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Sustainable Agriculture Reviews

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Contents

Surprising Facts About Soils, Students and Teachers! A Survey of Educational Research and Resources

Douglas Hayhoe

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, e.g. its concepts, concerns and protection, 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 article 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, of 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

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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 (Fig. 1).

Fig. 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)

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 4,500 students; but only ten of them are enrolled in soil and water science (Collins 2008). This study by

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 2011)	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

(continued)

Table 1 (continued)

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)

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, 4–11 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 (Fig. 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.

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, 2006	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. 7–12 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 years)	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 4–11 year	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 years), 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 years)	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 5 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

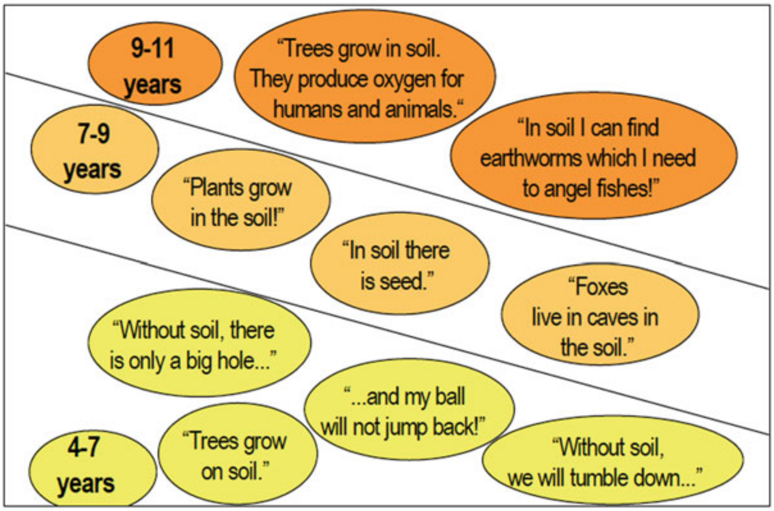

Fig. 2 A mind-map of children's previous concepts of soil (Geyer et al. 2004)

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 m in depth, and another third between 1 and 10 m in depth.

Russell et al. (1993) worked with 58 children between 5 and 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 (Fig. 3)

The research summarized by these four articles was extensive in nature, and covered a span of ages from 5 to 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*,

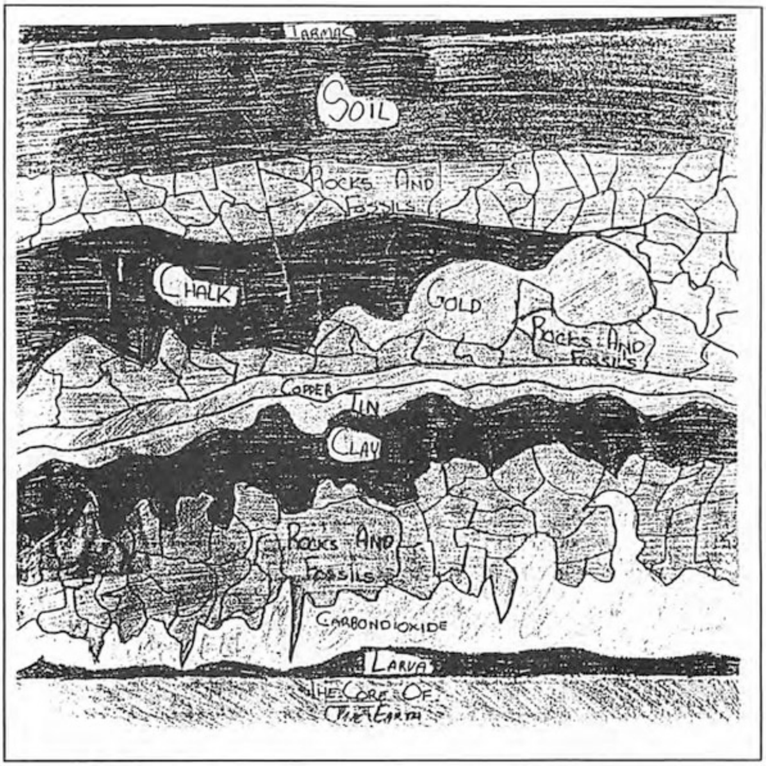

Fig. 3 Initial drawing, before treatment, by a junior level student in England, showing an unusual number of references to minerals (Russell et al. 1993)

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 (2 weeks later), but only the experimental group was exposed to the 9-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 to 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. 6 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.

Fig. 4 Diagrams made by a 9-year-old student before the soil fieldwork (*left*), soon after, 6 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

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 5 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 1 m 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 eight students referred to both translocation and transformation. Only eight 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 2–3 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 5 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 and 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 out4 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)

Table 4 Gains on 26 knowledge questions about soils (Lippert 2006). Grade 7 students studied a web-based module on soils for 2–3 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

- 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)

Table 5 Significant gains retained after a 1-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		

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 4–5 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 Macklem-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 (nine 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). Seventy four 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 Macklem-Hurst (2002), students met twice a week for a total of 4.5 h. 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.

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

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-h 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 ten 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 (Fig. 5). Five months after the activities on soils, and 4 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

Table 7 Pre-test selections of 74 preservice teachers on soils (Hayhoe et al., manuscript submitted for publication). 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 *100–1,000 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

Fig. 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)

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 (Fig. 6). 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 (Fig. 7). 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 2 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 under-

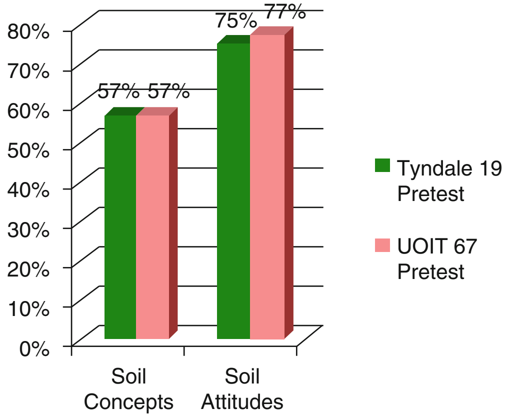

Fig. 6 Teacher understanding of soil concepts and attitudes toward soils (Hayhoe et al. 2011). Preservice elementary teachers at a small private Christian university in Canada (Tyndale) performed the same as their counterparts at a mid-sized public university (UOIT) on pretests for soil concepts and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

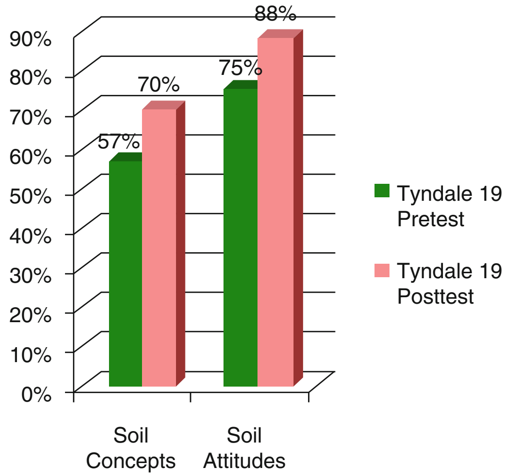

Fig. 7 Pre-post gains in teacher understanding and attitudes towards soil (Hayhoe et al. 2011). Preservice elementary teachers at a small private Christian university in Canada (Tyndale) gained in both soil concepts and soil attitudes, although there was no significant correlation between gains for individual teachers

standing 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.