona's, Water Sources	The Phoenix, Arizona, water supply comes from three primary sources: aquifers, the Salt and Verde Watersheds managed by The Salt River Project, and the Colorado River. The complexities of these systems are explored.
7	Global Case Study: Bali's Water Management	Balinese "water temples" and the management of irrigation systems as a sociocultural practice are presented. Are major water infrastructure investments the only way to manage society's need for water?

understandings and new ways of teaching sustainability science.

Developing New Understandings

A first goal of the course is to develop preservice teachers' content knowledge regarding sustainability science and their ability to critically evaluate sustainability problems and solutions. Because SSFT preservice teachers as a population enter the course with limited sustainability knowledge (Foley et al., 2015), the unit was designed to first provide sufficient coverage of water issues followed by scaffolded student interaction with the material.

Digital Stories

The unit begins by presenting the topic of water through seven digital storytelling video vignettes spanning approximately 60 minutes (Table III). Preservice teachers watch at their convenience before attending class. The digital stories visualize authentic sustainability stories that consider global and local issues, following the cadence of a captivating documentary. The stories are produced by the SSFT course design team, and an in-depth discussion of the video design process is forthcoming (Archambault, Shelton, and Hale, submitted) To obtain a sense of the video content, the Water unit trailer is viewable at http://sse.asu.edu/courses/scn400/.

These digital stories present a narrative story, which prompts consideration of how sustainability issues are shaped by and for various technologies, landscapes, peoples, and places. For example, one of the Water unit vignettes tells the story of traditional water systems in Bali, describing how these once locally sustainable systems were remade by well-meaning international nongovernmental organizations and corporations to serve more people with water. But without understanding how local practices were rooted in an intimate knowledge of available water resources, the modern system broke down continually, resulting in less efficiency and an inability to cope with stochastic rain patterns and seasonal flooding conditions. The technology proved sound in one context but was applied in a way that was not suitable for the local setting, making water a less sustainable and usable good.

In another Water unit vignette, we explore the Central Arizona Project (CAP), a 300-mile canal system that brings water from the Colorado River to the Salt River Valley and the major urban center of Phoenix, Arizona. The video shows the historical aspects of water management in a desert climate, because the CAP supplies water not only to the city but also to a hydroelectric plant that provides electricity. Technological advances have allowed Phoenix to grow to a metropolitan area of 4.5 million residents, but based on future projections of rainfall and climate change, it is doubtful that Phoenix can sustain this level of growth without considering different methods for conserving water and a more detailed understanding of its water resources. This is a critical aspect of water management for the metropolis of Phoenix and many other desert cities. However, preservice teachers are generally unaware of where water for the city comes from, undermining their ability to teach about it and limiting the development of sustainability concepts surrounding water management in the American Southwest.

These described digital stories, along with others that visualize the human and natural water cycles and those that teach preservice teachers how to directly apply SEFT's four ways of thinking to real-world situations, make up the video content for the Water unit and have the explicit goal of being "explanatory stories" that underscore how human values influence the application of science and technology and why these systems are not always sustainable, equitable, or legible to the general citizen or end user. Combining water system concepts with sustainability ideas aims to facilitate learning different notions, strategies, and examples in a short amount of time through interrelated ideas, which altogether provide a richer understanding of the topic—geoscience and sustainability science are complementary topics that work to reinforce each other. It also gives an overview of the complex interplay between human and natural systems using both local and international examples.

TABLE IV: Water unit written reflection prompts.

Way of Thinking Addressed	Prompt
Systems thinking	What makes up Phoenix's water system?
Futures thinking	How has Phoenix used (or failed to use) futures thinking to develop policies governing the production and distribution of water?
Values thinking	How does values thinking play a role in how, and for what purposes, water is used in Phoenix?
Strategic thinking	What are some strategies to ensure that Phoenix starts using water more sustainably?

Formative Assessments

The digital stories are followed by a 10-question multiple-choice online quiz, serving as an accountability check. Preservice teachers value the quiz to stay on track and monitor their learning (Shelton et al., 2016). They also write a reflection designed to promote deeper thinking and a personal connection with the video content. In two written paragraphs, preservice teachers consider the sixth digital story about the CAP, a critical water supply for Phoenix, and address the prompts in Table IV. The prompts were designed to (1) ignite interest, through the exploration of the relevant, local issue of water security in their desert climate, and (2) develop deeper understandings about issues preservice teachers may not have previously considered. Because most preservice teachers care deeply about making the world a better place, the prompts also aim to resonate with their interest in finding solutions and positive outcomes to big, complex, yet practical problems.

At the core of the Water unit is the value that understanding complex Earth systems offers a rich way to motivate the exploration of sustainability problems—be it through exploring visual narratives of water stories throughout the world or critically considering local water sourcing options and solutions. It also examines the natural system and the myriad ways that humans interact with, and affect, these biophysical systems, as well as different ways that the cultural values of water are understood and used by different societies. Next, the unit goes beyond developing preservice teachers' understanding of the content to empowering them with the pedagogical content knowledge (Shulman, 1986) needed to teach these concepts.

Developing New Ways of Teaching

How might the big, complex ideas that preservice teachers consider in the videos and online assignments be translated for K–8 students? The second half of the Water unit focuses on classroom applications of water sustainability. To empower future teachers to not just know the concepts but also be able to teach them, two activities were developed: a collaborative exercise designed to explore water systems and a written evaluation of a lesson plan. Each stage of this process reiterates geoscience concepts in relation to sustainability concepts, underscoring how foundational scientific concepts about Earth systems are an integral part of understanding how values drive knowledge production and how human-created technological systems, like canals and sewers, reflect values that are not rooted in sustainable practices.

TABLE V: Water unit lesson plan evaluation prompts.

Writing Prompts
1. How was strategic thinking exemplified in the lesson plan?
2. How did the information in the lesson plan reinforce the data, logic, and ideas in this week's online content?
3. Explain how you might modify the plan to connect the lesson to the daily lives of K–8 students to inspire action and change.

Collaborative Centers: Exploring Water Systems

During the 75-minute FtF class meeting, preservice teachers engage in a collaborative learning activity in which they create demonstrations of the water cycle and human-managed water systems using different presentation modalities, such as building a physical model with clay, markers, and paper; drawing a graphic display; or writing a narrative story to describe the system (see the full lesson plan in the supplemental file available in the online journal and at http:dx.doi.org/10.5408/16-177s1). The activities emphasize considering the interconnectedness of human and environmental systems and are intended to simulate a learning experience that might be adapted to the K–8 classroom. Geoscience concepts about natural systems are an integral entry point for understanding how human activity has changed water systems locally and globally. This approach informs how preservice teachers can use different SEFT ways of thinking to facilitate K–8 students' consideration of how to make more sustainable decisions in their lives, carrying concepts and ideas further as they learn more about the world.

Lesson Plan Evaluation

The unit culminates in an evaluation of an existing K–8 lesson plan on the topic of water that presents a hands-on learning activity in which elementary students learn about what happens to water once it goes down the drain in their home and how it becomes drinkable again, demonstrating an explicitly anthropocentric approach to water management by humans. The lesson plan was selected because it was an authentic online source and represented an adequate example of exploring water issues in the K–8 context. Table V illustrates the lesson evaluation prompts completed by preservice teachers. This assignment was designed to support preservice teachers in establishing connections between the water sustainability stories that they grappled with throughout the unit and how concepts can be made relevant to their future elementary curricula. It also aims to show them an example of interdisciplinarity in elementary lessons, in which concepts and standards from science, math, social studies, and English and language arts are integrated. This is important in establishing relevance for preservice teachers who are highly motivated by wanting to integrate the standards yet simultaneously find standards integration, especially across scientific content areas, to be a challenging task.

In summary, the Water unit was designed to both quell preservice teachers' fears about a lack of understanding of

TABLE VI: Evidence of teachers' interest in teaching the topic of water.

Data Source	Frequency Selecting Water/ Total Participants (%)	Was Water the Most Commonly Selected of the 12 Topic Options?	Data Source
"Of the 12 sustainability topic weeks in the course, which topic do you most envision teaching in your future classroom?"	116/123 (94%)	Yes	Course exit survey
"Of the 12 sustainability topic weeks in the course, which topic have you addressed in your classroom?"	36/53 (72%)	Yes	Alumni survey
Frequency of preservice teachers selecting water for their sustainability project topic	172/819 (21%)	Yes	Sustainability unit projects

geoscience concepts and give them practical tools and perspectives for teaching diverse K–8 students about sustainability concepts. The unit is an example of providing specific content knowledge and practical teaching strategies, but the question remains: What do teachers take from the learning experience?

Impact of the Water Unit

To assess how preservice teachers have been affected by the Water unit, the data sources listed in Table I were analyzed together.

Water Is a Popular Topic

Across all three data sources, participants consistently indicated that the Water unit was the SSFT topic they were most likely to teach in their own classrooms (Table VI). At the end of the course, the highest frequency of preservice teachers envisioned teaching the Water unit over other sustainability topics covered in the course. Furthermore, course alumni in their first year of teaching or student teaching listed water as the most common topic that they addressed in their classrooms. Finally, preservice teachers most often selected water as the topic for the sustainability unit they create for their final projects.

Why Water Resonates With Teachers

Next, we explored the reasons for teachers' interest in teaching the Water unit. On both the exit survey and the alumni survey, after teachers selected their preferred course topics, they were asked to indicate the reason for their selection. Thematic analysis of responses indicated that water was a compelling topic because it lent itself to teachers' development of (1) action-oriented understandings and (2) new ways of teaching. Both are discussed next.

Developing Action-Oriented Understandings

Participants explained that the Water unit was compelling because the unit helped them develop newer, deeper understandings of environmental systems and human interactions and inspired a personal desire to improve sustainability problems. Table VII presents exemplar responses. The evidence suggests that relevant concepts relating to Earth systems, such as the human and natural water cycle, resonate with the preservice teacher audience because they expose teachers to new and relevant ideas while connecting with teachers' desire to make the world a better place. Preservice teachers are generally uninformed about science, current events, and sustainability issues or unsure how to incorporate them into standards (Appleton, 1995; Westerback, 2006; Howitt, 2007). However, they care deeply about making the world a better place (Fullan, 1993). They stand to gain from the applied study of real-world water problems when considering their connections to sustainability.

Developing New Ways of Teaching

Participants also indicated that the Water unit was compelling because it could be so easily applied in their future classrooms. Future teachers explained that they felt empowered to teach the topic of hydrology and sustainability because it (1) was interdisciplinary, (2) connected to the established curriculum they are already expected to teach, (3) incorporated engaging content relevant to the real world and preservice teachers' lives, and (4) aligned with national and state standards to which they are already required to teach. Table VIII presents exemplar responses embodying these four subthemes.

Participants indicated that the study of water was exciting because it lends itself to a host of pedagogical opportunities for K–8 students. First, they cited interdisciplinary opportunities, explaining that the Water unit was relevant to a variety of other sustainability topics, including access and equity locally and around the world, food production, and population limitations. They also believed water was a useful topic for facilitating student learning across content areas, including math, science, social studies, and English and language arts. Second, participants expressed that the Water unit corroborates well with topics, standards, and units being taught in elementary and middle school classrooms and aligns with the Next Generation Science Standards (NGSS Lead States, 2013) and Common Core Standards (National Governors Association Center for Best Practices and Council of Chief State School Officers, 2010). Likewise, the topic is relatable to both teachers and K–8 students. Water is a particularly relevant topic in the desert southwest and is more age-level appropriate in terms of complexity and sensitivity than other SSFT topics, such as poverty and population.

DISCUSSION AND IMPACT

Through an exploration of SSFT's Water unit, we highlighted the curricular design decisions and processes

TABLE VII: Action-oriented understandings that teachers developed through the study of water sustainability.

Participant Response	Themes Embodied in the Response	Data Source
"Growing up we kind of see that the earth has so much water and you think its [sic] an endless supply, but you realize as you get older that its not. Classes like this allowed me to understand why."	1. Newer, deeper understandings	Course exit survey
"I never realized just how complicated the process of having clean water is. It opened my eyes to how much I take for granted the accessible water I have in my life."	1. Newer, deeper understandings	Course exit survey
"I did not know about regulations on municipal water versus bottled water, the process our water goes through again and again to make it accessible to all houses."	1. Newer, deeper understandings	Course exit survey
"I had never thought twice about using plastic water bottles. I didn't even know that they can be harmful to the environment."	1. Newer, deeper understandings 2. Desire to create action-oriented change	Course exit survey
"It was an eye opener as to how much water is wasted on a day to day basis. Furthermore, the fact that our water resources are being depleted without being replenished is very scary. My habits as well as my families at home have changed drastically. We have taken inventory of the areas that need change. We have purchased small cups for brushing our teeth. We tried turning the faucet off as we brushed and then only let water run as we rinsed, but we felt that wasn't enough. We purchased small cups and used that amount wisely to rinse. We feel that by making this small change we have made a big difference in preserving water. We also time out [sic] showers now to five minutes instead of a long shower that lasts longer than needed. Although these changes have been small ones, we feel that we are making a positive difference."	1. Newer, deeper understandings 2. Desire to create action-oriented change	Course exit survey

TABLE VIII: New ways of teaching that teachers developed through the study of water sustainability.

Participant Response	Themes Embodied in the Responses	Data Source
"In teaching 6th grade science this year, [in] much of my core curriculum I am able to connect back to the topics discussed in this course. I completed a water unit with them [my students] in which they looked at various countries worldwide and their access to clean drinking water. They considered the connections that clean water has on other aspects of people's lives."	1. Interdisciplinarity 2. Established curriculum	Alumni survey
"Population and poverty are both ideas that are already taught in a social studies curriculum. These topics are interwoven with the topics of food and water. Students should see that population has a direct link to water, food and poverty."	1. Interdisciplinarity 2. Established curriculum	Course exit survey
"I would like to teach students about where their food and water comes from, as this is extremely relevant to each of their lives. Students should be aware of the challenges that we face related to food and water access, availability/security."	1. Interdisciplinarity 2. Real-world relevance	Course exit survey
"I really enjoyed my unit lesson plan on The Great Pacific Garbage Patch that we did for the final project. In my lesson plan, I interwove sustainability in with other science concepts that the students have to learn in/by the 6th grade, such as the water cycle and food webs. I also incorporated math into my lesson plan by having the students dissect their own garbage and finding out the percentages of the types of garbage they found (plastics, glass, paper, etc.). Finally, I included a writing portion, where students will be able to create brochures to be given to restaurant managers to ask them to be more conscientious of the waste that they create. Students will be engaged, using the current standards, and combining the problem solving skills of scientists in a real world problem to come up with solutions. I imagine I will come up with many lesson units like these in the future. Not only are they engaging but also teach students how to problem solve by using real world context and engineering design challenges which use higher order thinking skills."	1. Interdisciplinarity 2. Established curriculum 3. Real-world relevance 4. Standards	Course exit survey

that make the development of this learning experience possible. Evidence from course alumni and preservice teacher-students suggest that SSFT's approach for connecting Earth systems to sustainability topics is particularly popular among preservice teachers and a meaningful learning experience that affects them as teachers and as citizens.

Reflections: Designing the Unit

The design decisions for the Water unit were rooted in teaching best practices, vetted over repeated iterations of the course (Archambault et al., submitted). One of the biggest challenges the course designers faced was making decisions about the best content to convey the complex interplay of geoscience and sustainability while engaging and challenging preservice teachers. One example of this challenge has been in determining the video content that makes the cut for the digital stories. The design team acknowledges that the digital storytelling videos ultimately used in the course do not necessarily render the whole story of the water cycle. Rather, specific representative aspects are presented, because they are worth investigating and engaging with for purposes of the course. As MacKian (2010) notes, "We choose what to observe, what to record, what to render visible, and there is no such thing as immaculate perception" (p. 360). Stories, whether textual or visual, are performances that require analysis, interpretation, and presentation—they are movements, shapes, and gestures of everyday experiences (Dewsbury, 2010). They are impressions of what was, is, or could be, and this type of experience is key when exploring sustainability science and geoscience concepts.

The videos not only inform about certain topics but also serve as points of initial inquiry, encouraging learners to ask themselves how certain systems they may take for granted, like water or energy, are parts of historical patterns and embedded value systems. It is critical that instructors address this issue, connecting the online materials to relevant discussion and action in the FtF environment. Unlike traditional notions of science concepts (Chandler, 2010), sustainability acknowledges that problems and stories are multifaceted and should be interpreted with a critical lens. The present analysis of SSFT's Water unit suggests that study of water, and geoscience in general, benefits from taking the sustainability perspective.

Reflections: Affecting Preservice Teachers

The present findings extend our understanding of the impact of SSFT beyond the initial work by Foley et al. (2015) by examining a number of data sources over the 4 y of the course. Water overwhelmingly affected preservice teachers, and this impact extended longitudinally in course alumni, who reported bringing water sustainability concepts into their classrooms.

The reasons for these impacts are multifaceted. SSFT employs an intervention targeting individuals as citizens and future teachers. One cannot separate these two aspects of identity. If one is affected as a citizen, learning new ideas and deepening one's understanding of complex sustainability and environmental science issues, it is likely that these ideas will carry over into the classroom in some way, whether overtly, through formal teaching, or covertly, in the "hidden curriculum" in the class. Similarly, if preservice teachers are emboldened to teach sustainability topics, by pursuing such topics in the classroom, they can likewise be affected personally, as citizens. In the FtF Water unit activities, engaging in a simulation of what it would be like to apply the content to a K–8 audience or thinking about a lesson plan evaluation develops preservice teachers' conceptual understanding even more deeply. Preservice teachers continue to develop their ideas about water and sustainability after the unit ends, throughout the SSFT course (as they engage in their classroom internships and the remaining units in the course), and beyond (as ideas, ways of thinking, and new ways of teaching evolve over time).

CONCLUSION

SSFT is a small-scale effort to answer the call to produce sustainability-minded and scientifically knowledgeable citizens prepared with the skills, attitudes, and literacies that are needed to engage with sustainability, technological, and societal issues content (Stibbe and Luna, 2009; Nolet, 2013, 2016). The course was designed to provide creative examples for preservice teachers to consider and use in their own teaching after graduation. The use of both online and FtF learning components aims to integrate digital storytelling video, reflection, and hands-on activities in an engaging and modern way. The use of virtual spaces aims to engage preservice teachers, foster autonomy, and differentiate for individual needs. By exploring teachers' feedback regarding the Water unit, we see that this method is an effective way to enable teachers to take control of the informational content, including geosciences, environmental science, and sustainability concepts, with innovative pedagogical elements, such as modeling activities, that dovetail with current academic standards but have a focus on teaching ideas about values and sustainable environmental practices.

SSFT attempts to answer the call from the NRC Committee on Science Learning, stating that increased effort on science literacy is important in the K–8 space (NRC, 2007). The SSFT model may provide a useful example for other initiatives targeting teacher education regarding the geosciences and sustainability. Through SSFT, we created accessible and engaging content for elementary educators, animating geoscience content through sustainability science. Geosciences are a critical and foundational aspect of the sustainability concepts in the course. By teaching them in a way that is easily accessible and grounded in material examples, and by using activities that model the geosciences, as well as SEFT's four ways of thinking, SSFT is able to engage with preservice teachers in a unique and inspiring way. Complex and often wicked problems, such as groundwater remediation, water management, and equitable distribution across present and future societies, require creative, adaptive educators who can propose and strategically implement novel solutions. They also require educators who can inspire hope and action among their students, the next generation of changemakers.

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