Soil-Net - Development and impact of an innovative, open, online soil science educational resource

Journal Item

For guidance on citations see FAQs.

oro.open.ac.uk

Soil-Net: Development and Impact of Innovative, Open, Online Soil Science Educational Resources

Stephen H. Hallett[1*] and Sally P. Caird[2]

[1]*School of Water, Energy and Environment, Cranfield University, Bedford, UK*
[2]*School of Engineering and Innovation, The Open University, Milton Keynes, UK*
* Corresponding author*

ABSTRACT:

Despite recognition of soil as a major global natural resource and longstanding policy recognition of its importance for understanding environmental systems and stewardship in a rapidly urbanizing world, soil science has been under-represented in teaching National Curriculum in UK schools. Alongside concerns about declining student participation in science education, a key challenge is how to effectively engage students and address inadequacies in soil education. A UK government-funded initiative led to Soil-Net, an innovative, open, online soil educational website resource to support school curricula. Following a decade of online availability, this paper analyses website data on the adoption, use and impact of Soil-Net 2006-2016. First, data analysis based on geo-identification of over a million and a half users revealed patterns of adoption and usage by territory. Though originally targeted in the UK, Soil-Net is now being used worldwide in 223 countries and territories. Second, analysis of student scores on soil science knowledge quizzes available to be used alongside school education and curricula assessments, provided evidence of student learning supported by Soil-Net resources. Third, analysis based on user ratings and qualitative feedback revealed good satisfaction ratings by primary and secondary school students, teachers and parents. Usage data analysis offers an initial evaluation of Soil-Net, although further research is required to evaluate support for curricula and student learning. Next steps include development of website resources using innovative pedagogies to ensure applicability and sustainability, and research to further evaluate how Soil-Net is used in schools, and its contribution to soil science teaching and learning.

Key words: digital open educational resources, interactive learning media, school education, science education, soil science

Introduction

Over the past 30 years, significant advances have been achieved in soil science, across pedology, chemistry, biology, soil mineralogy, soil fertility and physics (Brevik and Hartemink, 2010). Not only is there now a better scientific understanding of many of the basic principles of soil science and interrelated systems (Field et al., 2011; Lal and Stewart, 2013), although importantly, there have been major developments in the understanding of both the ecological and non-ecological functions of soils in providing essential ecosystem services (Blum, 2005; Jones et al., 2012; Crossman et al., 2013; Lal and Stewart, 2013; Baveye et al., 2016). These key functions include the role that soils play in the production of biomass for food, feed, fiber and fuel (Cruse et al., 2013), their essential support for ecological habitats and biodiversity, acting as a biological habitat and gene reserve (Blum, 2005), their key role in the global hydrological cycle (Brevik, 2009), their role in mediation against various forms of pollution (Jones et al., 2012), and their contribution to carbon sequestration, being both a source and sink for carbon dioxide and other gases that influence climate change (Jones et al., 2012; Crossman et al., 2013; Lal and Stewart, 2013). Soils are a source of raw materials for building, and have a critical role in the foundation for buildings and infrastructures (Jones et al., 2012; Pritchard, Hallett and Farewell, 2014). Soils also provide a preservation medium for past cultural landscapes, and archaeological artefacts (Kibblewhite et al., 2015), and a record of geogenic history (Blum, 2005).

Concerns about poor public awareness of the role of soils in sustaining life have been raised in several policy reports by the Department for Environment, Food and Rural Affairs (Defra) in the United Kingdom (UK) and the European Commission (EC) (Defra, 2004; EC, 2006; EC, 2012). Most of the world's highly productive soils have developed over thousands of years, although land area is finite and the world soil resource base has a fixed suitability for food, feed, fiber and fuel production (Cruse et

al., 2013). The majority of world soils may be considered as non-renewable resources over the period of a human lifetime (Friend, 1992; Cruse et al., 2013). Moreover, the Food and Agriculture Organization (FAO) estimate that a quarter of the world's agricultural soils have been significantly degraded through land-use practices, and natural and climate change impacts (FAO, 2011). It is therefore important to build awareness of the need to manage the natural environment and ensure its preservation for future generations (Defra, 2004; EC, 2006; EC, 2012; Hallett, 2008; Jones et al., 2012). Soil science education is important for teaching knowledge and understanding of environmental systems, and the value of environmental protection and stewardship. This is particularly challenging in the urban context; Hartemink et al. (2014, p.8) noted that "since we live in an increasingly urbanized world, for many students the connection to the land is limited". A particular challenge is finding effective ways to engage students with science education against concerns about the decline in student participation and engagement with science learning. One report on science education in England found a decline in students' engagement, confidence in their science abilities, and enjoyment of science learning between UK Year 5 (ages 9-10), when they begin secondary school, and Year 9 (ages 13-14), the year of taking their GCSE (General Certificate of Secondary Education) examinations (Greany et al., 2016). By the time students choose their A-level (Advanced level) subjects for examination aged 17-18, only a quarter of English secondary school students choose at least two STEM (Science, Technology, Engineering, Math) subjects for examination, based on Department for Education (DfE) 2014-2015 data (AT Kearney, 2016). Similarly, in higher education, there have been reports of significant reductions in soil science degree programme enrolments and graduations in the US and Canada (Baveye et al., 2006; Margenot et al., 2016). Such reports point to the need for an engaging soil science perspective, including

recommendations for "…incorporating soil science in primary education is a foundational step toward improving public awareness and understanding of the importance of soils to society" (Margenot et al., 2016, p.837).

Although soil, air and water are the three major natural resources necessary for life, soil has historically received a low priority in the school curriculum (Cooper et al., 1994; Defra, 2004). Curricular deficiencies are mainly attributable to the inadequacy of the scope and substance of teaching-support and curricular provision available. Whilst soil issues in the UK are directly addressed through several subjects taught within the Primary and Secondary school curricula (see Department for Education website at gov.uk), there are opportunities to incorporate soil-related issues more broadly in school curricula. An extensive review found that, although prior to 2005 there had been soil-related information, online resources and educational activities available, this was difficult for teachers to find and understand, especially given the lack of any common semantic ontology (Hallett et al., 2005). This identified a clear need for soil education resources made easily accessible to teachers.

In 2004, Defra's seminal soil-focused policy document, 'The First Soil Action Plan for England: 2004-2006', identified as its first policy-objective how "Defra will work with stakeholders to develop a programme of education and awareness of soil issues among the general public, those working with soils and the professionals that guide, advise or instruct soil managers" (Defra, 2004, p.5). The 'First Soil Action Plan' led to the formation of partnerships to address inadequacies in soil science education in the National Curriculum for England and Wales, including support for the development of Soil-Net. Initial examination of 146 web resources across Australia, Belgium, Canada, Denmark, France, Holland, Italy, Palestine, UK and the US (Hallett et al., 2005), showed that whilst some of these resources were considered exemplary, most

resources had limitations. Soil education resources were needed to overcome the limitations of existing resources through addressing four key criteria namely, the provision of good content covering soil science-related disciplines, a student-centered design with a compelling user interface, well-structured content linked to the appropriate taught curricula, and suitability for the UK educational context.

This paper describes the design, development and subsequent usage of Soil-Net, an innovative, multi-disciplinary, soil education website enhanced by an interactive multimedia-based online delivery to support curricula and independent learning, following a government-funded collaboration between educational institutions. Soil-Net's innovation relates to its novelty as a digital educational resource, designed to address hitherto unmet requirements for soil education and awareness identified by policy makers. Soil-Net is an open-access, free to use web resource supporting teachers and students learning about soils (Hallett et al., 2007). Since the launch of Soil-Net in 2006, the continued importance of stewardship, education and awareness has been recognized by policy makers through the EC's 'Thematic Strategy for Soil Protection' (EC, 2006), and reports on its implementation (EC, 2012; Jones et al., 2012), and subsequently the Global Soil Partnership, established by the FAO in 2012 (fao.org/global-soil-partnership/en/). This paper reports on the analysis of the adoption, use and impact of Soil-Net, following a decade of online availability of the resources to students, teachers, educationists, policy-makers and the public, and discusses the implications of findings for further research and development.

Background – design, development, and deployment of Soil-Net
Prior to the launch and deployment of Soil-Net, a number of design and development phases were undertaken. The design was informed by learning and instructional theories, including constructivism and experiential learning, cognitivism and

behaviorism, which helped in designing learning activities using a range of media for educational contexts. Constructivism was the principle influence, viewed as more appropriate for supporting learning in the fast and changing information age (Conole, 2013). Connectivism as an approach through online, collaborative peer learning and information sharing, requires ongoing moderation of online content, and due to resource-constraints has not been incorporated in the learning design to-date. Soil-Net design features address:

- Vision;
- Key learning themes;
- Target users;
- Planned learning delivery methods for using online resources in the classroom, laboratories, home environment and outdoors;
- Curriculum mapping;
- Soil-Net structure, resources and types of rich media used for engagement;
- Design details;
- Assessment provision of learning outcomes;
- Trials and deployment of Soil-Net.

Soil-Net Vision

The vision underpinning the Soil-Net design provides a compelling and intuitive multimedia teaching and learning experience in soil science, recognizing soil as one of the three most important natural resources, alongside air and water. Soil-Net seeks to convey how, without soil, it would be impossible to feed the world's population, provide fiber and textiles, support the biodiversity of animal and plant life, or provide the foundations for the built environment and infrastructure. Lesser-known but critical soil functions, such as filtering water, regulating hydrological flows through landscapes, retaining carbon stocks, recycling organic materials, and preserving archaeological records are described. Baveye et al. (2016) regard the concept of soil functions as offering an appropriate entry point for didactic programs helping to explain the structure, properties and processes of soils.

Key Learning Themes

The learning design underpinning the development of Soil-Net resources aims to develop knowledge and understanding of soil ecosystem services and functions (Blum, 2005; Crossman et al., 2013; Lal and Stewart, 2013). Soil-Net has both a global focus, and a particular focus on England and Wales, where there are 752 soil types found in a land area of only 151,174 km^2, each having a diversity of profiles (Clayden and Hollis, 1984). Soil-Net addresses key soil themes including:

- Farming, food and fiber production;
- Forestry and timber production;
- Ecology, with reference to ecological habitats and biodiversity;
- Soils and water systems, with particular attention to the global hydrological cycle;
- Land reclamation and soil functions in pollution processes;
- Soils and infrastructure in the built environment;
- Soils and archaeology, addressing the preservation function of soils;
- Soils and climate change, examining soil functions as both source and sink for greenhouse gases;
- Soils and health, addressing the role of soils as a source of minerals and pathogens;
- Land quality and planning, addressing the incorporation of soils issues in land use planning; and,
- Soils and gardening, addressing the function of soils in gardening and plant husbandry (Hallett et al., 2007).

Target Users

The web educational resources are targeted at Primary (Elementary) school Key Stages 1-2 (ages 5-11), and Secondary school Key Stages 3-4 (ages 11-16) in England and Wales, and are partitioned and directed according to relevant curricula for these ages. Soil-Net provides educational material for school students, their teachers (including those from backgrounds outside soil science), parents and interested members of the public. The website home page offers entry points that correspond with the different user groups (Figure 1).
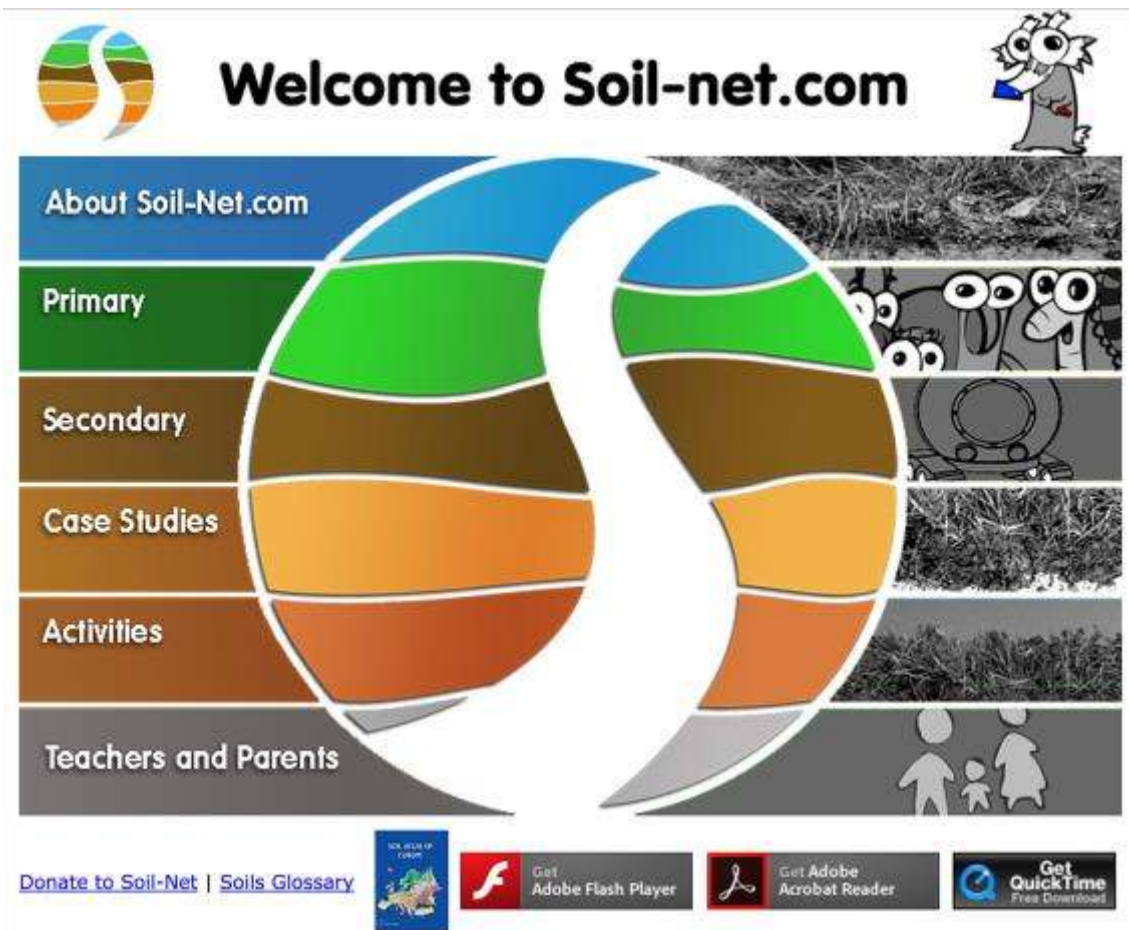
Figure 1. The Soil-Net Home Page

Planned learning delivery

Soil-Net is intended to be used by teachers and students in different learning contexts. This includes teacher-led learning in the classroom, in the Information and Communication Technology (ICT) laboratory, science laboratories, and outdoors through fieldwork. Soil-Net supports crossover learning (Sharples et al., 2015), whereby the teacher may task the students with an activity, which is then continued outdoors, online or at home, and then presented and assessed back at school. The planned learning delivery also addresses student-led learning where the student learns independently, or as part of a shared group experience in educational contexts, and in the home environment where they may undertake research activities. Whilst Soil-Net supports self-directed learning, it is designed to support teaching in schools where teachers are

guided by educational policies on how best to support students with different abilities and disabilities.

A blended-learning design is needed to support learning using multimedia educational resources in online and face-to-face contexts, capitalizing on digital innovation to reach large-scale audiences. Soil-Net offers flexible, open educational resources, able to support self-paced student learning in a variety of educational contexts, without learning being limited to specific places or times.

Curriculum mapping

Soil-Net presents teachers with advice in dedicated web pages referencing a selection of teaching aids and resources to assist in supporting student learning. Further materials are provided supporting lesson plans, and supporting 'mapping' soil science educational materials and resources against various relevant UK National Curriculum programs. Curriculum maps were prepared to guide teachers to appropriate materials and resources, relevant to a wide-range of taught modules of the UK National Curriculum, promoted by two of the foremost UK qualification award bodies, OCR (ocr.org.uk) and AQA (aqa.org.uk). An assessment of the relevance of Soil-Net to subjects taught in primary schools for Key Stage 1 (ages 5-7) and 2 (ages 7-11) was made, with curriculum maps created for Science, Geography, History, ICT, Art and Design, and Citizenship. Similarly, at Key Stage 3 (ages 11-14), curriculum maps were created for Science, Geography and Citizenship. At Key Stage 4 (ages 14-16), curriculum maps were developed linking Soil-Net resources to the GCSE (General Certificate of Secondary Education) modules examined by the qualification award bodies, OCR (Chemistry, Physics, Additional Science, Additional Applied Science and Biology, and Citizenship), and AQA (Science). Soil-Net presents a didactic and approximately hierarchical learning design, aligned with the school educational stages, and a wide

range of student ages and abilities, with flexibility to accommodate different student abilities.

Soil-Net structure

Soil-Net Primary and Soil-Net Secondary follow a progression of introductory materials supported by further in-depth materials (Figure 2). In Soil-Net Primary, the *Digging shallow* and *Digging deeper* Sections, approximate to Key Stage 1 (ages 5-7) and Key Stage 2 (ages 7-11). For Soil-Net Secondary, the materials approximate to the Key Stage 3 (ages 11-14) curriculum, with additional case studies supporting Key Stage 4 (ages 14-16). The materials, structured around thematic Sections, each having a set of explanatory Topics, are designed to enable student progression in alignment with their school year group, with successively more detail becoming available and more challenging themes being introduced at the Soil-Net Secondary level.
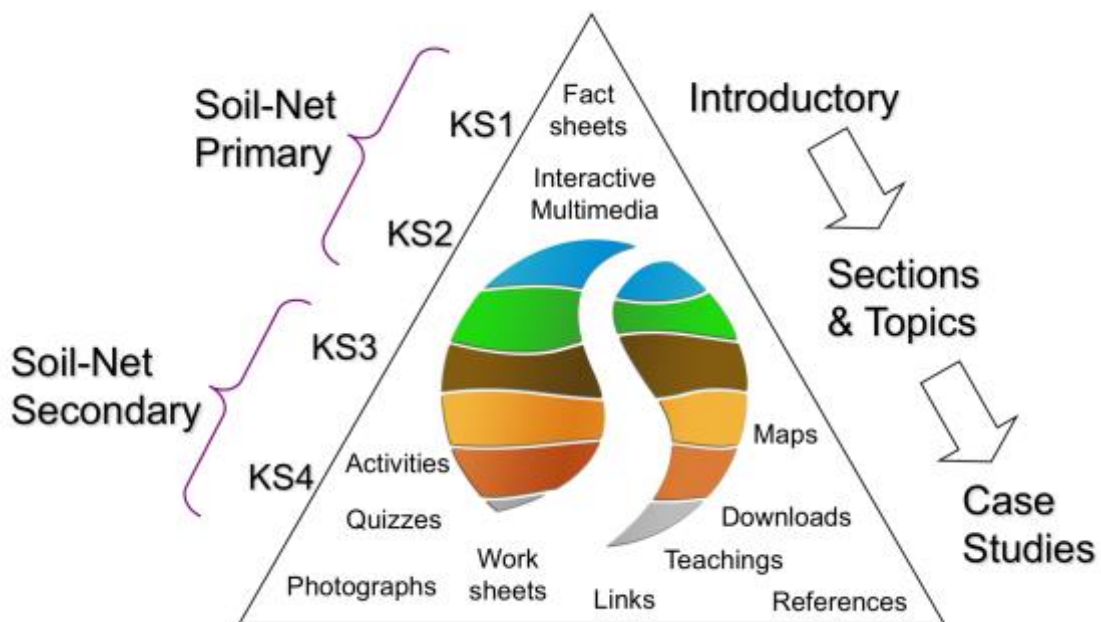

Figure 2. The structure of the Soil-Net resources

Soil-Net Resources

Based on Laurillard's (2002, p. 90) principal forms of digital learning media corresponding to a typology of different learning experiences, Soil-Net resources may be classified as including mainly 'narrative' and 'interactive' media with some limited 'adaptive media' available, although not incorporating 'productive' and 'communicative' rich media at this stage.

Soil-Net resources contain 'narrative' media (Laurillard, 2002), providing descriptions, explanations and demonstrations, supporting learning through assimilation. This covers pedagogical resources, including structured textual information, indoor and outdoor soil experiments (e.g. soil hand-texturing, jam-jar soil structure experiments, watering soil, testing soil), case studies, the soil chemistry challenge, soil factsheets and worksheets. There are also numerous learning resources, including features on school gardens, a study resource for a Wormery, a Worm hunt, and many other activities, for example Soildoko (*sic*), Colouring sheets, Mushroom growing and Maze puzzles, and 2700 high-quality, environmental photographs provided as a free teaching resource.

Soil-Net materials also contain 'interactive' learning media resources (Laurillard, 2002) that respond to learner instructions supporting student exploration, reflection, feedback and understanding. These resources include over 50 interactive Topic-related multiple-choice quizzes, knowledge quizzes, for example *Whose Poo? And Whose Clues?* and eco-lifestyle quizzes. There are also interactive soil maps provided by the SoilScapes Interactive mapper for England and Wales based on Postcode, an interactive school garden, virtual 3D soil walks (a form of virtual field trip) and animations.

Soil-Net also includes 'adaptive media' resources, which enable students to experiment and make changes in a learning environment (Laurillard, 2002), for example, the Terrain builder is an erosion simulator, designed to enable student observation of water erosion at work in a 'digital landscape' created by students using the software tool. Accompanying the resources are extensive classroom-trialled teacher-support aids and lesson plans, presented by school Key Stages, and a suitability statement for their use in a range of educational contexts.

Detailed Design

The detailed design of Soil-Net Primary and Secondary resources reflect the anticipated progression of student learning throughout their school education. Soil-Net Primary comprises interactive animations presented in a cartoon style. The user interface allows younger students to drive a 'soil machine' through short interactive quizzes and activities, intermixed with summary texts applicable to each Topic. The use of animated characters, together with a voiced theatrical cast, is used widely throughout. To avert any representation difficulties, a cast of soil animals was chosen, namely a badger, worm, snail, centipede, mole and ladybird. This was felt appropriate as there is a long-standing literary tradition of anthropomorphizing animals to convey narratives, especially environmental narratives. Soil-Net Primary also offers numerous activities, puzzles, and themed coloring sheets (Figure 3) as well as simple maps, glossaries and factsheets. This design offers a recommended "…measure of play and creativity…" to engage students with soil science education and their connectedness to the land (Hartemink et al., 2014, p.5).

Figure 3. Examples of Soil Activity sheets in Soil-Net

Soil-Net Secondary follows an encyclopedic approach with key thematic Sections containing descriptive Topics (Figure 4) (Hallett et al., 2007). Each of the 54 Topics finishes with an interactive knowledge quiz, providing users with a test of their learning.

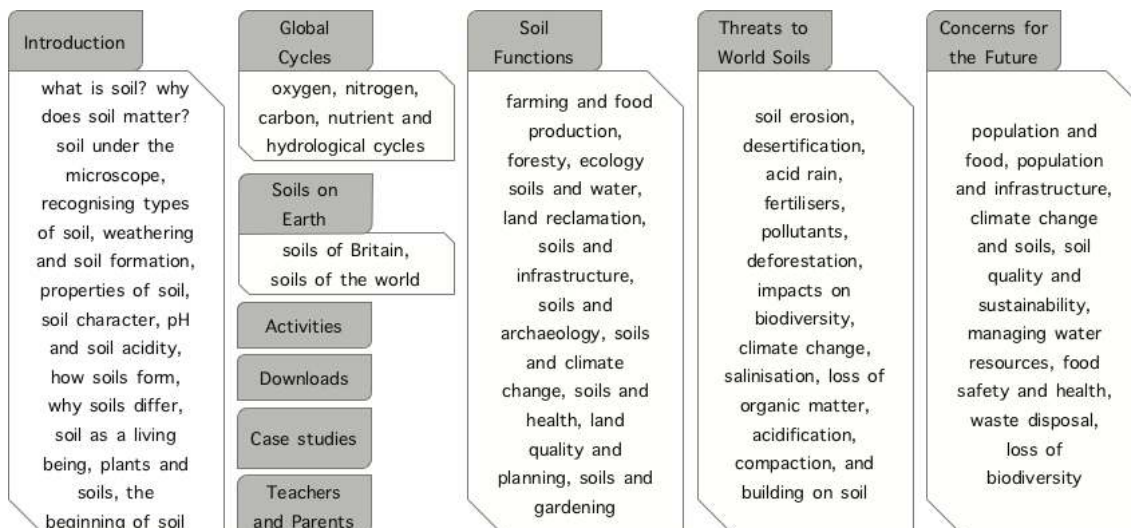| Introduction	Global Cycles	Soil Functions	Threats to World Soils	Concerns for the Future
what is soil? why does soil matter? soil under the microscope, recognising types of soil, weathering and soil formation, properties of soil, soil character, pH and soil acidity, how soils form, why soils differ, soil as a living being, plants and soils, the beginning of soil	oxygen, nitrogen, carbon, nutrient and hydrological cycles	farming and food production, foresty, ecology soils and water, land reclamation, soils and infrastructure, soils and archaeology, soils and climate change, soils and health, land quality and planning, soils and gardening	soil erosion, desertification, acid rain, fertilisers, pollutants, deforestation, impacts on biodiversity, climate change, salinisation, loss of organic matter, acidification, compaction, and building on soil	population and food, population and infrastructure, climate change and soils, soil quality and sustainability, managing water resources, food safety and health, waste disposal, loss of biodiversity
	Soils on Earth			
	soils of Britain, soils of the world			
	Activities			
	Downloads			
	Case studies			
	Teachers and Parents			

Figure 4. Soil-Net Sections and Topics

Case studies comprise an important component of Soil-Net resources. These were designed to be concise and to support teaching plans and student understanding, with detailed case studies offered for older students or those interested in further examination of key themes. Additional themes introduced include: soil techniques, equipment and technologies, and soils in literature. There is also guidance for the interested student, concerning soil hobbies and activities, and soil-related careers.

Learning Outcomes Assessment

Interactive knowledge quizzes are provided to assess and consolidate the anticipated learning outcomes accompanying the Soil-Net Secondary Topics. The quizzes each follow a model of some ten multiple choice questions, providing instant feedback. Student learning is further supported through opportunities to repeatedly retake the quiz, permitting users to improve their knowledge. It was anticipated that teachers would use quiz results to support formative and summative assessment.

Soil-Net trials and deployment

The development and deployment phases of Soil-Net involved trials in several schools, and continuous engagement with students, schoolteachers, educationists and other

professional experts. This process was supported through a range of approaches, including the involvement of the Bedfordshire SETNET, the Science Learning Centre, and the Primary and Secondary school participants in Soil-Net trials in Hampshire and Bedfordshire, UK. Feedback received was positive, facilitating improvements, such as the inclusion of additional photographic resources, prior to a series of public launch events held in 2006-2007. These included the 'Hands on Soil' exhibition at the British Association for the Advancement of Science (now the British Science Association) in East Anglia, the Association of Science Education South East Annual Conference in Birmingham for 5-16 year old students, and teachers, and the British Educational Training and Technology Show in London. The launch events allowed many thousands of students, Primary and Secondary teachers, parents and members of the public an opportunity to trial Soil-Net (Hallett et al., 2007).

Methods

Various data sources were used to prepare three forms of analysis. First, to examine adoption and use of Soil-Net resources, 'Google Analytics' were utilized to access detailed site user statistics. JavaScript code within every web page in Soil-Net triggers a logging event when users open the page, or link from it around the site. This detailed log was accessed and analyzed to determine a range of user-specific characteristics, including geo-identification of users by territory to reveal patterns of adoption and usage. Statistics produced examine rates of uptake by country since the launch of Soil-Net from January 2007 to December 2016. This data also allows determination of the most popular web pages, as well as other facets of use, e.g. period of visit time, return visits, linkage paths through the site, and inbound referral pages. Data were extracted and manipulated in Microsoft Excel (Microsoft, 2017) and the statistics package "R" (R

Core Team, 2016), and cartographical output was produced using QGIS (Quantum GIS Development Team, 2017), a free and open source Geographic Information System.

A second level of analyses assesses student learning outcomes based on the completion of 54 interactive knowledge quizzes, one for each Topic presented within the Sections (aimed at Soil-Net Secondary students). Quizzes were written in Adobe Flash, each quiz logging the quiz taken, the date, the score achieved (%), and the Internet Protocol (IP) address. Data logged over the period May 2006 to November 2012 for every quiz undertaken were extracted and manipulated in R. From this data, a series of Box and Whisker plots were constructed, providing insight into the learning outcomes observed.

Finally, a third level of analysis assesses user feedback data from August 2006 to November 2012 through satisfaction ratings provided voluntarily for Soil-Net resources. Each page footer contains a feedback panel written in Adobe Flash, allowing users to record a 5-class Likert-scale rating of materials from 'Poor' (1) to 'Excellent' (3) across each of the Soil-Net Sections. Users can also record their status (student, teacher or parent), usage of the page resources for projects or in-class, and textual commentary feedback. This is recorded, along with a unique identifier. The ordinal ranking was used to produce a statistical summary for materials across each of the Soil-Net Sections. In addition, an analysis of textual feedback from users was accessed to conduct a qualitative assessment with illustrative comments from teachers.

Findings

Findings on the adoption, use and impact of Soil-Net were analyzed at three levels. The first level examines the adoption and use of Soil-Net: (a) by countries and territories, and (b) year-on-year since the launch. The second level examines student learning on soil science, following analysis of learning outcomes on the quiz assessments linked to

soil-science Topics covered across Soil-Net Sections. The third level uses volunteered data from users who provided ratings of Soil-Net resources, which was used to analyze satisfaction data based around different types of users: students, teachers and parents, and their satisfaction with the core teaching Sections in Soil-Net.

Adoption and use of Soil-Net

Since Soil-Net was launched in June 2006, the website has received 1.57 million online visitors, and has served 4.78m web pages of educational resources. This is a significant outcome for the project, aimed as it was at Primary and Secondary UK schools in England and Wales, and at students, teachers and parents participating in the school Key Stages 1-4. Google Analytics statistics revealed that Soil-Net has become popular in many other countries and territories. Since its launch, Soil-Net has been accessed in 223 countries and territories worldwide (Figure 5), with the top ten, excepting the UK, comprising USA, Canada, India, Australia, Philippines, Ireland, Malaysia, Germany, South Africa, and Indonesia. Within a year of the launch of Soil-Net in 2007, it was being used in 150 countries and territories, rising to 200 by 2014, and 223 by 2016.
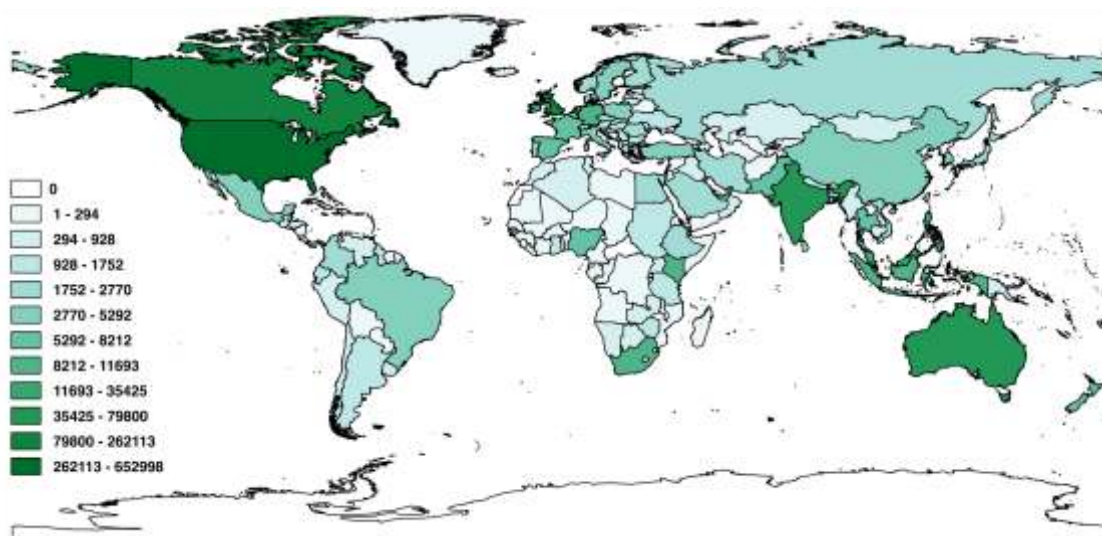

Figure 5. Total usage of Soil-Net by country

Units: Number of users (Google Analytics) | Period: Jan 2007 to Dec 2016

Accounting for different time zones, Google web traffic statistics revealed the predominant use of Soil-Net has been during weekdays, and times when students are usually at school. There were observed dips in the online use of Soil-Net during weekends and school holidays in the US and the UK, namely the countries with the highest number of Soil-Net users.

Figure 6 shows that the number of Soil-Net users in the top six countries has steadily increased since the 2006. In 2007, the UK was the country with the most users, although by 2010 the number of US users had overtaken those in the UK.
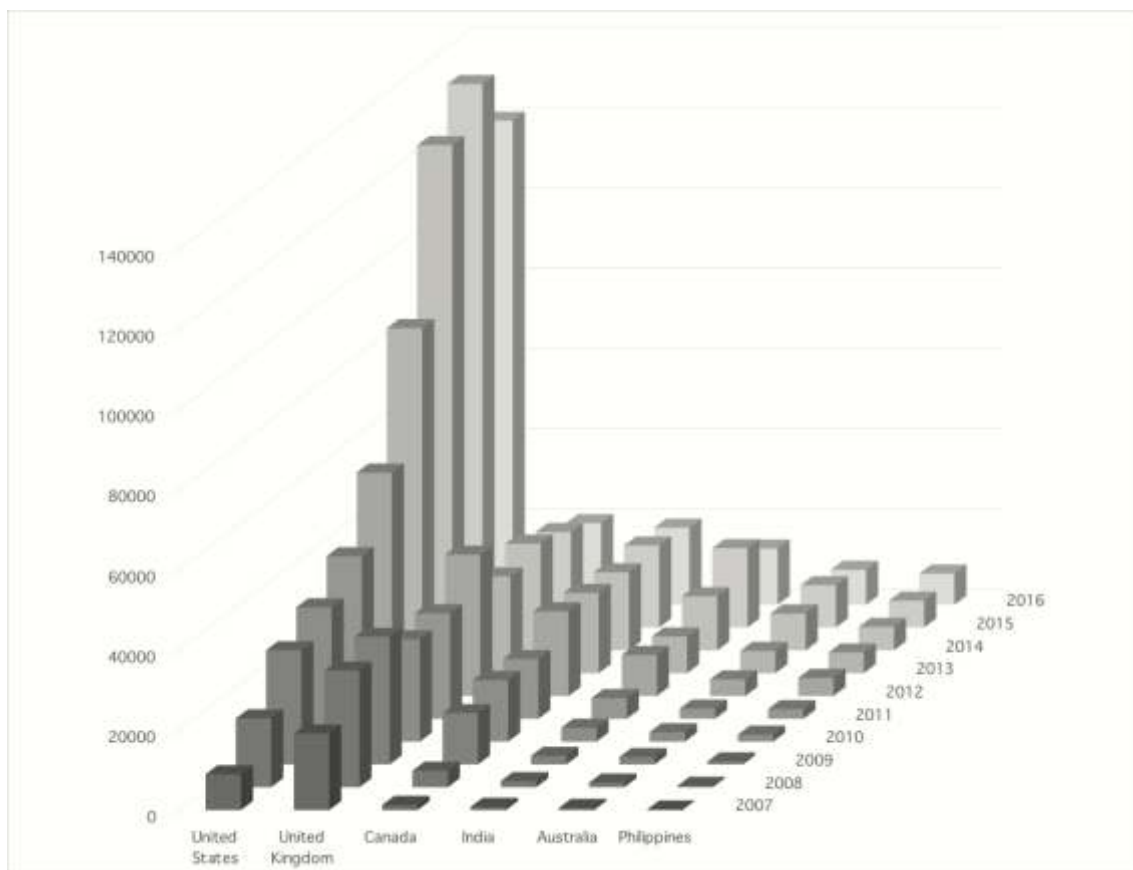
Figure 6. Usage of Soil-Net per year by country over the Top 6 countries
Period Jan 2007 to Dec 2016

Figure 7 identifies increasing numbers of users year-on-year until 2015, when the number peaked at 269,360 users. In 2016, there was a small decline in the users, coinciding with the emergence of greater numbers of tablet computer users. This may be suggestive of a need to review the technological standards used in Soil-Net delivery. One issue is the heavy reliance on Adobe Flash to deliver the rich media content. Currently, 'iPad' tablets and 'iPhone' smartphones from Apple do not support Flash, and 'Android' (Google) tablets and phones will, but only after manual interventions to install the required components.
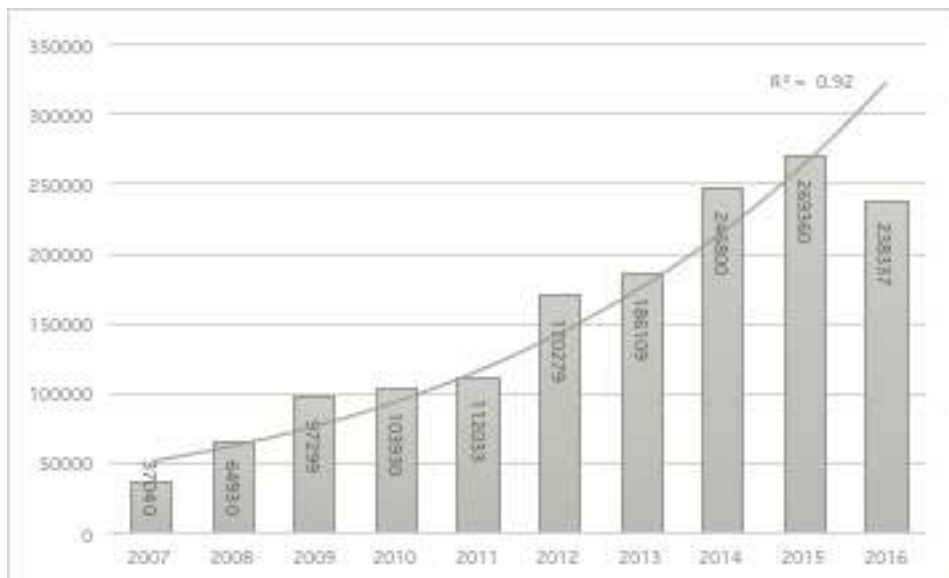
Figure 7. Usage of Soil-Net per year

Period: Jan 2007 to Dec 2016

Soil-Net and student learning

As a key to reinforcing its learning potential, Soil-Net includes online 'quizzes', allowing users to consolidate knowledge and understanding of the principle Sections covering soil-related Topics. These interactive quizzes are in the 'Secondary School'

part of the site, no such data being captured for the 'Primary School' part. The interactive quizzes are available to be used alongside more formal school education and curricula assessments, and an analysis of scores provides some evidence of student learning and awareness of soil science issues supported by Soil-Net resources.

The quizzes presented on Soil-Net were undertaken 11,485 times, over the period May 2006-November 2012 and were principally completed by users in the UK (37%), US (37%), Canada (7%), India (3%), Australia (3%), Ireland (1%), United Arab Emirates (1%), Philippines (1%), South Africa (1%), New Zealand (1%) and other countries and territories (8%). The outcome of each quiz was recorded with information used to present the data analysis and insight below.

Resources in Soil-Net Secondary follow a tiered design, whereby six core Sections contain 54 soil-related Topics (Table 1), each accompanied by a quiz. Users tend to follow a sequential pathway through Soil-Net Topics, supported by corroborating evidence from the web statistics and the date order in which the quizzes are undertaken. Aside from the quizzes in the *Activities* Section, the most completed quiz returns are in the *Introduction* Section, the least in the *Concerns for the Future* Section. The statistics also reveal the popularity of the bank of photographs, where some 2700 free-to-use images are provided, which together were rated as 'Good' or 'Excellent' by 1490 users.

Table 1. Soil-Net quiz sessions undertaken, distributed by Sections and Topics

Introduction	5052	Soil functions	850	Threats to world soils	419	Concerns for the future	82
How do soils form?	221	*Ecology*	140	*Acid rain*	48	*Climate change*	12
pH and soil acidity	232	*Farming and food production*	121	*Acidification*	19	*Food safety and health*	9
Plants and soils	144	*Forestry*	121	*Building on soil*	22	*Loss of biodiversity*	6
Properties of soil	382	*Land quality and planning*	19	*Climate change*	22	*Managing water resources*	11
Recognising types of soil	516	*Land reclamation*	45	*Compaction*	18	*Population and food*	15
Soil as a living being	372	*Soils and archaeology*	39	*Deforestation*	20	*Population and infrastructure*	12
Soil under the microscope	618	*Soils and climate change*	50	*Desertification*	32	*Soil quality and sustainability*	9
The beginning of soil	92	*Soils and gardening*	123	*Fertilisers*	28	*Waste disposal*	8
Weathering and soil formation	360	*Soils and health*	26	*Impacts on biodiversity*	26	**Activities**	**4616**
What is soil?	1241	*Soils and infrastructure*	51	*Loss of organic matter*	32	*Whose Clues?*	1407
Why do soils differ?	133	*Soils and Water*	115	*Pollutants*	36	*Whose Poo?*	3209
Why does soil matter?	741	**The soils on Earth**	**169**	*Salinisation*	19	**Grand Total**	**11485**
The global cycles	**297**	*Soils of Britain*	80	*Soil erosion*	97		
The carbon cycle	59	*Soils of the World*	89				
The hydrological cycle	42						
The nitrogen cycle	70						
The nutrient cycles	44						
The oxygen cycle	82						

Sections shown in bold, topics in italics. Period 5/2006 to 11/2012

To understand the distribution in greater detail, a series of Box and Whisker plots were compiled covering each quiz. These charts present, for each Section's quiz results, boxes recording the 25th and 75th percentiles, with the median value shown using a horizontal line within the box, and the minimum and maximum range expressed using horizontal whisker marks. Outliers are marked where observed. Table 1 identifies the number of responses recorded for each quiz.

Introduction Section

Quizzes for the introductory Sections (Figure 8) highlight how, for each of the quizzes, a significant proportion of users achieved full scores. The median values recorded highlight the most prevalent scores, which were above 75% in all cases, with the exception of two of the twelve quizzes, 'Why do soils differ?' and 'The beginning of soil', which each resulted in median scores of 60%. Excepting these two Topics, the upper quartile limit of all other quiz results was 100%. Particularly good results were achieved by students completing quizzes addressing 'Soils under the microscope' and 'Plants and Soils' Topics, which is evident from the median scores of 100%.
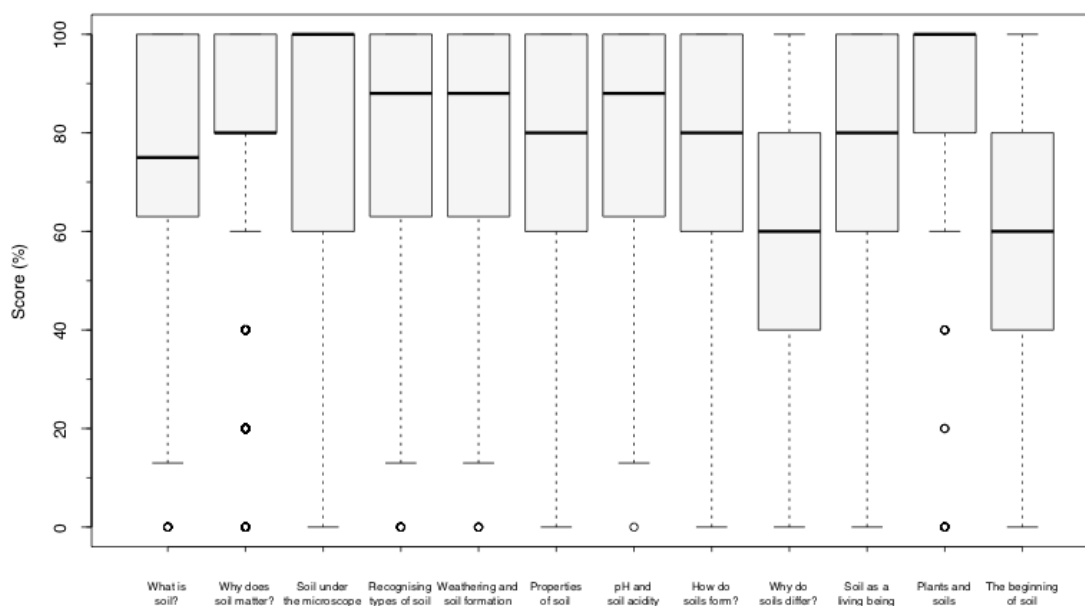
Figure 8. Introductory quizzes

Period May 2006 to Nov 2012

Global cycles and Soils of the Earth

The individual median values for Topic quizzes in both the *Global Cycles* and the *Soils of the Earth* Sections were above 75% in all cases. Analysis of the data in Figure 9 identified the upper quartile limit of 100% score for each of the results of quizzes on the 'oxygen', 'nitrogen', 'nutrient' and 'hydrological' cycles, by comparison with 88% for student responses when tested on their knowledge around the 'carbon cycle'. This appears surprising given the carbon cycle is generally well covered in curricula.

Data interrogation revealed that different students completed each quiz (Table 1), which limits making comparisons across quiz results through data-analysis alone (although teachers may collate student scores in schools). This is exemplified by the high median score (88%) of students taking the 'Soils of Britain' quiz which was principally completed by students from the UK (80%) and the US (8%). By contrast, the students

completing the 'Soils of the World' quiz (median score 75%) were principally from

Thailand (32%), the US (22%) and the UK (19%), achieving a wider spread of scores
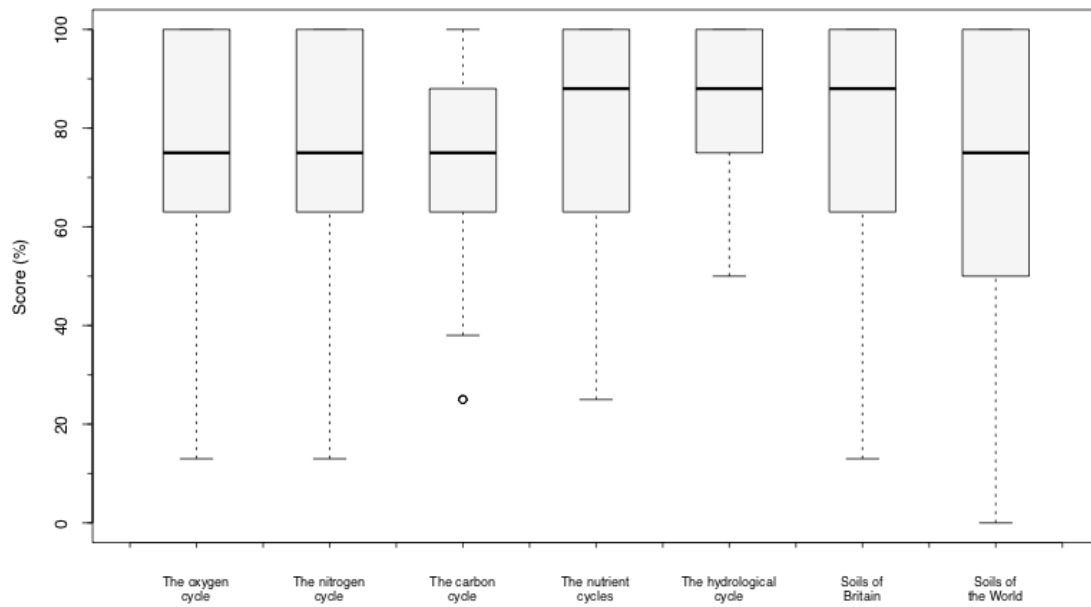
and the lower median value.

Figure 9. Global cycles, and Soils on Earth quizzes
Period May 2006 to Nov 2012

Soil functions

A key component in Soil-Net teaching is the coverage of the functions that soil

performs (Figure 10), akin in part to the concept of ecosystem goods and services

(Crossman et al., 2013; Lal and Stewart, 2013). The median values for all 11 quizzes in

this Section were each above 75%. For 'Farming and food production' and 'Soils and

Water', the median score was 100%. With the exceptions of 'Forestry', 'Soils and

Climate Change' and 'Land Quality and Planning' Topics, the upper quartile limit of all
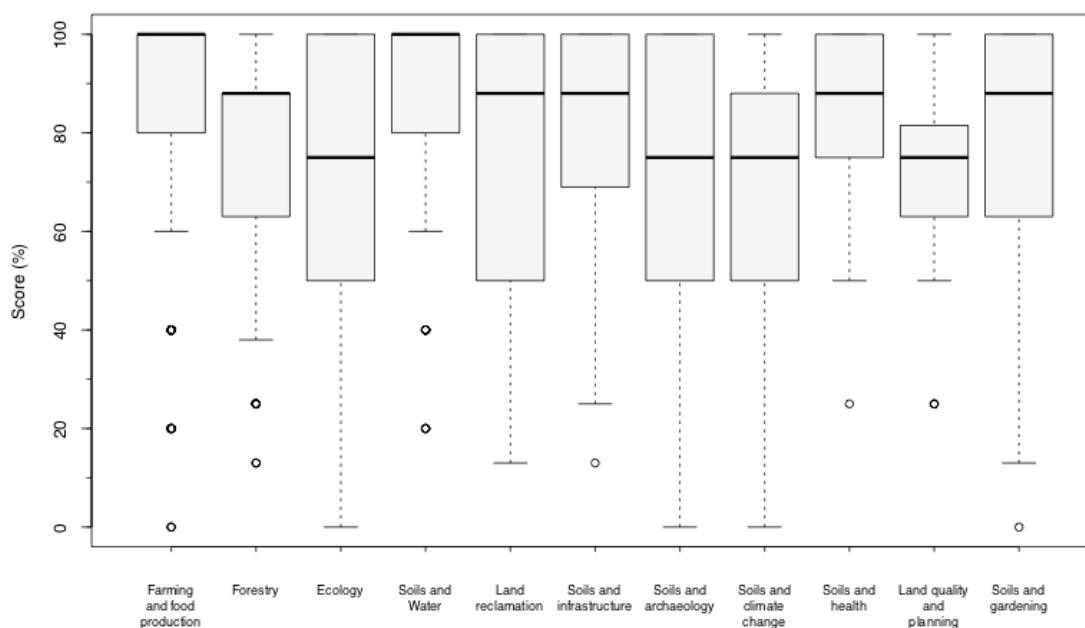
other responses was 100%.

Figure 10. Soil functions quizzes

Period May 2006 to Nov 2012

Soil threats

Soil-Net supports teaching about the threats faced by soil resources internationally and the principal causal risks to the capacity of the soil system to undertake key functions (Figure 11). The median values for all 13 individual quizzes in this Section were at or above 75%, with the exception of the quiz results from 'Building on soil' (63%) and 'Deforestation' (69%). No students achieved a 100% score on the 'Building on soil' quiz (n=22). An upper quartile limit attained from the responses at 100% was achieved in only 5 of the 13 quizzes. Overall, attainment in the '*Soil Threats'* Section was less than achieved in earlier Sections. Many of the *'Soil Threats'* themes, such as climate change, are not typically taught in school with a strong soils component. This suggests the need for improved education through Soil-Net and school curricula on soil threats, particularly on 'Acid rain', 'Deforestation', 'Climate change' and 'Building on soil', with their relatively low quartile limits.
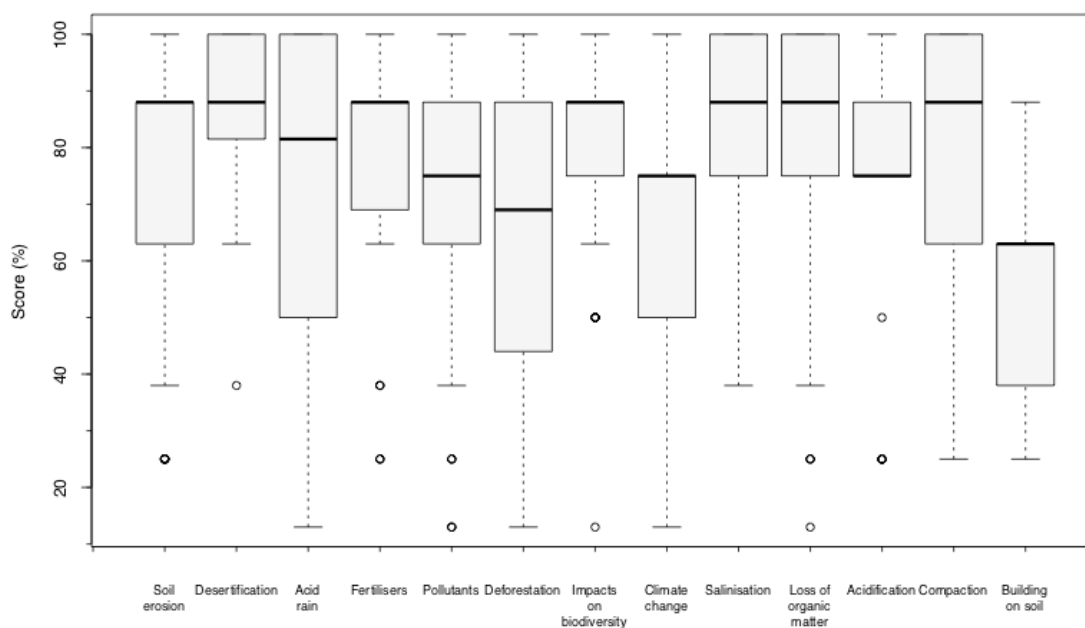
Figure 11. Soil threats quizzes
Period May 2006 to Nov 2012

Future concerns, and Activity quizzes

The *'Future Concerns'* Section addresses future environment and soil resources (Figure

12). There was a mixed set of outcomes observed across the seven Topics. The median

values for the quizzes in this Section were at or above 75%, although an upper quartile

limit at 100% was achieved from the responses in only 2 of the 7 quizzes. The relatively

large interquartile range (47% to 91%) for the 'Waste disposal' quiz (n=8) is surprising,

since students should have messages on waste disposal and recycling reinforced through

school curricula. Messages concerning 'Soil quality and sustainability' and 'Loss of

biodiversity' in particular appear to be well understood by students, and relate to themes

embedded in many parts of the UK curriculum.

Following the core texts in Soil-Net, there is a large range of *'Activities'* for

students to explore. Amongst these are two further quizzes, 'Whose Poos?' (median

score 88%, n=3209) and 'Whose Clues?' (median score 75%, n=1407). Both are

extremely popular, taking a light-hearted view (Figure 12; Table 1). 'Whose Poos?'

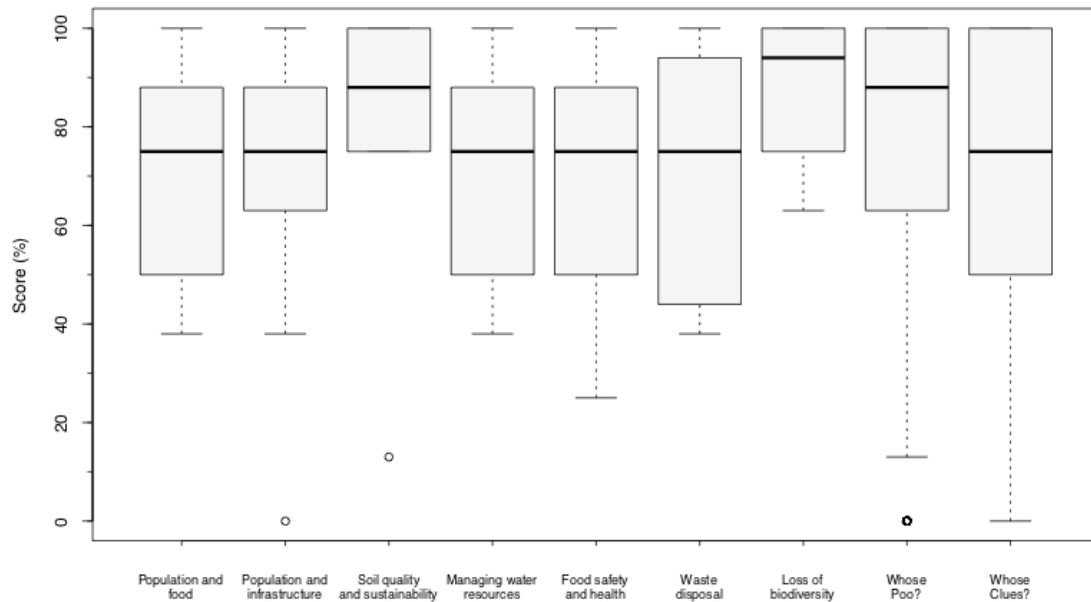being the most popular quiz and page across Soil-Net.

Figure 12. Future concerns and activities
Period May 2006 to Nov 2012

The data used in this analysis revealed insights into the use of Soil-Net, and the

general learning outcomes for the users. The information gathered can be used to inform

the development of additional, supplementary materials, and further educational

resources.

Satisfaction ratings with Soil-Net educational resources

Overall, 5,999 Soil-Net page ratings were received from August 2006 to November

2012, comprising: 3998 student responses (Secondary=3868, Primary=130), 1682

teacher responses (Secondary=1604, Primary=78), and 302 parent responses

(Secondary=295, Primary=7). Across the Soil-Net website, for all pages where ratings

were recorded, the median response was 'Good' (4) for the total user group of primary

and secondary school students, teachers and parents, suggesting a tendency to approve

of the resources. Where student responses outnumber considerably the teacher responses, so teacher responses outnumber those from parents. Initial analysis of parent responses revealed no clear patterns in their ratings, therefore further analysis was restricted to student and teacher users.

Table 2 reports the distribution (%) of user ratings (Excellent to Poor) from teachers and students across Soil-Net Sections, aggregated to include all ratings on the Topics within Sections. Across the core Soil-Net Sections, 50% to 60% of student users provided 'good' or 'excellent' ratings. Most of the student ratings were positive, noting that 69% to 76% of students provided a 'satisfactory' or better rating, whilst between 19% to 24% of students provided 'poor' ratings.

Conversely, teacher responses were more mixed, with particularly positive responses to the *Soil Functions* and *Soils of the Earth* Sections. Across the Soil-Net Sections, 41% to 100% of teachers provided 'good' or 'excellent' ratings, and 48% to 100% of teachers provided a 'satisfactory' or better rating, whilst between 0% to 48% of teachers provided 'poor' ratings. Further inspection of the 423 'poor' ratings given by teachers across Soil-Net revealed that 58% were given by students masquerading as teachers, evidenced by the irrelevant textual comments accompanying the rating. This points to difficulties in ensuring that only appropriate website users have rights to provide feedback.

Table 2. Student and Teacher satisfaction ratings of the Soil-Net Sections

Satisfaction Rank	*Students* Soils Introduction (n=1477)	*Teachers* Soils Introduction (n=397)	*Students* Global Cycles (n=82)	*Teachers* Global Cycles (n=30)	*Students* Soil Functions (n=159)	*Teachers* Soil Functions (n=57)	*Students* Soils on Earth (n=139)	*Teachers* Soils on Earth (n=33)	*Students* Soil Threats (n=153)	*Teachers* Soil Threats (n=47)	*Students* Future Concerns (n=29)	*Teachers* Future Concerns (n=3)
1	23%	48%	21%	33%	19%	21%	22%	18%	24%	34%	24%	0%
2	7%	4%	9%	0%	5%	4%	4%	3%	3%	2%	0%	0%
3	18%	7%	21%	17%	16%	9%	24%	6%	12%	15%	10%	0%
4	18%	12%	16%	13%	23%	12%	12%	15%	17%	19%	21%	0%
5	33%	29%	34%	37%	37%	54%	40%	58%	44%	30%	45%	100%

Satisfaction rank range: 1 (Poor), 2 (Minimal), 3 (Satisfactory), 4 (Good), 5 (Excellent). Period Aug 2006 to Nov 2012

Further analysis showed that 2136 students and 779 teachers reported that they had specifically used Soil-Net resources in class and/or to support a project. Moreover, qualitative feedback from teachers was broadly positive, providing an insight into the use of Soil-Net resources, both in schools and informal settings. The following comments illustrate some positive feedback.

"…Excellent background knowledge for teachers and I love and use the resources…"

"It is absolutely wonderful that you have this material so incredibly organized and available for educators and students for free! I love the activities and reading pdf downloadables (*sic*) and found them INCREDIBLY helpful. I like the easy to understand language used in the 'topic' Sections of the download."

"At last, a really great website on soil."

"Amazing resources and so user friendly … it has saved me hours of planning."

"I am a teacher, but I am using these activities for our Cub Scout World Conservation badge! Absolutely fantastic resource!!!..."

"We're about to plant our seeds in the school garden and I'll be flagging up your website just before. We're also doing rocks and soils as our topic, so I'm so pleased I have all this information."

"This is an excellent resource! I have been looking for one website that would give me the versatility for a multi-age classroom."

Particular attention was given to teachers who provided textual feedback accompanying poor ratings. Examples of such comments included the following feedback:

> "…my pupils think that it needs more animations…"
>
> "…children are really enthusiastic about rocks and soils but some of the resources on this web site are a real let down and could be made so much more useful..."
>
> "Where are the work sheets located…"
>
> "You are showing images of dry soil rather than how it would normally be seen in the ground…"
>
> "You should do the (*secondary*) front-page like the primary…"

Comments received also provided qualitative insight into the use of Soil-Net outside England and Wales, expressed through feedback received from teachers in the USA, Canada, Spain, Australia, Tibet, Qatar and Afghanistan. Constructive commentary also revealed where web glitches were located, and areas where improvements and extensions could be made to Soil-Net, for example translation of materials into other languages and development of curricula aimed at older students.

Summary and discussion

In summary, Soil-Net is an innovative, open, online educational resource designed to address the gap in the provision of soil science education in schools, reflecting considerable advances in research around the important functions and ecosystem services provided through soils, and the international policy recognition of the importance of soil. Conventional soil science education across international educational institutions has focused strongly on providing real-world experiences through field and laboratory work, active/experiential learning, and mapping activities, supported by classroom activities (Hartemink et al., 2014). Whilst Soil-Net supports learning in such varied contexts, it goes beyond conventional learning designs to offer innovative,

digital, educational resources capable of being delivered at scale, and designed '…to create a sense of wonder about the soil and its utilitarian and scientific value.' (Hartemink et al., 2014, p.8).

Following an extensive design and development project supported by government-funded collaboration between educational institutions, Soil-Net was designed to support school curricula, with a vision for soil education, key learning themes, the target learners/users, the planned learning delivery methods in educational contexts, curriculum mapping, the website structure, resources and design details, and assessment of learning outcomes. An analysis of data on the adoption, use and impact of Soil-Net found that the educational website resources have been in use in 223 countries and territories, where there is substantial evidence that the teaching and learning resources provided have been widely consulted. The findings indicate that the number of people using Soil-Net has far surpassed expectations, reaching over a million and a half users to-date. This is of significance given the original focus was to support school science education solely in England and Wales.

The findings show that Soil-Net supports science learning outcomes, and reveal good ratings awarded by primary and secondary school students, teachers and parents for resources accessed. The data analysis based on completed soil science knowledge quizzes, available through Soil-Net to be used alongside school curricula and assessments, provided evidence of student knowledge and learning, supported by Soil-Net resources. Furthermore, the quiz data analysis identified several Soil-Net Topics where student learning outcomes could be improved, drawing attention to the need to develop curricula and educational resources to address teaching a range of 'Soil functions' and 'Soil threats' themes. Despite the extensive adoption and use of Soil-Net educational resources, the learning outcomes as evidenced by the knowledge quiz

results attest to the continued importance of improving soil education to address the poor public understanding and awareness of soil functions and threats to their capability to function in global ecological and non-ecological cycles (Barnes, 1987; Defra, 2004; EC, 2006; Baveye et al., 2006; FAO, 2011; EC, 2012; Margenot et al., 2016; Baveye et al., 2016).

The analysis has centered on three areas: usage and adoption through web-statistics, user knowledge through quiz scores, and user satisfaction through feedback data. Whilst this offers an initial evaluation following a decade of availability of Soil-Net educational resources, an analysis of the usage data alone would not be sufficient in providing evaluation. Soil-Net has a blended learning design whereby the online educational resources are designed to be used in a variety of educational contexts by teachers and students, and therefore a full evaluation would require further research on teacher and student experiences using Soil-Net resources across different year groups, curricula and school systems in different countries.

In addition to requirements for further research, there are opportunities for development of curriculum-aligned content. Moreover, the focus of the existing Soil-Net resources, aimed at the 5-16 age range, could be extended to focus more strongly on supporting curricula for the 16-19 age group undertaking A-Levels and Vocational Qualifications, as several teachers have recommended. However, the learning design for Soil-Net was unrestricted to students of a particular age, ability or year group, which permits the applicability of the resources to students in different age groups and school systems, together with accompanying 'curriculum maps' to guide teachers to appropriate materials. Another area for future development would be to extend the popularity of Soil-Net resources from Anglophone countries, providing translation options for using the resources in non-English speaking countries. Moreover,

curriculum maps could be adapted in close alignment with other educational systems and contexts to develop a world Soil-Net.

A series of reports have identified a wide range of innovative pedagogies enabled by Internet connectivity (Sharples et al., 2015), enhanced by rich 'narrative', 'productive', 'interactive', and in particular 'communicative' and 'adaptive' multimedia ICTs (Laurillard, 2002, p.90), supporting connectivism through collaborative and personalized learning, which could be considered for further development of Soil-Net. Advanced formative and summative learning analytics to support individualized learning would support further investigations of the findings on learning patterns and outcomes. Additional innovative pedagogies provide opportunities in different learning contexts (Sharples et al., 2015). Notably, these include crowd learning, enabling students from different nations and cultures to share perspectives and ideas online; geo-learning, which enables the exploration of local environments using interactive (soil) maps and guides, whilst connecting online with students; remote access to laboratories and scientific experimentation, and; augmented reality and virtual reality.

In parts of the world, including vast territories across Africa, there is inadequate detailed information on soils (Jones et al., 2013). Further development of online soil educational resources could provide opportunities to work with teachers and students to crowdsource soil science research data in the countries willing to participate. For example, there are opportunities to deepen links for Soil-Net with initiatives such as the 'UK Soils Observatory' (Lawley, 2014), and to contribute to the development of more detailed maps, as part of supporting student learning, and to contribute to soil educational resources.

Incorporating such innovative pedagogies in Soil-Net would require development to ensure the sustainability of the website resource. A key challenge is that

much of the site's visual identity derives from its extensive use of Adobe Flash. Developing a modern, standards-compliant HTML5 version of Soil-Net is not a simple task, due to the deep levels of component interaction and software inter-dependencies. A variety of technical approaches could be adopted to decide the correct path. The available web statistics provide considerable insight into the technical environments in which Soil-Net users operate, which helps identify appropriate future technological developments. Resolutions include placing Soil-Net resources in other media delivery platforms.

In conclusion, Soil-Net has been widely used internationally by students, teachers and parents, surpassing its original objectives targeted at school science curricula in England and Wales, to support positive student engagement with science learning. Next steps include further development of website resources using innovative pedagogies to ensure applicability and sustainability, and further research to evaluate how Soil-Net is used in science education, and the consequent contribution to soil science teaching and student learning.

References

Kearney, A.T. 2016. Tough choices: The real reasons A-level students are steering clear of science and maths. [Online] Available at https://www.atkearney.co.uk/documents/10192/7390617/Tough+Choices.pdf/a7408b93-248c-4b97-ac1e-b66db4645471. Accessed June 19, 2017.

Barnes, R F. 1987. Human Resource Needs, Educational Challenges, and Professionalism in the Agronomic Sciences'. Journal of Agronomic Education 16 (2), Fall, 49–54.

Baveye, P.C., A.R. Jacobson, S.E. Allaire, J.P. Tandarich, R.B. Bryant. 2006. Whither Goes Soil Science in the United States and Canada? Soil Science 171 (7) 501–18. doi:10.1097/01.ss.0000228032.26905.a9

Baveye, P.C., J. Baveye, J. Gowdy. 2016. Soil "Ecosystem" Services and Natural Capital: Critical Appraisal of Research on Uncertain Ground. Front. Environ. Sci., 4:41. 07 June 2016. doi:10.3389/fenvs.2016.00041.

Blum, W.E.H. 2005. Functions of Soil for Society and the Environment'. Reviews in Environmental Science and Biotechnology 4(3) 75–79. doi:10.1007/s11157-005-2236-x.

Brevik, E.C. 2009. The teaching of soil science in geology, geography, environmental science, and agricultural programs. *Soil Surv. Horiz,* 50,4:120–123.

Brevik, E.C., A.E. Hartemink. 2010. Early soil knowledge and the birth and development of soil science. *Catena*, 83:23–33. doi:10.1016/j.catena.2010.06.011

Cooper, T.H., J.W. Schultz, M.K. Barton. 1994. Introducing soil science into the K-12 curriculum. p. 1-6, in P. Baveye, W.J. Farmer, T.J. Logan (eds). Soil science education: Philosophy and perspectives. SSSA Special Publication 37, Soil Science Society of America, Madison, Wisconsin, U.S.A. doi:10.2136/sssaspecpub37.c1

Crossman, N.D., B. Burkhard, S. Nedkov, L. Willemen, K. Petz, I. Palomo, E.G. Drakou, B. Martín-Lopez, T. Mcphearson, K. Boyanova, R. Alkemade, B. Egoh, M.B. Dunbar, J. Maes. 2013. A blueprint for mapping and modelling ecosystem services. Ecosystem Services, 4, pp.4-14.

Clayden, B., J.M. Hollis. 1984. Criteria for Differentiating Soil Series. Technical Monograph 17, Soil Survey of England and Wales, Rothamsted Experimental Station. Harpenden. 159pp. [Online] Available at http://www.landis.org.uk/publications. Accessed April 24, 2017.

Conole, G. 2013. Designing for Learning in an Open World: Explorations in the Learning Sciences, Instructional Systems and Performance Technologies. New York Heidelberg Dordrecht London: Springer.

Cruse, R., S. Lee, T.E. Fenton, E. Wang, J. Laflen. 2013. Soil renewal and sustainability. Chapter 17. In Lal, R., B. Stewart (Eds.), Principles of sustainable soil management in agroecosystems. June 477-500. CRC Press Taylor & Francis Group, Boca Raton, FL. ISBN 9781466513464.

Defra .2004. The First Soil Action Plan for England: 2004-06. Department for the

    Environmental, Food and Rural Affairs, London, PB 9441, 37pp. [Online]

    Available at

    http://webarchive.nationalarchives.gov.uk/20081023133800/http:/www.defra.go

    v.uk/environment/land/soil/pdf/soilactionplan.pdf. Accessed April 24, 2017.

EC (European Commission). 2006. Communication from The Commission to The

    Council, The European Parliament, The European Economic and Social

    Committee and The Committee of the Regions. Thematic Strategy for Soil

    Protection (COM(2006)231 final. [Online] Available at http://eur-

    lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52006DC0231. Accessed

    April 24, 2017.

EC (European Commission). 2012. Report from The Commission to The European

    Parliament, The Council, The European Economic and Social Committee and

    The Committee of the Regions. The implementation of the Soil Thematic

    Strategy and ongoing activities (COM/2012/046 final. [Online] Available at

    http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52012DC0046.

    Accessed April 24, 2017.

Field, D.J., A.J. Koppi, L.E. Jarrett, L.K. Abbott, S.R. Cattle, C.D. Grant, A.B.

    McBratney, N.W. Menzies, A.J. Weatherley. 2011. Soil science teaching

    principles. Geoderma, 167-168, 9–14. doi: 10.1016/j.geoderma.2011.09.017

FAO (Food and Agriculture Organization). 2011. The state of the world's land and

    water resources for food and agriculture (SOLAW)-Managing systems at risk.

    FAO of the United Nations. Rome and Earthscan. London. [Online] Available at

    http://www.fao.org/docrep/017/i1688e/i1688e.pdf. Accessed April 24, 2017.

Friend, J.A. 1992. Achieving soil sustainability. J. Soil Water Conserv., 47(2):157–167.

Greany, T., I. Barnes, T. Mostafa, N. Pensiero, C. Swensson. 2016. Trends in Maths and Science Study (TIMSS): National Report for England. Research report November 2016 – UCL Institute of Education, Department of Education report: Government Social Science. [Online] Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/572850/TIMSS_2015_England_Report_FINAL_for_govuk_-_reformatted.pdf. Accessed April 24, 2017.

Hallett, S., M. Clarke, N. Edwards, P. Bullock, V. Bray, M. Kibblewhite. 2005. Audit of soils-related education and awareness initiatives. Final Report to Defra project SP0549. [Online] Available at http://randd.defra.gov.uk/Default.aspx?&Module=More&ProjectID=13359&SearchText=sp0549. Accessed April 24, 2017.

Hallett, S., P. Bullock, T. Simmons, N. Edwards, J. Dunleavy. 2007. Soil-Net.com – An Internet portal for education. Final Report to Defra project SP0552. [Online] Available at http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=2&ProjectID=13381. Accessed April 24, 2017.

Hallett, S. 2008. Soil-Net.com: A soils-focused educational Internet resource for school. p9-13. European Society for Soil Conservation, Newsletter 3/2008. [Online] Available at http://www.soilconservation.eu/assets/newsletter_3_2008.pdf. Accessed April 24, 2017.

Hartemink, A.E., M.R. Balks, Z. Chen, P. Drohan, D.J. Field, P. Krasilnikov, D.J. Lowe, M. Rabenhorst, K. van Rees, P. Schad, L.A. Schipper, M. Sonneveld, C. Walter. 2014. The joy of teaching soil science. Geoderma, 217–218, 1–9. doi: 10.1016/j.geoderma.2013.10.016

Jones, A., H. Breuning-Madsen, M. Brossard, A. Dampha, J. Deckers, O. Dewitte, T. Gallali, S.H. Hallett, R. Jones, M. Kilasara, P. Le Roux, E. Micheli, L. Montanarella, O. Spaargaren, L. Thiombiano, E. Van Ranst, M. Yemefack, R. Zougmoré (eds.). 2013. Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg. 176 pp. [Online] Available at http://esdac.jrc.ec.europa.eu/content/soil-map-soil-atlas-africa. Accessed April 24, 2017.

Jones, A., P. Panagos, S. Barcelo, F. Bouraoui, C. Bosco, O. Dewitte, C. Gardi, M. Erhard, J. Hervás, R. Hiederer, S. Jeery, A. Lükewille, L. Marmo, L. Montanarella, C. Olazábal, J-E. Petersen, V. Penizek, T. Strassburger, G. Tóth, M. Van Den Eeckhaut, M. Van Liedekerke, F. Verheijen, E. Viestova, Y. Yigini. 2012. The State of Soil in Europe. Joint Research Centre Reference Report. EUR 25186 EN Joint Research Centre. Luxembourg: Publications Office of the European Union. [Online] Available at http://ec.europa.eu/environment/soil/three_en.htm. Accessed April 24, 2017.

Kibblewhite, M., T. Gergely, T. Hermann. 2015. Predicting the preservation of cultural artefacts and buried materials in soil. Science of the Total Environment. 529, 249-263. [Online] Available at http://www.sciencedirect.com/science/article/pii/S0048969715004854. Accessed April 24, 2017. doi: 10.1016/j.scitotenv.2015.04.036

Lal, R., B.A. Stewart. 2013. Soil Management for sustaining ecosystem services. Chapter 19. In R. Lal, B. Stewart (Eds.), Principles of Sustainable Soil Management in Agroecosystems, June 521-533. CRC Press Taylor & Francis Group, Boca Raton, FL. ISBN 9781466513464.

Laurillard, D. 2002. Rethinking university teaching (2nd Ed.). London: Routledge
Falmer, p.90.

Lawley, R., B.A. Emmett, D.A. Robinson. 2014. Databases: Soil Observatory Lets
Researchers Dig Deep. Nature 509, no. 7501 (22 May 2014): 427.
doi:10.1038/509427b.

Margenot, A.J., K. Alldritt, S. Southard, A. O'Geen. 2016. Integrating Soil Science into
Primary School Curricula: Students Promote Soil Science Education with Dig It!
The Secrets of Soil. Soil Science Society of America Journal 80 831–38.
doi:10.2136/sssaj2016.03.0056.

Microsoft. 2017. Microsoft Excel 2016 for Mac, version 15.36, Redmond, Washington:
Computer Software.

Pritchard, O.G., S.H. Hallett, T.S. Farewell. 2014. Soil Impacts on UK Infrastructure:
current and future climate. Engineering sustainability: Proc. Institution of Civil
Engineers, 167 (4) 170-184. doi:10.1680/ensu.13.00035.

Quantum GIS Development Team. 2017. Quantum GIS Geographic Information
System. Open Source Geospatial Foundation Project. [Online] Available at
http://qgis.osgeo.org. Accessed July 16, 2017.

R Core Team. 2016. R: A language and environment for statistical computing. R
Foundation for Statistical Computing, Vienna, Austria. [Online] Available at
http://www.R-project.org. Accessed July 16, 2017.

Sharples, M., A. Adams, N. Alozie, R. Ferguson, E. FitzGerald, M. Gaved, P.
McAndrew, B. Means, J. Remold, B. Rienties, J. Roschelle, K. Vogt, D.
Whitelock, L. Yarnall. 2015. Innovating Pedagogy 2015: (Open University
Innovation Report 4). Milton Keynes: The Open University. [Online] Available

at http://proxima.iet.open.ac.uk/public/innovating_pedagogy_2015.pdf.

Accessed April 24, 2017.