Surprising facts about soils, students and teachers!
A survey of educational research and resources.

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Abstract

Soil is one of the key resources that sustain life on Earth, not just as the foundation for almost all our food supplies, as important as that is, but also in the way that it filters water, supports biodiversity, and perhaps even moderates global climate. Yet the world's soils are under increased pressure on many fronts. They face unprecedented threats from erosion, deforestation, desertification, salinization, sealing (paving over), contamination, loss of biodiversity, and climate change. The importance of soil and the need to sustain it against these threats, however, have elicited little interest, not only by scientists and the general public, but also by the educational systems of most countries. While increasing attention has been paid to other important environmental topics, such as loss of biodiversity, climate change, deforestation, fresh water availability, and the world's oceans, little attention has been placed on soil so far.

A way of meeting this challenge that has been instituted in a few countries has been to include soil science (its concepts, concerns, protection, etc.) as a core topic in the country's national science curriculum, so that from a young age students learn the key concepts of soil science and how and why people should protect soil in a sustainable way. The research surveyed in this paper shows that elementary students as young as preschool have some initial ideas about the depth of soil and its usefulness in supporting plant growth, but have little understanding of its composition, formation, or origin. Middle school students (10-12 years in age) arrive at the topic with more understanding in some areas, such as the thinness of soil layers, but are still ignorant concerning its age and origin. After several weeks of hands-on activities combined with "minds-on" discussion, students as young as 5-6 years in age are able to get "soil on their mind," as evidenced by the diagrams they draw before and after intervention, while students 10-12 years in age are able to understand the three-dimensional nature of soil, as well as start to understand its formation process and age.

Elementary teachers begin their profession understanding substantially more soil concepts than their students. Over 80% know that soil is formed by the weathering of rocks, that earthworms mix the soil and allow for more air and water to enter, and that decomposition provides soil nutrients for plants to grow. Very few of them, however, are aware of how many life forms there are in a handful of soil, how many years it takes for soil to form, how much of soil is space for air and water, which component of soil has the smallest particles, or what role humus plays. After two or three classes of intensive hands-on activities, they also are able to make substantial gains in their understanding, reducing by 33% what was lacking in their understanding of soil concepts. They can also make gains in their attitudes towards the need to protect soils, compared with other environmental challenges.

The little research that has been done with secondary students shows that their initial ideas about soils, and their ability to achieve a deeper understanding of soil through classroom activities, is similar to that of middle school students. No studies have reported on secondary school science teachers' understanding of soil. Two studies with secondary school agriculture teachers indicate mixed results as to how prepared they are to teach soil science. This review concludes with a brief description of resources available for soils education, including equipment kits and unit manuals for elementary school, and journal articles, websites, and electronic resources for all grades. Given available soil education research and resources, this work suggests that the most important thing people concerned about soil education can do is advocate for the inclusion of soil science as a separate topic in their national elementary science curriculum, if that is not already in place.

Keywords

Soil concepts, sustainability, education, hands-on activities, initial ideas, gains in understanding

1 Introduction

Soils are one of the planet's most important and indispensible resources. Understanding soils is key to properly sustaining them. Given the need to feed a growing world, there is a great deal of research that focuses on the role of soils in agriculture (Banwart, 2011). Healthy soils, however, are not only essential for food and forests; they also filter water, transform nutrients, and sustain the world's biodiversity. Furthermore, according to soil researcher John Zak, they may also play an important feedback role in climate change projections (personal communication, April 24, 2012). Yet of the world's most basic resources, soils remain the least studied and the least understood, both among scientists as well as the general public, although a recent focus on soil awareness and education by soil scientists in Europe indicates an ability by people of all ages, starting with young children, to learn key concepts about soil science (Figure 1).

Science education research – students' initial understandings of science concepts, the most effective teaching strategies, etc. – has been blossoming for three decades, with over a thousand conference papers and peer-review journal articles appearing annually. Very little research on elementary and secondary soil science education, however, has been reported. For example, the initial understandings and misconceptions of school children or their teachers about light and what pedagogical strategies are most effective in helping students learn about light have been the focus of at least 50 published articles. A similar abundance of information is available for many other school science topics such as force, motion, electricity, matter, substances, chemical reactions, plants and animals, ecosystems, the cell, and reproduction. Even in the Earth and Space section of the science curriculum, topics much less crucial to our survival than soils science– earthquakes and volcanoes, rocks and minerals, phases of the moon, stars and planets – are mentioned much more frequently. In contrast, perhaps one or two articles are published on elementary and secondary soil education each year.

Soil science does not feature prominently in most educational systems, at least in America. At the University of Florida, for example, a campus with almost 50,000 students, the College of Agriculture and Life Sciences has some 4500 students; but only 10 of them are enrolled in soil and water science (Collins, 2008). This study by Collins documents a declining trend of the number of undergraduate students enrolled in soil science across the nation and notes that, based on anecdotal talks with colleagues around the world, this trend appears to be international.

The frequency of soil science education in elementary and secondary is similar to that at the university level. Table 1 summarizes references to soil in the curriculum documents of various English-speaking countries and regions. Soil science is explicitly mentioned in Canada, South Africa, the United States, and their provinces and states, although other earth and space topics such as geology and astronomy appear more frequently. In contrast, soil science doesn't appear as a unique content topic at all in most European national curriculum documents, although, as mentioned above, soil educators in Europe are active in promoting soil education to adults and children in events outside of the classroom (i.e., Blum and Kvarda, 2006; Broll, 2006, 2009; Creamer, 2009; Hallett, 2009; Houskova, 2009; Towers et al., 2010). In Africa, a region where many families live close to the land, information is limited and what is available provides a mixed picture. Soil science doesn't seem to feature prominently in the Nigerian science curriculum (Oludipe, 2011). In parts of Ethiopia, however, soil fertility and water and soil issues are an important part of the work of school environmental clubs, where students implement environmental conservation at school compounds and family lands (Edwards et al., 2010).

This article reviews existing research on soil science in elementary and secondary teaching and learning, and summarizes the English-language resources available to increase understanding of soils and awareness of the essential role they play in sustaining life on Earth.

2 Results of Research on Elementary and Secondary Teaching and Learning about Soils

In this section, studies on student and teacher initial understanding about soil, and what programs have been effective in helping them understand soil better, are grouped by level (elementary or secondary) and by subject (students or teachers).

2.1 Elementary Students' Understanding of Soil

2.1.1 Initial Understandings

This section talks about four studies that report on elementary students' initial understanding of soil concepts (Table 2). Several other studies report pre-post gains in understanding of soil concepts (Table 3), but did not report on the student's initial understandings as demonstrated on the pre-tests.

Geyer et al. (2003, 2004) worked with 150 children, 4 to 11 years old, in primary schools in Germany. The purpose of the study was to identify aspects of soil and agricultural ecology that could be taught to children at different ages, whether the children could understand the three-dimensionality of soil and its interactions with ecosystems, and how soil science learning works with very young children. The children were introduced to the program with the question: "Why should soil be interesting for you?" The youngest children referred to soil as a playing-ground, while the older children had some idea of soil's three-dimensionality, and referred to seeds, plants, trees, and earthworms, which all live in the soil (Figure 2).

The researchers also asked the 150 children to draw pictures that illustrated their ideas about soil. These pre-intervention pictures revealed the following initial understandings of soil:

- 4-7 years: children set the horizon (the ground) at the very bottom of the picture. They don't have any place in the diagram or in their mind for 'soil'
- 7-9 years: some drawings allow for space for soil, but this is not developed
- 9-11 years: they already have an idea of how soil could look, its genetic processes, and to some extent, it's physical properties

Happs (1981, 1984) interviewed 40 students in Waikato, New Zealand from Gr. 7 to university level. The study was concerned about what students think of the nature, origin, age, and depth of soil, along with changes that might occur in soil. Students were first given a variety of familiar materials related to soil (loose portion of topsoil, section of turf, grass with root system, clay, sawdust, potting-mix, pebbles), and asked to identify what they saw, as a help in eliciting from them their concept of soil and soil development. Various stimulus words were also placed on cards to further aid the questioning: soil, colour, silt, rocks, sand, clay, consistence, texture, structure, profile, living things, vegetation, water, parent material, etc. A further multiple-choice survey was constructed on the basis of the interviews and administered to an additional 221 middle and secondary school students.

Although nearly everyone described soil as providing support for life, many also referred to it as "dirt." Almost half thought that soil was formed the same time as the earth, i.e., having an age as old as 100,000,000 years, although a few thought it might be only 20 years old. Some saw soil as the product of rotting vegetables and animals, a few as originating in volcanic ash. Some upper school and university students recognized that soil development was a "multi-source mechanism." Most recognized that soils continually changed over time, but couldn't describe how. Only in their estimate of the depth of soil were student answers close to the scientific view: one third thought that soil was under 1 meter in depth, and another third between 1 and 10 meters in depth.

Russell et al. (1993) worked with 58 children between 5 to 11 years of age. They first engaged the students with exploration activities such as looking through soils with a magnifier, thinking about which soils would be best for plant growth, and looking down a hole outside to think about how deep soil might go if you could dig as deep as you wanted. They followed this exploration stage with pre-intervention interviews to elicit the students' views on soil. These interviews focused on the following topics:

- *The function of soil:* More than half of students didn't know or had no response. About a third thought that soil was for growing plants.
- *The nature of soil:* Almost half of the students made no reference to soil composition; 12 students (mostly upper-level) referred to soil as a mixture; 8 of the youngest students referred to soil as mud or sand.
- *Changes in the properties of soil:* About a third of the students mentioned changes in water content or wetness of soil.
- *The origin of soil:* Few students offered ideas as to where soil came from. Some referred to the formation of soil over millions of years, from rotting vegetation, as well as sand or gravel.

The students were also asked to make detailed drawings of what they thought was under the ground. They may have been given more direction than for the drawings reported above by Geyer et al. (2003, 2004), as the results were consistent but also more specific:

- Younger children tended to draw 'no-layer' diagrams
- Other students drew various layers under the ground, including such things as soil, clay, sand, lava, or where they found worms, pipes, bones, tar, stones, rats, and Earth's core
- Some of the older students clearly marked out a layer of soil in their drawings (Figure 3)

The research summarized by these four articles was extensive in nature, and covered a span of ages from 5-12 years. It included student discussions and interviews as well as analysis of labeled diagrams and pictures drawn by students. Similar results regarding student views of the nature and function of soil, changes in soil, and the origin and age of soil emerge. Before instruction, students of all ages:

1. Are unclear about the nature and composition of soil
2. Have some idea of a layer of soil under the ground
3. Tend to think of soil as supporting plant growth and as a home for other forms of life
4. Have little idea of the age of soil, often considering it to be millions of years old
5. Have little idea of how soil forms from weathering and erosion, which contributes to its composition of sand, silt, clay, and humus
6. Have some idea of the depth of soil, closer to reality than for the other attributes.

Several qualifications should be noted about this work. *First*, the students involved in the research appeared to be all from urban schools. Students growing up in rural communities, especially those living on farms, may have given more informed answers. *Second*, the students in these three reports were from similar Western European cultures. Would students from urban schools from other cultures have responded differently? *Third*, if this same research had been done with students in North American provinces and states where soil had already been studied as a formal topic in primary school, such as California, Ontario, or Texas (see Table 1), would the data from junior students be substantially different than what we saw here? I am not aware of any data on this question, since soil is not usually one of the topics included in international science assessments. *Fourth*, these three studies were conducted 10, 20 and 30 years ago. When the astronomical beliefs of Gr. 6 British students were surveyed in the mid 1990s (Sharp, 1996), for example, it was found that the students knew significantly more about astronomy than Gr. 6 British students who had been surveyed only a decade or so earlier (Baxter, 1989). This advance was attributed to the great increase in number and quality of astronomy and space programs appearing on television in the intervening decade. Might the same be true of soil science over the past two or three decades? The U.S. Smithsonian Soils exhibit was seen by millions in its 18-month showing in 2008-2009 (Collins, 2008; Megonigal et al., 2010). The more permanent "Underground Adventure" soil exhibit in Chicago's Field Museum has also been seen by many. There is also an increasing amount of high quality soil education outreach taking place across Europe, coordinated by the European Network of Soil Awareness (Broll, 2011), as well as soil education websites in many countries (see below). In general, however, there is no indication of a widespread change in soil science information available to students and the most likely assumption is that initial understandings of most students today have not changed.

2.1.2 The Effect of Treatment Activities

Five studies have attempted to quantify the effectiveness of various "treatment" or "intervention" programs for increasing elementary students' understanding of soil concepts to inform teaching strategies over a range of ages (Table 3). Gulay et al. (2010) assessed Turkish 5 and 6 year old's understanding of five aspects of soil: its characteristics, living beings that live in or under it, its importance, protection of the soil, and the causes and effects of soil erosion. The subjects were divided into control and experiment groups, both of which received the pre-test, post-tests, and delayed post-test (two weeks later), but only the experimental group was exposed to the nine-day program of treatment activities. The children were selected on the basis of two criteria: (1) a low socio-economic background, and (2) not having been exposed to any prior education on soil, erosion, and the environment. Treatment activities included story, games, drama, songs, fieldtrip, experiment, art, and work with soil in a corner of the classroom. The program focused on a puppet, Tipitop, and was called "We are Learning about the Soil with Tipitop and His Friends." The pre-post tests consisted of 12 questions administered orally by adults along with slide figures and photographs. There was no significant difference in pre-test scores between the experimental and control groups. The experimental group performed significantly higher on post-tests scores and delayed post-test scores than either the control group or their own pre-test scores. Unfortunately, no details were given as to which soil concepts were best understood initially or which were learned most effectively during treatment.

Geyer et al. (2003, 2004) also worked with children from 4-11 years in age. Teacher lessons and fieldwork involved students examining soil pits, various soil layers, and animals that live in the soil. Interviews took place before and after the fieldwork, and students submitted labeled diagrams before, immediately after, several weeks after, and a year after the classes on soils. Diagrams submitted after fieldwork included more realistic colours and identified layers of the excavated soils. Students remembered soil layers weeks and months later. Figure 4 demonstrates one 9-year-old student's diagrams before the fieldwork, immediately after, several weeks later, and a year later. Before the lessons, soil is merely a playing ground. After fieldwork, the student documents the layers. Six weeks later, soil has become part of his life, and a year later, he still remembers the layers of soil. It is now part of his 'normal life.' After analyzing hundreds of diagrams from the 150 students aged 4-11 years, drawn before and after the fieldwork lessons, the authors concluded that:

- students aged 4-7 years could remember soil layers, after fieldwork, but were particularly interested in soil animals, which they "drew frequently and very exactly"
- students aged 7-8 years remember soil colours and soil genetic processes
- students above 9 years in age are interested in the science and ecology of soil, and remember genetic processes and some physical properties very well. Animals and plants are less important. They understood the difference in forest ecosystems and agriculturally managed ecosystems. They were also able to make their own conclusions to their studies.

Russell et al. (1993) also involved students aged 5-11 years. Following initial interviews, students were exposed to intervention strategies (i.e., classroom activities) over five weeks. The intervention phase of Russell et al. employed a number of strategies, including encouraging the children to evaluate their ideas side-by-side with the "right" ideas, develop more specific definitions for soil-related words, generalize across concepts, and use secondary sources of information. The specific soil intervention activities consisted of teaching the children to take a closer look at soil, compare different soils, and develop ideas about what is under the ground. Several weeks later, a set of data was elicited from the students complimentary to the pre-test data (log books, drawings, discussions, post-intervention interviews) and was analyzed to reveal:

- *The nature of soil:* Younger children (age 7-9) initially had difficulty understanding that soil was composed of various materials such as sand, clay, and living material. When stones were rubbed together, producing dust, the children still had no idea that this had anything to do with the origin of soil. When they started straining soil through cloth material, however, they began to see that it was made up of several different components. Eventually they were able to conceptualize soil as made up of several organic and inorganic components, although none of them mentioned air as one of these.
- *Comparing soils:* Although some children tended to judge the 'goodness' of soil at first by appearance only, they soon learned to use better criteria (i.e., a fair test), including how well the soil supported plant growth.
- *Thinking about what's under the ground:* While a few hands-on activities related to this topic (i.e., digging a hole in the garden 1m deep), little time was left to consider secondary sources. Many children, however, began to understand that underneath soil we come into contact with rocks. (Rocks were the next activity studied in this intervention phase, after soils.)

Post-intervention interviews revealed a complex picture of both learning and un-learning that took place concerning the nature of soils and what is in soil, including:

- *Living things:* More students referred to living things as one of the constituents of soil after intervention than before (57% vs. 27%), where living things could be plants, roots, seeds, microorganisms, or small creatures.
- *Soil constituents:* While younger students mentioned fewer constituents of soil after intervention than before, perhaps because they un-learned several things that they previously thought were constituents, older students mentioned more constituents after than before!
- *Organic matter (dead not living):* The same number of students mentioned organic matter after intervention as before (61% vs. 60%).
- *Inorganic matter:* After intervention approximately the same number of students mentioned
- *Particle size:* more students after intervention referred to different-sized particles in soil than before intervention (74% vs. 31%).
- *Origins of soil:* Before intervention, 28 students referred to the translocation of soil from another location, while 8 students referred to both translocation and transformation. Only 8 students mentioned soil being transformed. After intervention, 27 students referred to the

transformation of soil, while only 18 referred to its translocation. (Often, students referring to the translocation of soil thought of it as coming from gardens, garden centres, etc., brought by humans.)

- *Nature of soil transformation:* More students thought of soil as having inorganic origins after intervention than before (26% vs. 12%), some mentioning volcanoes sending forth lava, rocks being ground down, sand coming from the sea, things colliding together, etc.
- *Types of soil:* When students were shown five samples of soil, and asked to classify each as soil or non-soil, pre-post results were mixed concerning three of the samples, showing the continued subtlety of understanding what soil really is, given various human perspectives of soil. (The three samples included sandy topsoil, chalky soil, and damp peat.)

Lippert (2006) used a web-based basic soil module with pop-up test and audio files as a treatment for 97 Gr. 7 students in South Carolina. Students answered a multiple-choice pre-test in class, then studied the web-based module over two to three days in a computer lab, and then answered the post-test in class. A month later, they answered the same post-test again. The purpose of the research was to see whether a web-based module was effective in instructing students on soils. Results were positive, with pre-post gains on 21 of the questions exceeding 30%. Three questions showed moderate gains (20-29%), and two questions showed little gain (10-19%). When the same module and tests were given to 150 university students, results were only slightly better. Results on the delayed post-test indicated a drop-off in knowledge from the post-test scores taken immediately after the module, although there were still significant gains over the pre-test (Table 4).

Insufficient information is available to draw conclusions about the gains for specific items. In addition, the gains made by the students for many of the 26 questions are quite significant, after only 2 or 3 days (periods?) in the school's computer lab. This contrasts with the five weeks of intensive interventionist strategies employed by teachers in the study with Kindergarten to Grade 6 study reported by Russell et al. (1993), where the gains did not appear to be as significant. Finally, most of these 26 questions appear to be concerned with rather factual, technical details, and not concepts that lie at the heart of understanding soil science, which can be deeply engrained in student's thinking through hands-on investigations and minds-on discussion and questioning. The fact that the delayed gain (a month later) was much lower than the immediate gain or many of the questions appears to bear this out.

In another German study reported on by Randler & Hulde (2007), 123 students enrolled in two Gr. 5 and two Gr. 6 classes in a German middle school were given a pre-post test of five open-ended questions, with an intervening treatment program consisted of three different ecological experiments dealing with soil ecology: (1) investigating the water holding capacity of moss, (2) studying the erosion of grassland versus agricultural land, and (3) finding the water cleaning capacity of soil. The principal variable tested was the effect of learner-centered vs. teacher-centered classrooms. One Gr. 5 and one Gr. 6 class received the learner-centered treatment, with the other two receiving the teacher-centered treatment. In the teacher-centered classes, the teacher carried out the experiments and discussed the results with the students; in the learner-centered classes, the students carried out the experiments. The pre-tests were completed just prior to the teaching, the first post-test was carried out just after the teaching, and a delayed post-test was carried out four weeks later. For the post-tests, two additional questions were added to the same five used in the pre-test. The following are example items of the pre-post tests:

- Which specific characteristic is especially related to moss? (water holding capacity)
- What specific material from everyday life has a similar characteristic? (sponge)
- Water above the ground is often dirty, ground water is nearly clear. Explain. (Plants and soil material filter dirty water.)
- Steep sloes often are planed with grass. What is the advantage? (Protects soil from erosion)
- What would happen if the soil is bare (without plants) (erosion would take away the soil)

Average scores were statistically the same for both treatment groups (Table 5). For the delayed post-test, however, the mean score of the teacher-centered groups had declined somewhat from the post-test scores immediately after the teaching, whereas the mean score of the learner-centered group remained the same, resulting in a significant difference between the two groups. The main conclusion from this is straightforward: learner-centered classrooms, where students engage in hands-on experiments, rather than just watching and listening to the teacher doing and discussing the experiments, results in significantly better long-term retention of the learning. This conclusion is consistent with a wide body of research concerning student learning in science.

2.1.3 Summary

Elementary students are initially unclear regarding the nature, composition, and function of soil is concerned, although they usually know that it supports plant growth in some way. They have little idea of the origin, age or formation of soil, although many of them, especially middle school students, understand that soil is not that deep and is often sitting on top of rock (Happs, 1984; Russell et al., 1993). Nevertheless, effective education programs can be mounted with students of all age groups, from pre-school to middle school. While a short-term teacher-centered program may lead to strong initial gains in student understanding of some facts and details about soil (Lippert, 2006), an extensive four or five week program of hands-on explorations combined with "minds-in" discussions for elementary students is likely required to permanently alter student understanding of key soil concepts (Geyer et al., 2003, 2004; Russell et al., 1993; Randler and Hulde, 2007).

2.2 Elementary Teachers' Understanding of Soils

Elementary teachers' understanding about soil may be just as important as that of students, especially in countries where soil is taught as a classroom subject. Very little research has been reported on this subject, however.

2.2.1 Initial Understandings

In a study of 108 elementary and middle school teachers in Nebraska, only one of the 38 items concerned soils (Gosselin and Macklin-Hurst, 2002), and this item elicited the lowest score of the test. While average scores on the 38-item pre-test were 55%, only 16% of students correctly disagreed with the statement, "Soils are deposited as natural rock layers."

In another study on 87 preservice elementary teachers in New York State, a pre-test was administered that included writing the definition of clay, listing products made from clay, and explaining the origin of clay (Rule, 2007). Only a minority of the preservice teachers thought of clay as a natural substance in the Earth (Table 6). Most naturally thought of modeling clay without making any connection between this and the Earth's natural substances. As far as the origin of clay was concerned, only three of the eleven suggestions could be considered scientific: that clay forms in the ground (9 responses), that it forms from chemical weathering (5), and that clay minerals are found in soil (4).

Since soil science is a topic at the Grade 3 level in Ontario, a study was conducted on preservice elementary teachers' initial understandings of a complete set of soil concepts (Hayhoe et al., in-press). 74 primary-junior (K-6) teachers out of a potential pool of 125, studying at a medium-sized public university near Toronto, voluntarily responded to a 32-item multiple-choice questionnaire. The preservice teachers represented the cultural diversity of the greater Toronto area, and all had a university degree, but very few in science. The teachers achieved a mean of 55% on the questionnaire, in contrast to a random score of 25% (Table 7).

In a further study, 25 of the 32 items were given to a second group of 98 preservice elementary teachers at the same institution, and to 41 preservice elementary teachers at a local private Christian university. The results were all very similar (Hayhoe et al, Manuscript submitted for publication). The results in Table 7 indicate that while these Canadian teachers understand a significant number of important soil concepts, they have misconceptions or lack of knowledge on many others and most likely need some instruction on soil to be able to successfully teach it to Grade 3 students. (It is important to note that most of these Ontario teachers had not received soil science education in their own Grade 3 schooling; it did not enter the curriculum until 1999-2000.)

2.2.2 The Effect of Treatment Activities

When geoscience topics such as soils are included in science methods courses taken by preservice elementary teachers, is there a significant gain in their pre-post test scores? In Gosselin and Macklin-Hurst (2002), students met twice a week for a total of 4.5 hours. The course content "was primarily presented through the use of both hands-on and minds-on approaches, including inquiry-based activities." Two collaborative projects concluded the course, one concerning weather phenomena, and the other concerning stream flow data. Post-test scores were then collected. The pre-post gain on the single item about soils was 16% (16%-32%), which compares unfavorably with the average on the 38 items of 25% (55%-80%). After instruction, most students still thought that soils were deposited as natural rock layers.

In a follow-up study by Hayhoe et al. (Manuscript submitted for publication), 19 teachers at the private Christian university participated in an in-class treatment consisting of two 3-hour classes of hands-on activities and discussion related to soils, together with some after-class work (Hayhoe et al., 2011). The class activities involved up to 10 hands-on experiments – ones that students studying the Grade 3 soils unit would typically do over a period of several weeks – together with group and class discussions and readings (Figure 5). Five months after the activities on soils, and four months after the course was over, the same post-test questionnaire was given to the teachers so that long-term pre-post gains on understanding of soil concepts could be analyzed.

An "environmental attitudes" survey was also developed and administered simultaneously with the soil concepts questionnaire. The preservice teachers answered a 20-item Likert scale survey to test their attitudes towards five environmental topics: climate change, energy usage, water, nuclear energy, and soils. The researchers wanted to see if concern for soils was correlated with initial understanding of soil concepts, and if exposure to soils activities increased concern for soils (in contrast to the other four environmental topics) as well as understanding of soil concepts. This 32-item soil questionnaire and 20-item environmental survey were given both to the 19 students from the private Christian university (Tyndale), in pre-post positions, as well as to the 74 students from the mid-sized public university mentioned earlier (UOIT), in pre-test position only. (Only 67 of the 74 students from the mid-sized public university completed both the soil questionnaire and the environmental survey.)

For the pre-test questionnaire and survey, the means for the two universities were the same, 57% for the soil concepts 32-item MC test and 75-77% for the 20-item Likert scale environmental survey, which measured their attitudes toward soils (Figure 6a). For the post-test surveys, the means for the 19 teachers from the smaller university went from 57% to 78% for the soil concepts and from 75% to 88% for the soil attitudes (Figure 6b). This research indicated that 10% of class time in a science methods course can significantly affect both the environmental concern and the conceptual understanding of teachers for soils, although an increase in the one was not correlated with an increase in the other (i.e., teachers who increased the most in their environmental concern for soils did not necessarily increase the most in their understanding of important soil science concepts).

In a second year of this study, the 32-item soil survey was reduced to 25 items, by removing items on which teachers had initially achieved 90% or so on previous pre-tests, and a few with poor discrimination indices (Hayhoe et al., Manuscript submitted for publication). When this 25-item soil concept survey was applied to a new cohort of preservice teachers at both the private and public universities, and the previous years' results were re-analyzed, the two years of data were very similar (Table 8).

The consistency of these results suggests that any effect is not peculiar to one particular cohort or university. The only significant effect was the pre-post gain: teachers gained 37% ([67.1-48.1]/[100-48.1]) of what was lacking in their understanding of these soil concepts. Comparing Table 9 with Table 7, on some items the preservice teachers made large gains: understanding how many life forms are in a handful of soil, how many years it takes for soil to form, what decayed organic matter is called (humus) and what it does, which component of soil settles down first in water (sand), and how to differentiate between dry soil and dry clay by texture. On some other items, they made modest but significant gains – 50% of good soil is space for air and water, the smallest particles in soil are clay particles, soil fungi are too tiny to be seen with a magnifier, and soil filters impurities out of our water – although on the delayed post-test scores, still only a minority of the preservice teachers answered these questions correctly.

2.2.3 Summary

Of the three studies on elementary teacher understanding of soils, the first only dealt with one concept (soil not being deposited like rock layers). The second only dealt with concepts related to clay, although in great depth. Only the third set of studies reported on a variety of soil science concepts. These found that preservice elementary teachers, most of whom had not studied science at the post-secondary level and probably never studied soil science, nevertheless initially understood many important concepts about soil. At the same time, they had many misconceptions or areas of ignorance about soils. Long-term gains made after only two to three classes in their science methods course reduced by a third what was lacking in their knowledge and understanding of soil science concepts. This is probably all that can be expected in a treatment program covering many soil science concepts in a modest amount of class time and readings.

2.3 Secondary School Students' Understanding of Soils

Only two studies report on secondary school students' initial understandings of soil (Table 10). The findings of Happs (1981, 1984) have already been reported (section 2.1.1). Drieling (2006, 2008) examined the ideas of senior students in Germany, 15-16 years of age, through the use of interviews and drawings. One student imagined that below the ground there was uniform matter where animals live and which perhaps had water underneath. Another students envisioned definite soil layers below the ground "in the sense of divided geological layers of different materials such as soil, sand, gravel, or rocks." A third student remembers digging a hole in the woods and seeing many different layers of colours and compositions in the soil below the ground. Drieling concluded that there was a wide variation among the students as to how closely their ideas approached the scientific understanding about soil layers and profiles.

Three studies have reported on effective treatment activities on soil understanding at the secondary level (Table 11). Cattle et al. (1995) introduced the use of computers in teaching detailed processes of soil science to upper secondary school and university students. Since technology has developed greatly over the intervening years, the details of this program are probably not of much use now. Drieling (2008) proposed using a constructivist model of activities for working with a group of Grade 11 students on understanding soil science in Germany orientation. This cycle of activities involved eliciting of pre-conceptions, restructuring of student concepts during activities through comparison with original ideas, clarification and exchange, construction and evaluation of new ideas, and finally application, and review of new ideas. She uses five concrete steps in this cycle (Drieling, personal communication):

1. Students imagine the ground under their feet and create a labeled sketch.
2. They next imagine that they shovel out part of the ground and note what they find.
3. They then use a spade or an auger to expose a soil profile, performing appropriate examinations on each horizon
4. They collect samples from the soil horizons and conduct lab tests such as pH.
5. They put together their results and draw conclusions
6. They compare and contrast their findings with the ideas they had initially.

The work of Moebius and Elsevier (2008) and Moebius-Clune et al. (2011) involved 48 secondary school students, engaging in 14 hands-on inquiry lessons concerning water runoff and infiltration into soils. Students asked their own research questions, which included "questions assessing the influence of compaction, vegetation, rock content, particle size, slope, and prior water content among others on runoff and infiltration partitioning." Students completed a series of worksheets to guide their inquiry, made journal entries, answers a series of questions addressing the experiment and making connections to real-world issues. (For the unit website, see Moebius and Elsevier, 2008). The pre-post test consisted of 13 multiple-choice questions from old multiple-choice Regents exams (New York), and 4 short answer questions. Because the students were from an agricultural area, many of them performed very well on the pre-test.

In addition to answering pre-post tests, student teams also presented final projects related to their own inquiry research on runoff and infiltration. The distribution of the final project scores was bimodal. On the high end, a group of eight students put in extra effort and moved beyond the majority. On the low end, a number of projects had obviously been given little effort. Interestingly enough, there was no correlation between test scores (13 multiple choice and 4 short answer), and final project scores, although there was a negative correlation between gains in test scores and final project scores, suggesting that the two methods of evaluation assessed different skills. Students also completed 11-item surveys assessing their interest in the project. Scores were high on most items (showing their enthusiasm and interest), and on two items they were very high. Students overwhelmingly said they enjoyed this kind of research more than the typical secondary school laboratory experiment, and that they learned to work in a team as research scientists do.

The studies by Happs (1981, 1984) showed that secondary students undoubtedly approach the subject of soils with a more advanced initial understanding than elementary students. The work of Drieling (2008) illustrates how the constructivist model of learning can be successfully combined with hands-on soil profile investigations to enable senior secondary students to radically change their ideas of soil. The work of Moebius-Cline et al. (2011) indicates that students can indeed benefit from an intensive inquiry activities on particular soil topics such as water runoff and infiltration. Other than these two studies, little work has been done with secondary students in general. (See below for work with students in specialized agricultural programs at the secondary school level.)

2.4 Secondary School Teachers' Knowledge of and Comfort Level with Soils

There are no published studies I am aware of concerning initial understanding of soil science by secondary school science teachers. Several studies have reported on the readiness and comfort level of secondary school teachers (agriculture, social studies, science) to teach about soils. Four of these are summarized here.

First, Puk and Behm (2003) studied the readiness of secondary school science teachers to teach about environmental topics including soils. They sent out 500 surveys to secondary school science and geography teachers across the province, and received back 226 completed surveys. Results indicated that teachers often did not teach the environmental components that had been infused into of the mainline science and geography courses. Reasons included lack of time and lack of knowledge on the part of the teacher. Soil concepts, in particular, were not taught by the majority of teachers.

Van Meter and Santucci (1990) were concerned about how frequently state soil surveys (used in planting, land management, and by conservationists) were used by secondary school agriculture and geography teachers across Indiana, an agriculture-focused state. He sent out 184 surveys to all secondary schools, and received back 145 completed ones. Survey analysis indicated that while secondary school teachers of agriculture were familiar with the soil surveys and most of them used the surveys in class, only a minority of geography teachers knew about them and very few of these made use of them in their classes. Interestingly, results were the same for urban and rural areas. The researchers concluded that soil surveys were sill primarily associated with agriculture and farm planning needs.

Wingenback et al., (2007) studied the knowledge and comfort levels of preservice agriculture teachers in Texas across the content topics of agricultural mechanics, employability characteristics, agriculture and the environment, animal science, plant and soil science, agricultural business management, soils and soil formations, and food science. They found that these levels were considered adequate for all topics except that of soils. Given what we know about the paucity of interest in soils and soil education in elementary and secondary education, this might not be surprising, although for the state of Texas soils do feature in the curriculum (Table 1).

Finally, Houck and Kitchel (2010) researched the content knowledge of preservice agriculture teachers in Kentucky. In contrast to the previous findings of Wingenbach et al. (2007), this study indicated that the teachers scored the highest on the topic of plant and soil sciences, compared with animal sciences, agricultural engineering, agricultural economics, and other agricultural social sciences. They note, however, that the students had more course preparation in plant and soil sciences than in any of the other topics.

In summary, a handful of studies suggest that secondary school geography and science teachers pay little attention to soil science, even though it may have relevance to some of their curricular topics. With regard to preservice agriculture teachers specifically, studies done in Kentucky and Texas give conflicting results as to how well prepared they are to teach soil science at the secondary school level, compared with the other topics in their curriculum such as animal science, food science, and agriculture management and engineering.

3. Resources Available for Elementary and Secondary Soils Education

There are many excellent resources available in English for teaching soils at the elementary level. These include complete equipment kits, extensive course manuals, articles from teacher journals, and websites with activities. At the middle school and secondary school level, resources are primarily available in the form of journal articles and websites.

3.1 Equipment kits and resource manuals for teaching a primary soils unit

3.1.1 Complete Equipment Kits

Many educational districts across North America have "science kit distribution systems" that are able to provide primary teachers (K-4) with a complete soil science kit for a month or more. When the teacher is finished with the kit, a staff of technicians refurbish the kit and send it on to another teacher. Although complete equipment unit kits cost between $500 and $1000, the price per individual use is relatively low. It contains all the equipment needed to lead a class through a series of engaging hands-on activities with soil (sand, clay, silt, loam, magnifying glasses, filters, seeds, trays, paper towels, etc. etc.). Most kits also come with a training CD for the teacher, a manual of detailed class lessons, activity cards or "black line masters" that can be used for each experiment, and assessment strategies and activities. The two kit programs described below (STC, FOSS) are ones that I have had personal experience with and can attest to their quality.

STC Soils. The National Science Resources Center (NSRC) STC unit kits are available in English, Spanish, and Swedish for a cost of US $480. This kit is aimed at the Gr. 2 level, although it has been used successfully in Gr. 3 classrooms across Toronto. The unit includes 16 detailed hands-on lessons for students to work through, using personal workbooks and comes with a teacher's guide, a Teacher's Tools CD, 16 reusable student guides, and materials for a class of 32. (See http://www.carolinacurriculum.com/STC/Elementary/Soils/index.asp, accessed on April 15, 2012). A sample lesson is available for download. The description on the NSRC website is accurate: "Soils, a 16-lesson unit for second-graders, deepens children's awareness and appreciation of soil. Using simple tests, students learn to identify sand, clay, and humus in soil. They also study how water affects different kinds of soil. Through long-term experiments, they explore how roots and plants grow in various soils and how, with the help of worms, old plants decompose and become part of soil. Then, applying what they have learned, they investigate their own local soil."

FOSS Pebbles, Sand and Silt. The Full Option Science System (FOSS) is part of the Lawrence Hall of Science. Like NSRC, FOSS kits cover all grades and strands of Kindergarten to Grade 6 science. They are available for US $924 (http://www.delta-education.com/fossgallery.aspx?menuID=2, accessed April 15, 2012). Like *STC Soils,* this kit is aimed at Gr. 2 but is also suitable for Gr. 1-3. In addition to the complete equipment the kit includes student videos and an up-to-date website with pages for parents, teachers, and students (http://fossweb.com/modulesK-2/PebblesSandandSilt/index.html, accessed on April 15, 2012).

Unlike *STC Soils,* the FOSS kit has students investigating rocks and minerals, leading them to see where sand and clay come from, and then using them to construct and build objects, before it concludes with soil explorations, where students put together and take apart soils, are introduced to humus as an ingredient in soil, and compare homemade and local soils.

3.1.2 Teacher Resource Manuals

Soils in the Environment (Andrews et al., rev. 2009). This 75-page, Gr. 3 resource manual, with 25 laminated student activity sheets, includes 23 lessons on almost every aspect of soil science appropriate for primary students. Topics include the composition of soil, soil and water, characteristics of soil components, infiltration, runoff, and sedimentation in water, soil profiles, organisms that live in the soil, growth of plant roots in soil, and using composters. (Contact the author for availability at www.bill-andrew.com, accessed on April 15, 2012).

Dig in! Hands-on Soil Investigations (NSTA, 2001). The National Resources Conservation Services (NRCS) and the National Science Teachers Association (NSTA) created this 129-page integrated resource, for elementary science teachers and supervisors. It is aimed at the Kindergarten to Gr. 4 level. Each lesson follows a five-step learning cycle – perception (30 min), exploration (30 min), application (30 min), evaluation (15-30 min), and optional extensions (30 min each) – and includes one or more student activity sheets (black line masters). Topics addressed in the 12 lessons include components of soil (sand, clay, and silt), formation of soil, soil layers, plants and animals that live in the soil, amount of soil on the Earth and its use in food production, needs of plants growing in soil, micro-organisms that live in the soil, food chains, worms, effects of water and wind erosion on soil, soil scientists, creating a school garden. The book is available in print (US $22) or electronic download (US $16) form NSTA (http://www.nsta.org/recommends/ViewProduct.aspx?ProductID=12309, accessed on April 15, 2012).

3.1.3 Summary

Complete equipment kits are ideal for primary teachers who are able to focus a unit of science teaching on soil. As they are expensive and require constant refurbishing, a central system is necessary to maintain science kits at the school, district, or regional level. Of the two kits reviewed here, the *STC Soils* is more focused on soils, and works very well for a curriculum unit only about soils. *FOSS Pebbles, Sand and Silt* is better for an integrated rocks-soil curriculum unit at the Gr. 1-3 level.

A complete teacher resource manual that includes a comprehensive series of lessons on soil science can also be a valuable resource. Of the two reviewed here, Andrews's *Soil in the Environment* contains more soil science. Although aimed at Grade 3, it would also be suitable for the junior level (Gr. 4-6). NSTA's *Dig in! Hands-on Soil Investigations* is as extensive a resource, but is more appropriate for the lower levels of primary school. It makes excellent use of the 5-E learning cycle and requires less teacher background knowledge.

Other excellent books include *Soils: Get the Inside Scoop* (Soil Science Society of America, 2011), and Brown and Dickinson's *Earth Science: A Multifaceted Investigation of Soil.* (Zephyr, 1994).

3.2 Short Articles on Soil for Elementary, Middle School, and Secondary School Teachers

Many excellent articles have been published in non peer-reviewed teacher journals and other science activity journals with helpful ideas or perspectives on teaching about soil science concepts at the elementary (Kindergarten to Grade 6), middle school (Grades 7-9), or secondary (Grades 10-12) levels. These are generally available for download from websites of libraries that subscribe to the journals (Table 14). These articles should be considered supplementary to the use of unit resources for teaching about soils, especially at the elementary level. For middle school and secondary school teachers and soil educators (including extension), the articles provide many good ideas.

3.3 Websites and other Electronic Resources for Soil Education

Table 15 lists European and American websites on soil education. Many of the European links are in the European Soil Data Centre inventory of educational material (accessed at http://eusoils.jrc.ec.europa.eu/Awareness/inventory.cfm on April 1, 2012). Many of the American links are on the US Department of Agriculture website for Soil Education (accessed at http://soils.usda.gov/education/ on April 15, 2012).

4. Conclusions

Studies conducted across a broad range of student ages, years, and countries conclude that students of all ages tend to begin the study of soils with very little understanding about its composition, formation, and origin, although they appreciate its necessity for life, especially plant life. With the use of an extended set of effective hands-on activities lasting over several weeks, however, children as young as 5 to 6 years are capable of achieving a lasting change in their mind-set about soils, as demonstrated by interviews, diagrams, and objective tests held months after the activities. Students above the age of 9 years can develop a deeper understanding of the three-dimensional nature of soil, and begin to understand its formation process and age. Secondary students are capable of going further, and often learn a little about soils in their secondary ecosystem unit. Like students, elementary teachers arrive at the study of soil with some pre-existing understanding. In-depth classes in preservice science methods courses can significantly increase their conceptual understanding. Little research has been done on soil understanding of secondary teachers. It is only taught in specific agriculture courses at that level.

Despite the importance of soil, and the ability of students, even those of young age, to learn about it, the science curriculum of most countries does not allot a regular unit to soils, although the topic is often touched upon in ecosystem units found in the biology part of the curriculum. Canada and some parts of the U.S. are an exception to this. In those regions, students study the topic in detail at the Grade 2 or 3 level, and many excellent equipment kits, teacher resource manuals, and teacher articles are available. Websites on soil education are ubiquitous throughout Europe and America.

Although the research on elementary and secondary soil education is limited, results consistently indicate that student exposure to information and hands-on experiments related to soil science can encourage long-term improvements in student understanding of soil science. Given the resources available, one of the most effective things that people concerned about soil education can do is to ensure that the topic finds a permanent place in their country's national curriculum (usually science, but in some cases geography), and that classroom teachers are given the necessary training, resources, and support by the countries soil science societies to teach it in an effective manner.

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Figures

Figure 1 Young children investigate a soil profile in Greven, Germany, during "Soil Action Week" (County Steinfurt, 2010). The European Network on Soil Awareness helps organize soil awareness public events at various locations in different countries (Broll, 2011).

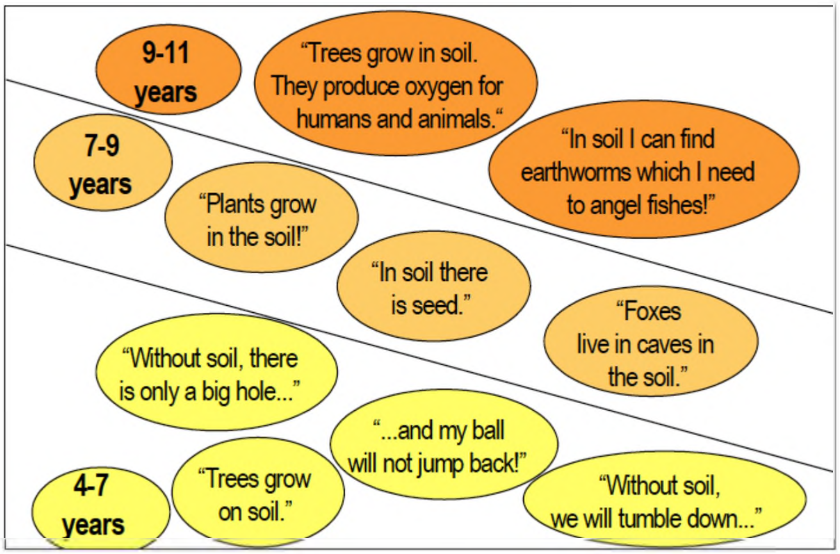


Figure 2: A mind-map of children's previous concepts of soil (Geyer et al., 2004)

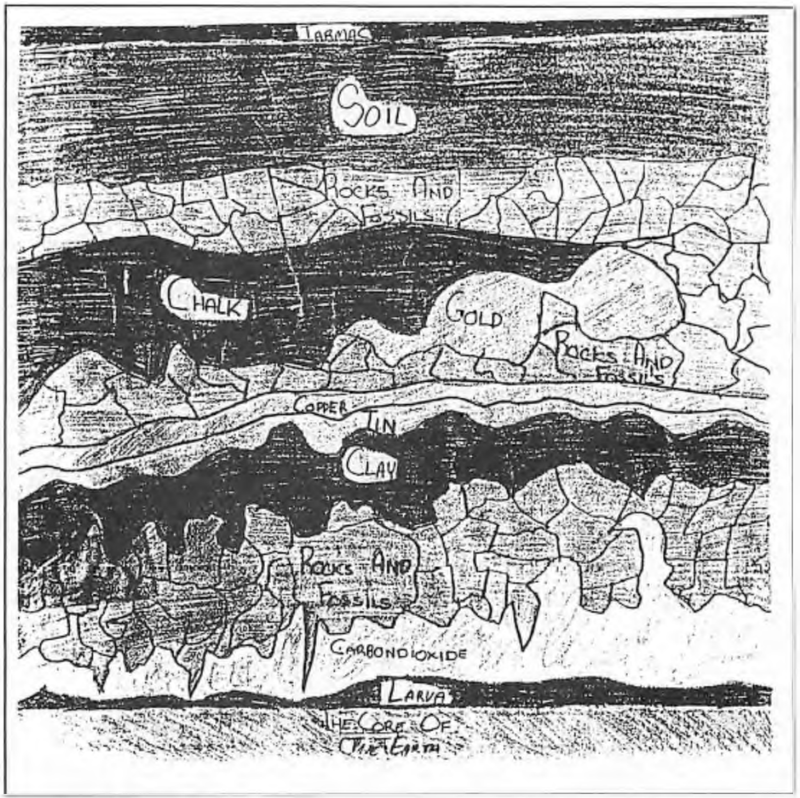
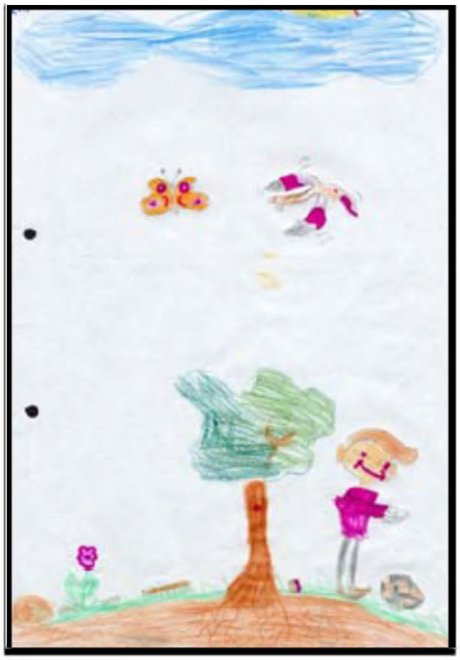


Figure 3: Initial drawing, before treatment, by a junior level student in England, showing an unusual number of references to minerals (Russell et al., 1993)



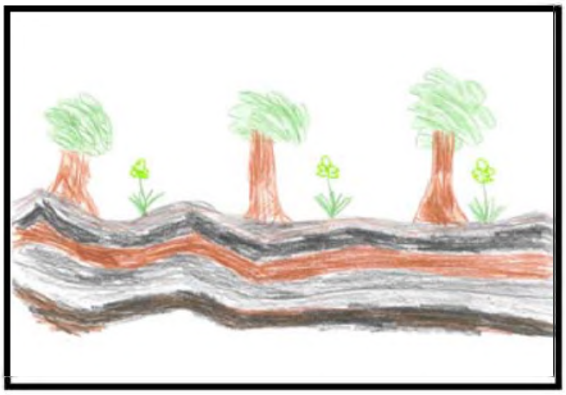


Figure 4: Diagrams made by a 9-year-old student before, soon after, six weeks later, and a year later, showing progress and permanence in learning soil layers (Geyer et al., 2004). Notice the surprising amount of underground soil features in the layers drawn in the last diagram.

Figure 5: Preservice elementary teachers studying soil observe its different components, notice its formation from the erosion of rocks, and ponder the role earthworms in it (Hayhoe et al., 2011)

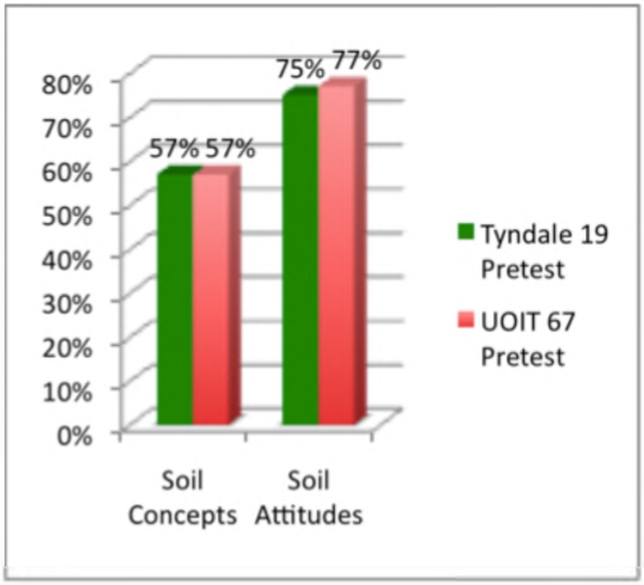


Figure 6a: Teacher understanding of soil concepts and attitudes toward soils (Hayhoe et al., 2011). Preservice elementary teachers at a small private Christian university in Canada (Tyndale) performed the same as their counterparts at a mid-sized public university (UOIT) on pretests for soil concepts and soil attitudes.

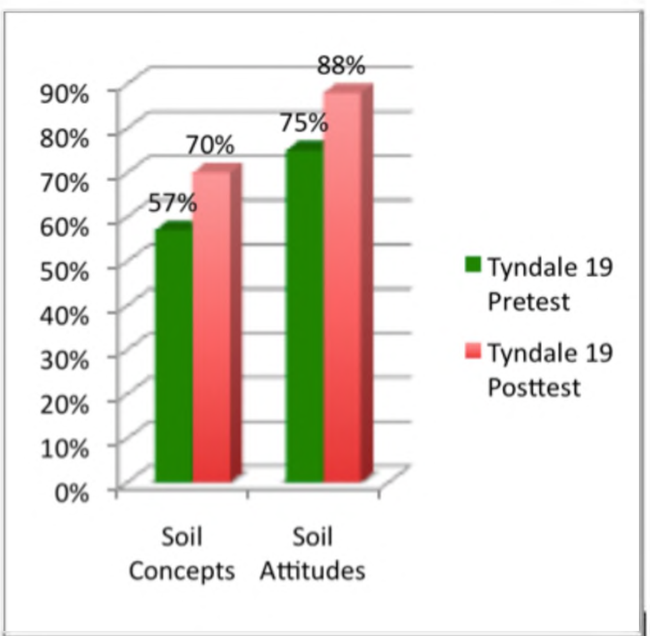


Figure 6b: Pre-post gains in teacher understanding and attitudes towards soil (Hayhoe et al., 2011). Preservice elementary teachers at a small private Christian university in Canada (Tyndale) gained in both soil concepts and soil attitudes, although there was no significant correlation between gains for individual teachers.

Table 1: The role of soil in elementary and secondary science curriculum documents in some English speaking countries and regions compared with other earth and space topics

Australia (ACARA, 2012)	Soil is briefly referred to as one of earth's resources in Gr. 2 and as part of the changes in Earth's surface over time in Gr. 4. Other earth and space topics, however, are given more prominence. Topics in astronomy, for example (sun and moon, solar system, and stars), are addressed in Gr. 1, 3, 5, 7, and 10; and topics in geology (rocks and minerals, plate tectonics, and natural disasters) are addressed in Gr. 4, 6, 8, and 9.
California (CDE, 2009)	Soil is mentioned several times in Gr. 2 Earth Sciences, with rocks, the rock cycle, and erosion, and several times in Gr. 6, with topography, ecosystems, and natural resources. Topics in astronomy and geology, however, such as rocks, earthquakes, planets, and stars, are mentioned at least twice as much. (The excellent Grade 2 FOSS unit and equipment kit, *Pebbles, Sand, and Silt,* comes from California. See Table 4.)
Canada (CMEC, 1996)	A Gr. 3 soil unit refers to soil components, the interaction of soils with water, living things and soils, and similarities and differences among soils. A Gr. 10 Sustainability of Ecosystems unit includes soil composition and fertility along with seven other ecosystem concepts. (The "illustrative example" focuses on soils.) Many provinces follow this document, such as Ontario, the most populous province (see below).
New York (NYSED, 2009)	Grades K-4 state that "soil is composed of broken-down pieces of living and nonliving earth material." Grades 5-8 refer to soil composition, soil monitoring, and soil pollution. However, rocks and minerals, and the moon, are all mentioned more frequently. Similarly in Grades 9-12, where soil is mentioned briefly in connection with ecosystems, while geological and astronomical topics are mentioned more often.
Ontario (Ontario MOE, 2007)	In the Gr. 3 soil unit, students assess the environmental impact of soils, and study the composition and characteristics of different soils, and the relationship between soils and living things. Detailed specific expectations are given. Soil also appears as part of the Gr. 9 Ecosystems unit, where students "plan and conduct an investigation … into how a human activity affects soil composition or soil fertility."
South Africa (DOE, 2002, 2003; CAPS,	In Grades R-3, along with rocks, soil is mentioned, in particular, the erosion of soil and the types of soil. In Grades 4-6, the formation of soil, and the need to maintain the fertility of soil, are mentioned in the context of ecosystems, while the composition and properties of soil are mentioned in the context of earth changes.

2011)	
Texas (TEA, 2010)	In Gr. 1, students sort components of soil by size, texture, and color. In Grade 3, they study the formation of soil by weathering of rock and the decomposition of plant and animal remains. And in Grade 4, they "examine properties of soils, including color and texture, capacity to retain water, and ability to support the growth of plants." In Grades 9-12, soil is a significant part of one of the strands in Environmental Systems.
United Kingdom (UK DOE, 2011)	Key Stage 1 mentions several topics but not soil. Key Stage 2 mentions some astronomy and environmental topics under physical processes and life processes, but soil is not mentioned. In Key Stage 3, geological topics such as rocks, and astronomical topics such as earth and moon, are mentioned several times, but soil is not mentioned. Similarly in Key Stage 4. It is difficult to see "soil" as a content domain in this science curriculum.
United States (NAP, 2012)	Soil is one of the examples of "Crosscutting Practices." It is found in Life Sciences at each end level (Grades 2, 5, 8, and 12). It is frequently mentioned in Earth and Space Sciences, in the subtopics of Earth Materials and Systems, Plate Tectonics and Large-Scale System Interactions, The Roles of Water in Earth's Surface Processes, Biogeology, Natural Resources, and Human Impacts on Earth Systems (Grades 2, 5, and 8).

Table 2: Initial understandings of soil by elementary students in various countries

Reference	Country	Students	Probe used	Topics studied	Initial student understandings
Geyer et al., 2003, 2004	Germany	Age 4-11	Interviews and labeled drawings	Purpose of soil; 2 or 3D picture of soil	Age 4-7 no idea of anything below ground Age 7-9 some idea of depth, but not soil Age 9-11 have some pre-ideas of soil
Happs, 1981, 1984	New Zealand	40 Gr. 7 students; (221 Gr. 7 to 12 students)	Interviews; (followed by a Likert scale test survey of 16 items).	Makeup, origin, depth, and age of soils. Changes that soils undergo.	The majority of students thought that soil (1) is a medium for plant growth and a home for small animals, (2) has always been there (a few said that it formed from organic matter), (3) is as old as the Earth, (4) is between a few cm and 10 m deep (a few said that it was several thousand km deep) and (5) does not change, or, changes to clay and then to rock in some undefined cycle. Many of the students used the terms “dirt” and “soil” synonymously.
Russell et al., 1993	UK	58 Gr. K-6 students (5-11 yrs)	Student log books, drawings, discussion. What is soil? What is in it?	Makeup, origin, and permanence of soil. Changes to soil that might occur and their reasons.	After exploration activities, to familiarize them with soil, but before intervention strategies, students thought the following: - soil’s use or function: for growing plants - age 5-8: soil is mud, sand, or stones - age 8-11: some idea of sand as a mixture - little idea of changes to soil, or its origin

Table 3: Pre-post gains in soil understanding by elementary students in various countries

Reference	Country	Students	Probe used	Topics studied	Treatment	Results
Geyer et al., 2003, 2004	Germany	Age 4-11yr	Interviews and labeled diagrams	Purpose of soil, ideas about soil layers, soil and ecosystems	teacher lessons, soil animals, fieldwork in a pit, observations of a variety of soils,	After some weeks, diagrams included a lot more detail about soil layers
Gulay et al., 2010	Turkey	Preschool children (5-6 yrs), from low socio-econ. back-ground, with little knowledge of environ. subjects.	12 test items administered orally with figures and photograph, pre-test, post-test, and delayed post-test.	Characteristics of soil, living beings on/under the soil, importance of soil, reasons and results of erosion.	9-day program in four different nursery classes with activities on characteristics of soil, living beings on or under the soil, importance of soil, protection of the soil, and identification of reasons and results of erosion.	The experimental group achieved significantly higher than the control group on the post-test, although both groups were similar on the pre-test.
Lippert, 2006	US	97 Gr. 7 students.	26 multiple-choice pre-post test items	A variety of mostly factual questions related to soil.	Web-based module for 2-3 days, based on slides used in extension education	Significant gains were found on most of the items
Randler and Hulde, 2007	Germany	123 Gr. 5-6 students	Pre-post tests with 5 open-ended questions related to content.	Three experiments: Water-holding capacity of the moss, erosion of grassland versus agricultural land, water-cleaning capacity of soil.	Teacher-centred presentation of experiments versus learner-centred hands-on work	No significant difference in pre-post gains for both groups for post-tests held immediately after treatment. For post-tests held a month later, the learner-centred group scored

						significantly higher.
Russell et al,. 1993	UK	58 Gr. K-6 students (5-11 yrs)	Student logbooks, drawings, individual discussion, and pre-post intervention interviews.	Makeup, origin, and permanence of soil. Depth of soil. Changes to soil that might occur and their reasons.	Detailed intervention strategies over five weeks, involving a variety of strategies.	Better knowledge that soil is made of living things, has particles of different size, and owes its origin to the transformation of previous inorganic substances.

Table 4 Gains on 26 knowledge questions about soils (Lippert, 2006). Grade 7 students studied a web-based module on soils for two to three days, and answered a pre-post test with the following question stems.

Question stem	Pre-post gain	Delayed gain
Soil is roughly what percent pore space?	56	35
The three particle sizes for soil minerals do not include:	10	8
The smallest soil particle is:	62	53
A texture triangle tells us:	31	22
Which statement is true?	77	67
Clays generally have:	69	52
Horizons:	11	5
The soil horizon which loses minerals and clay to the layer underneath it is labeled with the letter:	36	16
Bedrock breaks up because of:	26	12
Undeveloped soils have:	50	43
The five soil forming factors are climate, topography, biology, time and:	11	5
A soil will develop the fastest when the weather is:	49	34
Topography refers to:	33	26
Most organic matter is decomposed by:	23	21
In general, it takes about how long to form a layer of soil the thickness of a sheet of paper?	51	44
For plants to grow, they need how many nutrients?	50	40
Secondary plant nutrients are:	20	27
Which is correct?	38	34

If phosphorus is deficient in the soil, the plant leaves appear:	70	38
When a plant is deficient in potassium, the leaves:	36	20
Phosphorus doesn't move through the soil with rainfall because:	35	13
When a positively charged atom takes the place of another positively charged atom on clay, it is called:	43	43
An acid soil:	39	19
Soil acidity is not formed from:	39	15
For maximum plant nutrient availability, the ideal soil pH should be close to:	45	28
Erosion always occurs when there is:	42	32

Table 5 Significant gains retained after a one-month delay (Randler and Hulde 2007). Grade 5-6 students studied the water holding property of moss, soil erosion on grasslands compared with agricultural lands, and the water cleansing capacity of soil, and were tested for pre-post gains in understanding, in teacher-centered versus learner-centered environments.

Test	**Treatment**	**Mean**	**Out of**	**SD**	t-value	Probability
Pre-test	Learner-centered	1.37	5	0.89	-0.227	0.821
Pre-test	Teacher-centered	1.40	5	1.00		
Post-test	Learner-centered	5.50	7	0.91	-0.588	0.557
Post-test	Teacher-centered	5.60	7	1.08		
Delayed	Learner-centered	5.38	7	0.94	2.579	0.011
Delayed	Teacher-centered	4.91	7	1.06		

Table 6 Nature and origin of clay as understood by 87 preservice elementary teachers in New York State (Rule, 2007). The pre-test included writing the definition of clay, listing products made from clay, and explaining the origin of clay.

General category of definition of soils	**No. of teachers**
Unspecified moldable substance, used to make things, to be shaped	39
Natural substance found in the Earth, sediment found along riverbanks	39
Raw material for ceramics, used for pottery, solid substance	27
Art material, easy to form, used for making things	20
Manufactured artificial material, play dough	18
Material for making models, modeling clay	17
Type of soil, hard soil, thick soil, soil in the ground	13
Wet dirt, mucky substance reddish brown in colour, mud	11
Category of concept about origin of clay	
Formed by a mixture of particles with water. One of the layers within rock. Made from the breakdown of rock, a result of heating of rock, etc.	18
Pressure is needed for clay mineral formation. Pressure on soil and water plus time produces clay. It forms over years from compression and mixture of minerals and water.	12
Clay minerals are ground rock. Clay comes from the breakup of larger minerals into clay.	12
Clay forms from a mixture of materials – sediments and minerals.	9
Clay forms in the ground, from a specific mixture of minerals in the ground.	9
Heat, melting is involved in clay formation; melting caused by the heat of the Earth	9
Clay was here from the beginning of the Earth. God made it.	7
Chemical weathering forms clay; it originates from a series of reactions at Earth's surface	5
Clay minerals are found in soil. Minerals come from the soil	4

Clay minerals originate from organic materials. The minerals come from plants.	4
Evaporation and recycling forms clay	3

Table 7 Pre-test selections of 74 preservice teachers on soils (Hayhoe et al, in-press). Preservice elementary teachers at a mid-sized public university in Canada were tested for initial understanding of different soil concepts.

Some correct responses selected by more than two-thirds of the teachers	**%**
Sand is mainly formed on Earth by weathering of rocks	89
Earthworms mix the soil and allow for more air and water to be in it	88
When trees and plants die they decompose into soil nutrients used for plants to grow	84
Soil is essential for life and society to survey	84
Compost improves plant growth … by adding essential nutrients to soil	77
The component of soil that is slippery or sticky and keeps its shape after you let it go is clay	74
Rodents do not function as soil decomposers	73
Crop rotation helps maintain fertile soils	73
The life forms that live in the soil are decomposers	64

Some correct responses selected by less than one half of teachers	**%**	**Some incorrect responses selected**	**%**
One handful of fertile soil is likely to have more organisms than people living on earth	14	… people living in a small village	38
		… people living in a small city	45
It usually takes 100-1000 years to form 1 cm of topsoil	20	… 1-10 years to form 1 cm of topsoil	66
When we look at soil with a magnifier, we are very unlikely to see soil fungi.	27	… plant roots	28
		… silt	35
Soil is composed of solid particles with spaces between them for air and water to enter. In good soil, approximately 50% of the total soil volume is space for air and water.	27	… 25%	58

A very fine component of soil that feels like powder when it is dry is silt	45	… sand	28
		… clay	23
Clay particles are the smallest particles in soil	7	Silt particles …	46
		Sand particles …	34
You place equal amounts of sand, clay, and silt in three different test tubes of water, shake the test tubes, and sit them in a stand. In the test tube with sand, the solid will settle down first.	38	… with clay …	45
Decayed organic matter in soil is called humus	26	… decomposers	45
The role of humus in soil is to provide nutrients for micro-organisms and plant roots	28	… is to retain water for dry periods	41
One of the functions of soil is filtering impurities out of water	43	… supplying oxygen for us to breathe	22
		… none of the above	30

Table 8: Pre-test scores and gains on 25 items related to specific soil concepts, by preservice elementary teachers at two universities over two years (Hayhoe et al., manuscript submitted for publication)

Application of the soil concept test	Participants	Raw mean	st	% mean
Year 1				
UOIT pre-test	74	12.53	3.96	50.1*
Tyndale pre-test	21	12.43	2.53	49.7*t
Tyndale post-test	21	16.57	3.61	66.3*t
Year 2				
UOIT pre-test	98	12.45	4.23	49.8*
Tyndale pre-test	20	12.00	3.74	48.0*t
Tyndale post-test	20	16.95	4.41	67.8*t

*The differences between the four pre-tests (two institutions over two years) were not significant.

[t] The differences between pre-post tests for both years were significant ($p < .001$)

Table 9: Pre-post mean item scores averaged over two years for selected soils items with 41 preservice elementary teachers (Hayhoe et al, manuscript submitted for publication). The pre-test means in this table are for the 41 Tyndale preservice teachers, whereas the pre-test means in Table 7 are for 74 UOIT preservice teachers.

Pre-post test scores for items showing significant gains. Correct answers are given with the item stems below.	**Pre-test % Mean (%) (n=41)**	**Post-test mean (%) (n=41)**
One handful of fertile soil is likely to have more organisms than people living on earth	12	71
It usually takes 100-1000 years to form 1 cm of topsoil	10	60
When we look at soil with a magnifier, what are we very unlikely to see? Soil Fungi.	31	43
Soil is composed of solid particles with spaces between them for air and water to enter. In good soil, approximately how much of the total soil volume is space for air and water? 50%	26	36
A very find component of soil that feels like power when it is dry is silt.	36	62
What are the smallest particles in soil? Clay	10	24
You place equal amounts of sand, clay, and silt in three different test tubes of water, shake the test tubes, and sit them in a stand. In which test tube will the solid settle down first? Sand.	43	67
Decayed organic matter present in soil is called humus.	12	48
The role of humus in soil is to provide nutrients for micro-organisms and plant roots	45	62
Which of the following functions does soil do? Filter impurities out of our water.	24	31

Table 10: Initial understandings of soil by secondary students in three countries

Reference	Country	Students	Probe used	Topics studied	Initial understandings
Drieling, 2006, 2008	Germany	Gr. 11	Guideline interviews and drawings	Structure and components of soil and its functions	Soil is divided into layers of humus, sand, or gravel, or soil is a place where animals live, or a habitat for plans that also filters water. Diagrams reveal students' views on soil erosion, acidification, and hardening.
Happs, 1981, 1984	New Zealand	Gr. 12, University and teachers' college students	Interviews; (followed by a Likert scale test survey of 16 items).	Makeup, origin, depth, and age of soils. Changes that soils undergo.	Students - knew the difference between soil and dirt, in terms of some components - thought that soil come from a multisource mechanism - considered soils to be very, very old - thought the depth of soil was between a few cms and 100 m - held a complicated view of the soil-rock cycle

Table 11: Treatment activities on soils for secondary students in three countries

Reference	Country	Students	Probe used	Treatment activities	Results
Cattle et al., 1995	Australia	High school, university students (16-20 yr)		A computer program dealing with the five main types of soil degradation was developed, called "the Soil Stack."	Feedback from universities and colleges indicated that it has been used as a teaching tool and as review material in advanced courses.
Drieling (2008)	Germany	Grade 11 (6th form)	Interviews and drawings	A constructivist approach is used, where students first share their own pre-ideas, and they are exposed to hands-on examination of soil components and soil profiles	The constructivist model is successfully used to enable students to addess any misconceptions they have and be open to restructuring their ideas.
Moebius-Clune and Elsevier, 2008; Moebius-Clune et al., 2011	US	48 Gr. 10 students working in small teams	13 multiple choice items and 4 short answer items	14 hands-on inquiry lessons on water runoff and infiltration into soils, with student teams creating their own questions and doing their research.	Pre-post gains went from 63% to 80%. (Because students were from an agricultural area, many of them scored very high on the pre-test.)

Table 12: Soil articles for elementary, middle school (Grade 7-9), and secondary (Grade 10-12) teachers

Grade level	Title	Description	Journal	Author(s)	Date
Gr. 1-6	Boden (Soil)	Special issue of a journal for primary teachers in Germany devoted to Soil	Grundschulunterricht (Translated: Primary Education)	Various	April 2007
Gr. 1-2	"The radish party"	The nature of soil, and its importance and relevance of soil organic matter for young students.	Science and Children	Jeff Piotrowski, Tammy Mildenstein, Kathy Dungan, Carol Brewer	Oct. 2007, p 41-45
Gr. 1-2	"Second-grade soil scientists"	Inviting a professional soil scientist into a Gr. 2 class working with the *STC Soils* unit led to real inquiry.	Science and Children	Lori Gibb	Nov/Dec 2000, P 24-28
Gr. 1-6	"This land is your land"	Hands-on activities with readily available materials help students learn how to prevent soil erosion.	Science and Children	Ann Kennedy, Tami L. Stubbs, Jeremy C. Hansen	Dec. 2006, p 22-26
Gr. 1-6	"Is your soil sick?"	Students explore the testing of soil, learn about plant needs and how to analyze results.	Science and Children	Donna R. Sterling and Dori L. Hargrove	April 2012, pp. 51-55.
Gr. 1-8	"Synthetic soils: mixing the bad with the good"	Students put together a mix of soil components and waste to see how different plants grow.	Science Activities	Peter Veronesi	Summer 1996, pp. 27-33
Middle school	"Science sampler: The Science of soil textures"	Investigating the texture of soil, and seeing how it has an effect on many different kinds of activities.	Science Scope	Gary Bingham	Oct 2010, pp. 63-68
Middle	"Hands-in	Students study backyard soil to	Science	Vickie Furlough,	April 1997,

school	science"	make a county soil map, and measure soil moisture and porosity.	Scope	Amy Taylor, and Scott B. Watson	pp. 16-17
Middle school	"Life in a teaspoon of soil"	Students use hand lenses or microscopes to find fungi in soil.	Science Scope	Shirley Foster Fields	Feb. 1993, pp. 16-18
Middle school	"Soil is more than just dirt"	Students discover that soil is made of air, water, organic material, and different mineral grain sizes (sand, silt, and clay), and has a great diversity of organisms living in it.	Science Scope	Carrie Taylor and C. John Graves	April 2010, pp. 70-74
High school	"Soil searching: dishing the dirt on microbes"	Students conducting chemical tests on various soils for their level of microbial activity	The Science Teacher	Ann C. Kennedy, Karen L. Smith, Raymond L. Neff	Feb. 1995, pp. 34-38
High school	"Soil Testing: Dig in!	Students examine soil samples for physical appearance, water-holding capacity, sedimentation, and pH.	Journal of Chemical Education	Linda N. Fanis and Erica K. Jacobsen	Feb. 2006, pp. 240A-B, vol. 83, no. 2
High school, college	"Quick, easy method to show living soil organisms …"	This is a research article that describes in detail useful ways to show the details of microorganisms to high school and college students.	Journal of Natural Resources and Life Sciences Education	Thomas E. Loynachan	2006, Vol. 25, pp. 202-208
High school	"Fungi: Strongmen of the Underground"	Students measure the weight of strings exposed to fungi in wet soil, to develop a more complete understanding of fungi.	American Biology Teacher	Patricia D. Morrell and Jeffrey J. Morrell	Jan. 1999, Vol. 61, No. 1, pp. 54-55
High school	"Measuring the physical properties of soils:	Introduces a range of simple ideas about soil physical properties using a minimum of apparatus.	School Science Review	Paul Perkins	June 1994, Vol. 75, No, 273, pp. 82-83.

Table 13 Websites with soil education resources

URL	Origin and Content
European resources	
http://www.al.fh-osnabrueck.de/fileadmin/users/30/upload/Bowi_Medienkatalog_2009/medienkatalog_starten.html	Media Catalogue for the Introduction of Soil-related Topics in School Teaching in Germany
http://www.bgr.bund.de/bodenunterricht	Links to basic soil information and student worksheets in the German language for different levels and age groups.
http://www.cienciadelsuelo.es/	Spanish resource on soil science, also available in English. It is a multimedia- interactive program with different modules that outline the study of soil components and soil genesis.
http://ec.europa.eu/environment/soil/pdf/Broll.pdf	"Soil biodiversity: An excellent way to raise soil awareness," a presentation in English, by Broll (2010), on various aspects of soil education and outreach in Europe.
www.infovek.sk	Educational resources for Slovakia
www.let-group.com	Slovenian language website on the environment, including soil, for primary, secondary, and university students.
http://www.macaulay.ac.uk/news/dirtdoctors/	The Dirt Doctors: Uses cartoon characters and humour to represent different soils. Comparing human and soil health is an underlying theme. Macauley Land Use Research Institute.
www.soil-net.com	Elementary and secondary educational resource, supported by the British Society of Soil Science. It uses cartoons at the primary level (age 5-11) and informational text at the secondary level (age 11-16).
American resources	
http://archive.fieldmuseum.org/undergroundadventure/teachers/soil_biodiversity.shtml	Extensive soil resources for teachers and students for Kindergarten to Grade 8, by the Field Museum in Chicago
www.dirtthemovie.com	Tells the story of soil, "Earth's most valuable and

	underappreciated source of fertility--from its miraculous beginning to its crippling degradation." Available on itunes.
www.doctordirt.org	K-8 educational resources and activities on soils, developed by Dr. Dirt, i.e., Clay Robinson, soil scientist in West Texas.
http://extension.usu.edu/aitc/lessons/index.cfm	Activities used in extension, by the Utah State University
http://nacdnet.org/education/resources/soils/	Soil education resources sponsored by the National Association of Conservation Districts, USA.
http://soil.gsfc.nasa.gov/	NASA resources on soil science education
https://www.soils.org/lessons	Elementary and secondary educational lessons, developed by the Soil Science Society of America.
http://soils.usda.gov/education/	Soil education resources, and websites by the US Department of Agriculture, for elementary, secondary, and college levels.
http://tlc.howstuffworks.com/family/science-projects-for-kids-soil-experiments4.htm	Science Projects for Kids: Soil – 5 hands-on soil experiments for elementary students, by The Learning Company