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Article *in* Soil Science Society of America Journal · July 2016

DOI: 10.2136/sssaj2016.03.0056

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Published July 7, 2016

Integrating Soil Science into Primary School Curricula: Students Promote Soil Science Education with *Dig It! The Secrets of Soil*

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Principles of soil science are highly complementary with subjects required by state and national standards and offer an opportunity to integrate science, technology, engineering, and math (STEM) education and non-STEM subjects, such as history and anthropology. However, soil science is often absent from primary education curricula. This is a missed opportunity for both primary education and the soil science community. We integrated soil science into primary education using the Soil Science Society of America (SSSA) traveling soil science exhibit *Dig It! The Secrets of Soil*. This effort was unique in that primary school educators, The California Museum staff, SSSA, and University of California–Davis graduate students worked to make the exhibit into an external classroom for Grades 2 through 7. The goal was to raise awareness and knowledge of soils and their importance to society and to offer example career opportunities in soil science. Grade-specific presentations and activity-based workshops were designed to address California curricula standards. These efforts identified several gaps and opportunities in soil science outreach to primary education. Participatory and observational activities were critical for conveying concepts across all educational grades. Curricula standards represented a potential constraint and corresponding entry point to facilitate the incorporation of soil science into primary education. Our experience demonstrates the ongoing impact of *Dig it! The Secrets of Soil*, and illustrates the potential of collaboration between academic institutions like UC–Davis and SSSA to improve soil science education.

Abbreviations: SSSA, Soil Science Society of America; STEM, science, technology, engineering, and math; UC, University of California.

Core Ideas

- **There is a need to incorporate soil science into primary education.**
- **A partnership brought soil science to Grades 2–7 in the Sacramento–Davis area of California.**
- **Graduate students used the *Dig It!* soils exhibit to engage primary school students.**
- **Curricula standards are a potential constraint and entry point for soil science.**

Soils are the foundation of terrestrial ecosystems and are closely linked to global issues such as climate change, water resource sustainability, and food security. Therefore, teaching about soil roles in these areas offers a unique way to integrate chemistry, physics, biology, and geology. The multifaceted roles that soils have played in human interactions with the environment additionally represent an opportunity to teach history and anthropology through the lens of soils. There is a growing need for an informed soil science perspective, yet enrollment and graduation of soil science students in university undergraduate and graduate programs is in decline nationally and globally. This has been partly attributed to a lack of public awareness of soils and their value to society (Baveye et al., 2006; Hartemink et al., 2008). The near absence of soil science content in primary education curricula may be contributing to this lack of awareness.

The importance of soil science in primary school was suggested early on by Dawson (1956), and more recently, Drohan et al. (2010) called for the development of a national (US) soil science curriculum. As part of the International Year of Soils in 2015, the Soil Science Society of America (SSSA) launched an online

Soil Sci. Soc. Am. J.
doi:10.2136/sssaj2016.03.0056
Received 1 Mar. 2016.
Accepted 10 Apr. 2016.
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resource for K–12 teachers. This website provides soil science background for educators, as well as teaching resources such as grade-specific concepts, lesson plans, and classroom activities (http://www.soils4teachers.org/). However, time and resource demands of curriculum standards may challenge individual educators' efforts to incorporate elements of soil science. In some cases, explicit standards may preclude soil science from curricula, which may be grade specific. On the other hand, curriculum standards could facilitate large-scale integration of soil science into primary education. For example, the adoption of Common Core standards by 43 states by 2015 (Council of Chief State School Officers, 2015) is an opportunity to develop a basic set of soil science resources compatible with these standards and therefore adoptable at a national scale.

Outsourcing soil science education resources through partnerships between primary school educators and the soil science community is a potential strategy to incorporate soil science into primary education. To this end, a collaboration between soil scientists from University of California (UC)–Davis, The California Museum, USDA, and SSSA was developed to adapt a soil science exhibit as an external classroom for primary students. During its 2014 to 2015 tenure in Sacramento, CA, the SSSA-commissioned *Dig It! The Secrets of Soil* was used to raise awareness and increase knowledge of soils and their importance to society of visiting classes across grade levels 2 to 7. The objective of UC–Davis's role in this partnership was to contribute soil science expertise, assist in curriculum development, and facilitate and guide classroom tours at the exhibit.

APPROACH AND PRACTICES

The *Dig It!* Exhibit

Thorough descriptions of the exhibit and its development have been provided by Megonigal et al. (2010) and Drohan et al. (2010), respectively. An online explanation of the exhibit's motivation and history, along with photos of its components, is available at https://www.soils.org/discover-soils/dig-it. According to Megonigal et al. (2010), "the primary goal of public soils education should not be to teach, but to inspire. The goal to inspire guided the design of *Dig It! The Secrets of Soil*." The exhibit adopts an ecosystem perspective and is module-based (e.g., soil monoliths, looping videos, scale models).

Collaboration among Multiple Institutions

In describing lessons learned from the first deployment of the soils exhibit, Drohan et al. (2010) noted that greater visibility for soil science entails partnerships with professionals outside of the discipline. Our approach required collaboration among multiple organizations including the UC–Davis Soils & Biogeochemistry Graduate Group, The California Museum staff, SSSA, and primary school educators in the Sacramento Valley. In addition to hosting the exhibit, The California Museum coordinated and managed field trips (e.g., information technology [IT] support, trained staff, paperwork) and advertised the exhibit to schools, primary school educators, and the general public. Because field trips are a key demographic for museums (Anderson et al., 2006), materials and knowledge resources for primary school outreach may already be in place and accessible through partnerships with museums. Two UC–Davis graduate students worked closely with The California Museum staff, including: (i) training staff in soil science principles and specific aspects of the exhibit (e.g., monolith interpretation, clarification of soil orders, explanation of the global soil map); (ii) interpreting curriculum standards and adapting exhibit modules (see below and Table 1); (iii) transforming the exhibit as an external classroom; and (iv) serving as docents for visiting classes, which also extended to guided tours for the general public. Graduate student docents acted as a liaison with SSSA to communicate these efforts and their outcomes. Graduate students also worked with SSSA on supporting activities (e.g., soil science fair contests) that benefited the use of the exhibit as an external classroom and SSSA's development of online teaching resources December 2014 to February 2015 as part of the International Year of Soils. To organize further UC–Davis involvement, a graduate student-run seminar was established to train and organize additional student docents. The cost of UC–Davis efforts were estimated at US$22,000 (April 2014–2015), which included travel (32 miles round trip), parking, and salary for the two graduate student docents. While the two lead graduate student docents worked on this project intermittently throughout the year, the outreach fellowships covered the lead docents' full-time summer salary for 3 mo, totaling US$21,560.

Fitting Exhibit-Based Field Trips to Curriculum Standards

The UC–Davis graduate students and The California Museum staff compiled and interpreted California curriculum standards that could be addressed by components of the exhibit. Addressing curriculum standards illustrated the relevance of soil science and helped justify the field trip to primary educators. Providing a suite of standards addressed by the exhibit allowed flexibility and matching of individual educators' curricula with exhibit offerings, which can be a strong determinant of whether and where science field trips are taken (Kisiel, 2005).

Soil science principles illustrated by exhibit modules were applicable to science content standards, in particular in Earth Sciences, but this opportunity varied greatly by educational grade. California standards for second and sixth grades were most adaptable to soil science because of their emphasis on geology and earth sciences (Table 1). Science content standards for second grade describe soil-forming processes (weathering) and soil properties (texture, water-holding capacity). Given the strong suitability of soil science to meet second grade science standards and the effectiveness of introducing observation-based science at earlier rather than later education levels (Saçkes et al., 2011; Trundle, 2015), we suggest that second grade is a strategic entry point for a proposed national soil science curriculum (Drohan et al., 2010).

Table 1. Example of California curriculum standards from select grades and their interpretation for soil science concepts and integration with the SSSA soils exhibit *Dig It! The Secrets of Soil*.

Grade	Standard set	Specific standard	Description	Soil science concept†
			California science standards	
2	3: Earth Sciences	3b	students know smaller rocks come from the breakage and weathering of larger rocks	weathering, parent material[1,2]
		3c	students know that soil is made from partly weathered rock and partly from organic materials and that soils differ in their color, texture, capacity to retain water, and ability to support growth of many kinds of plants	weathering, texture, soil composition and properties[1,2,3,4]
3	3: Life Sciences	3b	students know examples of diverse life forms in different environments	soil biodiversity[5,6,7]
4	2: Life Sciences	2c	students know that decomposers, including many fungi, insects, and microorganisms, recycle matter from dead plants and animals	nutrient cycling, soil organic matter[5,7,8,9]
	3: Life Sciences	3a	students know that ecosystems can be characterized by their living and nonliving components	soil composition, soil organic matter[5]
			Students know that most microorganisms do not cause disease and that many are beneficial	soil composition, soil organic matter[5]
	5: Earth Sciences	5b	students know that natural processes, including freezing and thawing and the growth of roots, cause rocks to break down into smaller pieces	weathering[2,3,4,10]
		5c	students know that moving water erodes landforms, reshaping the land by taking it away from some places and depositing it as pebbles, sand, silt, and mud in other places (weathering, transport, deposition)	soil formation, weathering[3,6]
6	2: Shaping Earth's Surface	2a	students know that water running downhill is the dominant process in shaping the landscape, including California's landscape	geomorphology and soils, in particular alluvial processes[6]
			California Education and the Environment Initiative (EEI) curriculum	
2	From Field to Table	2.4.1	recognize the relationships among human needs, components of the food production system, and the ecosystem goods and ecosystem services made available by natural systems	soil ecosystem services, soil fertility, soil management[3,6,11]
			study the ways that people have learned to use knowledge of natural systems to improve the quality, quantity, and reliability of food production	ethnopedology, soil ecosystem services[1]
4	Life and Death with Decomposers	4.2.c	decomposers and their role in breaking down matter, various methods for generating compost	soil biology, soil organic matter[7,9]

† Relevant exhibit modules as superscript numerals: 1, Beneath it All; 2, CLORPT; 3, Soil Ingredients; 4, Texture Matters; 5, Hidden Horizons; 6, Get Soil Savvy; 7, Matters of Life and Death; 8, Skin of the Earth; 9, Soil Emissions; 10, All American Soils; 11, At Home in the World of Soils.

Adapting the Exhibit as an External Classroom

A total of 607 students were introduced to soil science using The California Museum from September to December 2014. Field trips ranged in size from 6 to 60 students spanning grade levels 2 to 7. Graduate student docents began the visits with a 15- to 20-min introductory lecture and discussion with students, followed by engagement with exhibit modules and activities for 45 to 60 min. Interactive modules and activities allowed small groups of primary school students to engage with graduate student docents to fortify the concepts introduced in the classroom lecture (Fig. 1).

The introductory presentation was designed to pique students' interest in soil science, frame the exhibit, and communicate key points about soils. Two versions of an introductory presentation were prepared by UC–Davis graduate students and museum staff for Grades 2 to 5 and 6 to 7. This division was based on California teaching standards and by primary educator and staff experience with science lesson plans. The objective of the Grades 2 to 5 presentation was to convey two core ideas: (i) soils are highly diverse (e.g., color and types of layers), and (ii) soils provide services to society (e.g., food, fiber, shelter, recreation). These concepts were emphasized and illustrated with slides and activities. For Grades 6 and 7, the presentation was designed to additionally introduce soil properties and principles

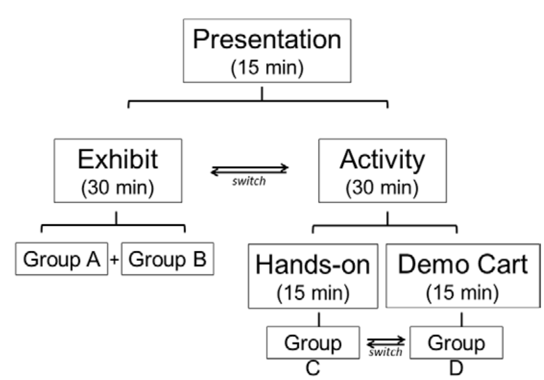

Fig. 1. Field-trip framework and flow used to introduce primary education students to soil science using the *Dig It!* soil science exhibit.

Fig. 2. Paraffin-coated peds used to demonstrate differences in soil structure and color to primary school students. Coating of peds enabled their use, whereas handling of untreated soils (e.g., soil texture by feel) was not possible due to hygiene and cleanliness constraints of the hosting institution.

such as particle size, texture, water retention, organic matter, and soil food webs.

Observation-based introductions to soil science can be more accessible and intuitive than lecture-based approaches (Brevik and Hartemink, 2010; Dawson, 1956). Primary school students participated in five observational activities:

1. Examination of peds expressing different colors and structure, handed out during the introductory presentation on soil principles (Fig. 2)
2. Simulation of rainfall infiltration and run-off in low- and high-permeability soils
3. Illustration of soil water holding capacity and plant-available water with a sponge (Fig. 3)
4. Comparative slaking of low and high organic matter aggregates
5. Filtration of food coloring by fine- and coarse-textured soils

Activities 2 to 5 were part of the demonstration cart overseen by graduate student or museum staff docent(s) (Fig. 1), with primary students observing in close proximity.

Hands-on activities can be highly effective for teaching soil science concepts. However, many activities such as the "texture by feel" method are not possible due to hygiene constraints in indoor classrooms. Given the effectiveness of demonstrating this method to convey the concept of soil texture (Reuter, 2007), the aversion to wetting soils in indoor classroom settings is an overlooked but significant obstacle to engaging younger students. This issue may also reflect the misconception of soil as "dirt" and unhygienic. To address this obstacle, we suggest "texture lines": a sequence of texture samples for students to texture by feel that transitions directly to a hand-wash station to minimize misplacement of soil samples by students in indoor environments.

OUTCOMES AND DISCUSSION

Approaches to Engaging Students

Combining concepts about soil diversity and ecosystem services was effective in conveying the importance of soils. This supports the rationale of Megonigal et al. (2010) that the *Dig It! The Secrets of Soil* exhibit was intended to showcase soils as the basis for a diversity of ecosystems, agroecosystems being one of these, and is consistent with recommendations for greater emphasis on holistic presentations of soils that showcase their services to society (Havlin et al., 2010). Concurrently, we observed that the "soils as natural bodies" concept was difficult

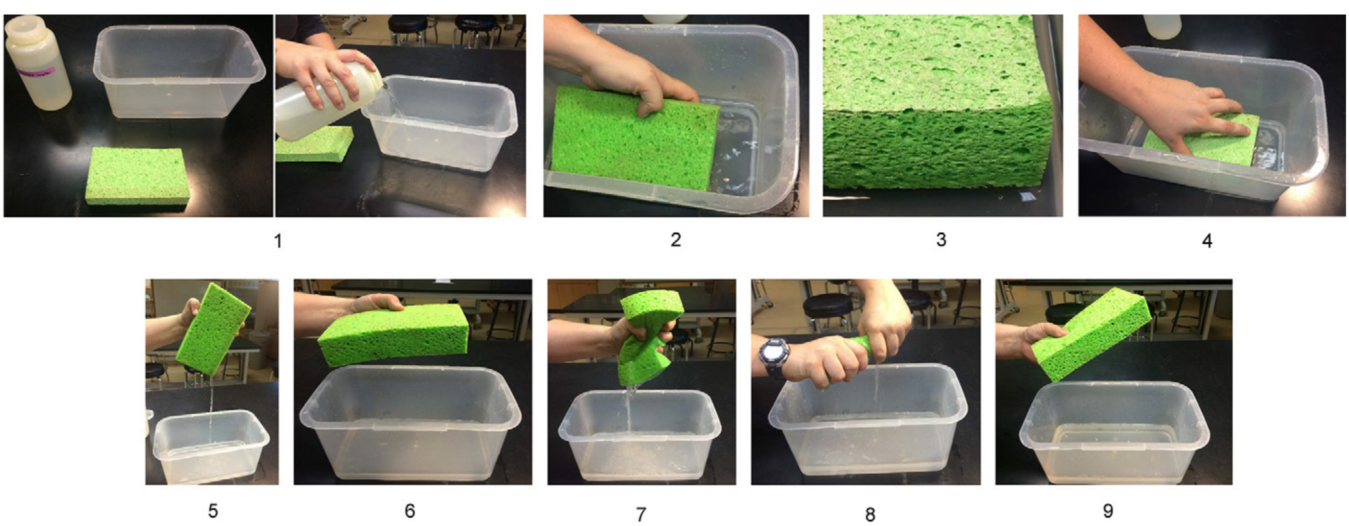

Fig. 3. Sponge demonstration to illustrate soil water storage and plant available water holding capacity: (1) a sponge, tray, and water are used to illustrate the metaphor of soil as a sponge, including the diversity of pore sizes; (2) placing the sponge on the surface of water allows water movement by capillary action, (3) which can be seen as a wetting front; (4) saturating the sponge by submerging, then (5) allowing excess water to run off (6) to leave a wet but not dripping sponge demonstrates saturation, gravitational water, and field capacity, respectively; while (7) gently squeezing the sponge to remove water, followed by (8) adding more pressure to remove additional water, demonstrates soil water storage potential and plant-available water; (9) although no more water can be squeezed out, the sponge retains moisture, illustrating that not all soil water is available. A detailed description of the demo is available at http://www.doctordirt.org/teachingresources/sponge.

or relatively less effective for primary school students. An exception to this was Grade 6 classes because of the emphasis on geology and earth science in this grade's education standards (see above and Table 1).

Five specific strategies were found to effectively engage students, especially Grades 2 through 4:

1. *Drawing on students' observational experience.* Asking students about their own observations of and experiences with soils initiated group discussions and helped illustrate concepts such as soil moisture and color. For example, offering the question "When you dig down in your backyard, what colors have you seen?" allowed students to realize through their own sharing of personal observations that soils differ in properties such as color and moisture.
2. *Relating geography and soils*. The exhibit's global soils map and US territories and states monolith collection were used to highlight similarities and differences among soils geographically. This was useful to explain soil-forming factors of climate and parent material for higher grade levels (e.g., Grade 6). Additionally, it helped students consider the monolith module in more detail: "Consider the states you and your family have traveled to. How do the soils differ? Why do you think this might be?" Because the monolith module was generally glossed over by students in favor of more interactive modules, this question was reframed to make students seek out monoliths for specific US states or territories with which they were familiar.
3. *Thought experiments.* A second strategy was to pose the ontologically charged question: "What is soil?" Thought experiments proved particularly helpful in this regard. For example, is soil merely crushed rock? Or must soils support life? If the latter, is it the actual or potential support of life that defines soil as such? If Martian "sediment" was brought back to Earth and tomatoes could be grown in it, does that mean it is soil? Such seminar-style thought experiments are in line with the problem-solving approach advocated by Dawson (1956) for soil science in primary education.
4. *Shock and awe*. The number of microorganisms in a single teaspoon of soil was an effective way to convey the wonders of soils.
5. *Avoidance of jargon and reliance on metaphors coupled with demonstrations*. Describing soil properties and processes in accessible terms and using metaphors that are readily conceptualized were key to communicating with primary students. Examples include: soil pore networks as Swiss cheese or a jar of marbles; horizons as layers in a cake; soil moisture storage and its plant availability as a sponge and water squeezable from the sponge (Fig. 3).

Accessibility and Consolidation of Soil Education Resources

Primary educators expressed interest in a pre-field-trip lesson plan for their students to better capitalize on the field trip experience. Primary educators can be strongly motivated by pre- and post-field-trip resources to better integrate science field trips into classroom activities (Anderson et al., 2006) because this can increase the overall impact of the field trip on students (DeWitt and Osborne, 2007). In our efforts to compile an inventory of online soil science resources for primary school educators, we observed an abundance of resources with similar and/or low content. There is a need to compile content into a centralized online resource targeted at primary educators as part of efforts toward a national soil science education curriculum (Drohan et al., 2010). For example, recent work by SSSA in conjunction with universities like UC–Davis has established teaching modules as part of the International Year of Soils in 2015 (accessible at http://www.soils4teachers.org/and http://www.soils4kids.org/). Digitizing resources currently limited to print, such as National Science Teachers Association (2001), can further increase the use of such resources in primary education.

There are also easily accessible soil science resources underutilized in primary education. SoilWeb products (http://casoilresource.lawr.ucdavis.edu/soilweb-apps/) are available to the public and offer resources like smartphone apps and Google Earth maps for students to link the relevance of soils to their school or home backyards. The potential of SoilWeb products for primary education extends beyond introducing students to soils. For example, soil maps generated by a class could be validated in an outdoor field trip guided by a soil scientist. An additional benefit of using SoilWeb products in classrooms is illustrating the utility of publically funded soil science. Similar resources include the mySoil app (available on iTunes) developed in concert with the UK Soil Observatory (www.ukso.org) to disseminate and crowd-source soil data (Lawley et al., 2014). Currently available for Europe, mySoil has 45,000 users and is planned to expand worldwide (Shelley et al., 2013).

Improving accessibility to existing soil databases is a promising avenue and may require digitizing soil science resources. For example, the National Museum of Natural History provides a web-based version of the *Dig It! The Secrets of Soils* exhibit to prepare for field trips to see the exhibit (http://forces.si.edu/soils/) (Megonigal and Megonigal, 2010). In this vein, the University of British Columbia has developed an open access, web-based educational tool, *Virtual Soil Monoliths* (http://soilweb.landfood.ubc.ca/monoliths/), that provides photos and explanations of soil monoliths (n = 197) collected by the university (Krzic et al., 2013). Digitizing resources track recent efforts toward developing online introductory soil science courses (McBratney et al., 2011). Increased accessibility to open access online courses is another possibility. Online-based approaches can be an effective way of complementing limited hands-on introduction of soils to students (Reuter, 2007), circumventing issues of hygiene, transport, insurance, and budgetary constraints often faced by field- or soil-sample-based approaches. Online resources could be useful for the initial stages of the multicomponent, project-based approaches to soil science advocated by Mellor (1991).

Questions for Soil Scientists

The work involved in distilling complex soil science concepts for primary students can drive discussion on pedagogy in the soil science community. Metaphors that may be effective to convey concepts to younger students are often debated or regarded with reservation because of ambiguity or connotations. Can concepts have pedagogic value but a less clear scientific value? For example, the concept of soil health or quality has a long and contentious history in soil science (Karlen et al., 1997, 2003; Sojka and Upchurch, 1999), yet it is featured heavily in the soils exhibit (Megonigal et al., 2010). Partly as a result of their involvement as volunteer docents, two UC–Davis graduate students went on to develop a graduate-student-run seminar, Soil Storytelling (now in its second year), that explores interdisciplinary approaches to soil science communication focused on positive, solutions-based storytelling to captivate wider audiences.

Multiple Frameworks for Presenting Soils

The soils exhibit was modeled on an ecosystem approach to soils (Megonigal et al., 2010) and simultaneously incorporates strong pedological modules (e.g., soil texture, soil-forming factors, global soil map). The utility of the traditional pedologic context for public outreach has been questioned (Brevik and Arnold, 2015), and reframing soil science concepts to reflect an ecosystem service perspective or other non-pedology perspectives has been proposed to improve the translatability of soil science to non-scientists (Bouma and McBratney, 2013; Brevik and Arnold, 2015). Based on our experiences with primary students, we suggest that these are not incommensurable and simply reflect different goals.

The goal of this outreach effort was to convey the diversity of soils and their importance to society, and it accordingly drew on both pedological (e.g., soil horizons, texture) and ecosystem (e.g., soils as the foundation of forests, meadows, etc.) concepts, as well as ecosystems services (e.g., food, fiber, shelter). Depending on the education grade, pedological concepts were highly complementary with or directly addressed by standards, such as the earth sciences content for Grade 2 (Table 1). The ecosystem service perspective was more intuitive to primary students ("what can soils do for or provide to you?"), whereas pedological concepts were more challenging for primary students to relate to. Additional perspectives for soil science in primary education that articulate the value and relevance of soils to society include soil security (Amundson et al., 2015; Koch et al., 2013; McBratney et al., 2014), soil ecosystem services (Robinson et al., 2012), soil as natural capital (Dominati et al., 2010; Robinson et al., 2009), and soil as an "actor" in environmental challenges (Bouma and McBratney, 2013).

Supplementary vs. Foundation Approaches to Integrating Soils in Curricula

Based on our experience with introducing primary education students to soils, we suggest two ways to integrate soil science into curricula: *supplemental* and *foundational* approaches. The supplemental approach seeks to fit soil science into preexisting niches. This is currently the predominant model for teaching soils to primary students and mirrors the increasing trend in US higher education of approaching soil science as a supplement to other programs such as agricultural sciences (Havlin et al., 2010). On the other hand, this "niche" approach to soils can reflect the multicomponent nature of disciplines such as agricultural science (Bouma, 2010). The exhibit was advertised by The California Museum from a supplemental approach to motivate and provide justification for primary school educators to bring their students to the exhibit, (i.e., satisfying elements of the Common Core standards like geology and biology). We suggest that the supplemental approach is more extensively utilized because it is more easily added to preexisting STEM lesson plans.

Soil science need not be limited to supplementing earth sciences lesson plans. We propose the concept of the *foundational* approach, in which soil science is the underlying or uniting theme for a suite of environmental, political, and cultural concepts or lessons. For example, soils offer a unique, unifying theme for teaching historical motifs such as the rise and fall of civilizations. This is well exemplified by Montgomery (2007). In US history, the Dust Bowl is a clear example of an environmental and socioeconomic crisis caused by mismanagement of the soil resource base. Another example would be the recollections of Japanese–American families living in internment camps during WWII and how they were affected by the highly wind-erodible soils surrounding them (NRCS and National Park Service, 2013).

A promising strategy is exploring the intersections of human culture and soils. This would complement an ecosystem services approach to soils and additionally offer an opportunity to incorporate economic theory (e.g., system failure) and concepts of sustainability (Robinson et al., 2014) across a number of examples such as Mayan, Easter Island, ancient Roman, and pre-Pueblo Native American societies. This can be applied to how modern societies view soils—including primary students in (sub)urban environments (Barrera-Bassols and Zinck, 2003). For example, the online blog *Soil and State* provides a number of contemporary examples of the intersection of soils and politics (http://soilandstate.blogspot.com/). Currently, Haiti and the Syrian Civil War exemplify how social and political instability can be catalyzed and exacerbated by deteriorating soil ecosystem services.

Foundational approaches that consider social, cultural, and even philosophical aspects of soil science also benefit soil scientists by providing an opportunity to reflect on their discipline. For example, how did the current field of soil science develop, and how has society's use of soils changed with time (Warkentin, 2006)? Fifty years ago, wetland soils were valued as productive landscapes for agriculture once they had been reclaimed (drained). Now there are nationwide efforts to restore these landscapes to enhance wildlife habitat, improve water quality, buffer against flooding, and sequester carbon. This evolution in perspective illustrates a shift from viewing soils as something to be conquered to valuing a wider diversity of the ecosystem functions provided by soil (Kelley, 1998; Reisner, 1993). Comparative analysis of historical and cultural attitudes toward soil presents a way for the public and the soil science community to consider their own views on soil (Churchman and Landa, 2014). Such discussions and outreach interactions have great potential to inform novel approaches for soil education (Field et al., 2013). To this end, we propose the creation of a centralized collection of outcomes and insights from the multitude of education outreach efforts (e.g., a SSSA-maintained website with guest blog posts), which are many but often isolated with little cross-talk, to better communicate, learn from, and build on the diversity of strategies in soil science outreach.

Potential of Multi-institution Collaboration for Soil Science in Primary Schools

Collaboration between academic institutions like UC–Davis and professional societies like SSSA with educational institutions like The California Museum present strong opportunities for soil science graduate students to gain valuable experience in outreach. At the same time, these collaborations can showcase and deliver institutional expertise in soil science to the public and inspire the next generation of soil scientists. Outreach efforts targeted at primary school students can also involve professionals that work in or with soil science (e.g., environmental engineers, agronomists, US Forest Service scientists).

Less used than museum field trips are outdoor field trips, in which students are taught in a natural environment (e.g., a national park or forest) (Kisiel, 2013). Outdoor field trips are especially suited to introducing students to soils and their role as the foundation of terrestrial ecosystems, as well as showcasing soil science practices such as morphological descriptions of soil profiles. This education strategy requires strong collaboration between the soil scientist and the primary educator (Tal et al., 2014) and could double as an opportunity to introduce students to potential career paths in soils.

CONCLUSIONS

Incorporating soil science in primary education is a foundational step toward improving public awareness and understanding of the importance of soils to society. It is also an investment in the next generation of soil scientists, as well as scientists in related fields (e.g., forestry and hydrology). We evaluated the potential of a SSSA-sponsored exhibit as an external classroom to introduce primary school students and educators to soil science using grade-specific tours and activity-based workshops. Multi-institutional collaboration among higher education (UC–Davis), public (The California Museum), government (USDA–NRCS and US Forest Service), and scientific society (SSSA) institutions were essential for successfully introducing primary school classes to concepts and careers in soils. Adapting the soils exhibit to state science standards and providing additional education resources (e.g., compilation of soil education websites) proved critical to engaging primary school educators. Education standards represent a potential obstacle but also an entry point for soil science in primary education, suggesting that a future focus on a national soil science curriculum should be compatible with the next-generation (2017) Common Core standards. Hands-on activities are particularly useful for primary students but can be discouraged by hygiene regulations, pointing to a need for engaging activities that are possible in classroom settings. The soil services perspective offers an intuitive introduction to soils for younger students and can also be used to integrate soils into subjects beyond the natural sciences, such as history and anthropology. We propose a centralized effort to compile education resources using similar partnerships of soil scientists and educators to meet previous calls for a comprehensive national soil science curriculum.

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