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A global perspective on soil science education at third educational level; knowledge, practice, skills and challenges

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ABSTRACT

The pivotal role of soil as a resource is not fully appreciated by the general public. Improving education in soil science represents a challenge in a world where soil resources are under serious threat. Today's high school students, the world's future landowners, agriculturalists, and decision makers, have the potential to change society's apathy towards soils issues. This research aimed to compare the level of soil education in high and/or secondary schools in forty-three countries worldwide, together comprising 62% of the world's population. Comparisons were made between soil science content discussed in educationally appropriate textbooks via a newly proposed soil information coefficient (SIC). Interviews with teachers were undertaken to better understand how soil science education is implemented in the classroom. Statistical analyses were investigated using clustering. Results showed that gaps in soil science education were most commonly observed in countries where soil science is a non-compulsory or optional subject. Soil science concepts are predominantly a part of geography or environmental science *curricula*. Consequently, considerable variability in soil science education systems among investigated countries exists. Soil information coefficient's outcomes demonstrated that a methodological approach combining textbooks and the use of modern digitally based strategies in the educational process significantly improved soil education performances. Overall, soil science education is under-represented in schools worldwide. Dynamic new approaches are needed to improve pivotal issues such as: *i*) promoting collaborations and agreements between high school and universities; *ii*) encouraging workshops and practical exercises such as field activities; and, *iii*) implementing technology tools. This, in turn, will prepare the next generation to contribute meaningfully towards solving present and future soil problems.

1. Introduction

Soils are an invisible, buried, hidden element of the environment. Soils, frequently referred to as earth, ground or dirt, might even be considered as dull and unexciting. Most people associate soils only with agricultural activities. In part, this may be because soil education is deficient in many countries. This may result in students perceiving the pedosphere as being less important than, for example, the hydrosphere or lithosphere (Urbańska et al., 2022). However, such an essential element of the terrestrial system cannot simply be ignored. Appropriate soil education at the school level serves to increase a general awareness of soil and the important, but often overlooked role it plays in sustaining human existence.

Over the past twenty years, significant advances and a better scientific understanding have been achieved in soil science and its subdisciplines (Brevik and Hartemink, 2010). In addition to a better scientific understanding, there have been major developments in the perception of both the ecological and non-ecological functions of soils in providing fundamental ecosystem goods and services (e.g., Blum, 2005; Brevik, 2009; Jones et al., 2012; Crossman et al., 2013; Cruse et al., 2013; Lal and Stewart, 2013; Pritchard et al., 2014; Baveye et al., 2016; Urbańska and Charzyński, 2021). Despite the importance of soils, an understanding of the role they play in supporting and sustaining human existence is still limited among the general public (Brevik et al., 2020). In attempting to explain why this is so, other questions arise: Is soil science education at the secondary school level appropriate? Is soil knowledge being promoted adequately? Is information regarding the need to protect soil resources communicated effectively?

Soil science education is important for understanding terrestrial environmental systems and the value of protecting them. Improving the way that soil concepts are taught will facilitate a realisation that unpolluted and productive soil is just as important as clean water or fresh air. Today's high school students, who are our future landowners, agriculturalists, and decision-makers, require a deeper appreciation of the basic functions of all environmental systems, including soils, and the interrelations between human activities and the natural world, thus being able to make appropriate decisions about contemporary environmental problems when and where they arise.

The importance of public awareness regarding the role of soils in sustaining life has been raised in several policy reports by the European Commission (EC, 2006, European Commission (EC, 2012), the Department for Environment, Food and Rural Affairs (Defra, 2004) in the United Kingdom, and by other role players. Over the span of a human lifetime, soils should be considered a nonrenewable resource (Friend, 1992; Cruse et al., 2013). However, people frequently overlook soils as components of the biophysical landscape which have developed over thousands of years yet can be destroyed in an instant. The Food and Agriculture Organization (FAO, 2011) estimated that 33 % of the global land area has been degraded. Currently, the world is faced with numerous ecological problems. High school students are aware of global warming, floods, and water and air pollution, but they are not necessarily sufficiently informed that soil resources and soil protection are equally important for humankind (Urbańska et al., 2022). Healthy soils are essential for plant growth, water filtration, and human nutrition.

They are fundamental to our survival and the best gift we can bequeath to our descendants (Defra, 2004; EC, 2006, EC, 2012; Hallett, 2008; Jones et al., 2012). Many countries have been supporting activities promoting soil science for some time. Since 2004, Germany, Austria and Switzerland have been selecting a "Soil of the Year" and have published information in social and traditional media via press releases, folders, flyers, workshops, conferences and other activities (https://de.wikipedia.org/wiki/Boden_des_Jahres). The International Union of Soil Sciences (IUSS) sees the need to make young people aware of the importance of soils in the environment. During the conference, "Celebration of International Year of Soils 2015 – Achievements and Future Challenges," the International Decade of Soils 2015–2024 was proclaimed by the IUSS President (https://www.iuss.org/international-decade-of-soils/). Since then, there have been many events at both national and international level: posters, image and book contests (such as the Poster Contest "Soilutions", and a book contest on soil biodiversity with the motto "Keep soil alive, protect soil biodiversity"), activities of soil science societies and institutions (such as the Soils in Landscapes of the World – 2018 Calendar designed by the Department of Soil Science and Landscape Management, Faculty of Earth Sciences, Nicolaus Copernicus University in Torun and the program, "Thus are Soils of my Nation", an educational project of the Latin-American Soil Science Society). Events have been held in various locations around the world, including Japan ("Where and how does your food grow?"), Spain ("Soil Art: Painting with Soils''), Argentina (''These are the soils of my country!"), México (''Thus are the Soils of my Nation"; (Spanish Society of Soil Science. International Decade of Soils, 2021); Hirai and Mori, 2020; Fritz, 2020; Reyes-Sanches, 2020a), Germany ("Life in the soil", „Beneath our feet - Soil as a habitat", "The Thin Skin of the Earth - our Soils") – exhibitions prepared by The Senckenberg Museum of Natural History in Goerlitz (https://www.senckenberg.de/de/museen-und-events/) and the US ("Dig It! The Secrets of Soil" which was a travelling exhibit from the Smithsonian Museum; (https://forces.si.edu/soils/02_00_00.html) . However, these infrequent events are insufficient to ensure an in-depth understanding of the role of soils in humanity's future. First and foremost, students should have access to appropriate educational content in the field of soil science. In order to achieve this, soil science education at school level, as well as the soil science educational content of many school-level textbooks, needs to undergo change so as to improve learning outcomes. The extra-curricular soil science activities and events related to soil science that universities offer may filter down to local school students but, by and large, their participation is negligible. It can be stated without doubt that these extra activities are not enough to reach the entire student population. In addition to university centers offering additional soil science classes designed for school students, there are many soil museums around the world (39 museums and 34 permanent exhibitions), but these facilities only have between 1000 and 10,000 visitors per year (Richer-de-Forges et al., 2020; muzeumgleb.pl/baza-wiedzy-o-glebie/ksiazki-o-glebach/). This number is, in view of the fact that almost eight billion people in the world are beneficiaries of soil resources, extremely low. Soil science societies, national ministries and departments of education should establish closer collaborations to develop appropriate methodological and didactic guidelines to make future generations aware of the importance of soils and risks threatening it. This process should not involve only a specific country but should become an international goal for all countries that care about Earth systems and human life.

Against the backdrop outlined above, this paper aimed to compare the level of high school soil education in forty-three countries around the world. It should be noted that the differences in the structures of educational systems throughout the world makes the very naming and differentiation of high school and secondary school levels problematic. According to the international standard classification of education (ISCED), the high school level corresponds to level 3 (upper secondary education). This level is typically designed to complete secondary education in preparation for tertiary education or provide skills relevant to employment, or both. Note that secondary education is divided into upper secondary education (described above) and lower secondary education; typically designed to build on the learning outcomes from ISCED level 1 (primary education). Usually, the aim is to lay the foundation for lifelong learning and some education systems may offer vocational education programmes (UNESCO Institute for Statistics, 2012). Thus, in this paper, the terms high school level and secondary school level are used interchangeably. It is important to emphasise that the analysis focuses on the content of the textbooks, not the testing of students' knowledge. The goal is to show what knowledge a student can *potentially* gain from a textbook. The review of information focused only on formal and compulsory education and did not include informal or extracurricular activities. Information related to the soil science content provided to students in secondary (high) schools was gathered from 43 countries. According to Field's concept of "knowing" soil, students can (Field, 2019): *i*) "be aware of" soil; *ii*) "know of soil"; and *iii*) "know soil". These concepts can be interpreted as the realisation of the operational goals of the lesson, i.e., the student *knows*, *understands,* and *is able to* - according to the Taxonomy of Educational Objectives: *Knowledge, Comprehension, Application* (Bloom et al., 1956). The following questions therefore arise: Which soil issues presented in the relevant school textbooks educate with regard to the above-mentioned skills? Are they equally important? Is the situation the same in every country? This research attempted to answer these questions and to review the soil science knowledge offered to students in selected countries of the world. It should be noted that education systems in countries are diverse and difficult to compare. The examples of Russia and Italy clearly show that soil science is taught in different ways and at different educational levels. Traditionally, compulsory general education in Russia includes primary (the 1st to 4th grades) and secondary school (the 5th to 11th grades). At the end of the 9th grade, students take semi-final exams, after which they can choose to either stay at school for two more years, or enroll in a technical college, where they can learn a trade. In the Russian Federation, students acquire elementary knowledge about soils from the 'World Around Us' course. They gain this through studying general geographic principles in the 6th year of school. The 'Geography of Earth' (grades 5 to 7) course is designed to teach students about geographical integrity and heterogeneity of the Earth as a planet populated by people, general principles of development of relief, hydrological networks and climatic processes, the distribution of plants and animals and the influence of the environment on people's lives and occupations. The "Geography of Russia" (grades 8 and 9) course aims to give students a general understanding of the geography of their country in all its diversity and integrity based on a holistic approach and knowledge about the interaction and interdependence of three main components, i.e., nature, people, and the economy. In Italy, education is compulsory between the ages of 6 and 16. Soil science topics are mainly taught in "Science" and "Techniques" curricula. In the former, soil science is explained through concepts of soil genesis, soil-forming processes (primary schools), soil horizons (lower secondary schools), and soil classification systems. In both curricula, according to the teacher's autonomous decision, further concepts such as soil erosion and degradation, and soil importance in the view of climate change can be discussed. Descriptions of educational systems in forty-three countries were analyzed in terms of similarities and differences through a newly proposed Soil Information Coefficient (SIC), and the results thus obtained were used to propose some initial guidelines to improve soil science education on a worldwide level.

2. Materials and methods

2.1. Research general background.

Information regarding soil knowledge and soil education was gathered from 43 countries worldwide, which countries together are home to 62 % of the world's population (Fig. 1). Data collection required the involvement of soil scientists in contact with teachers, as well as the

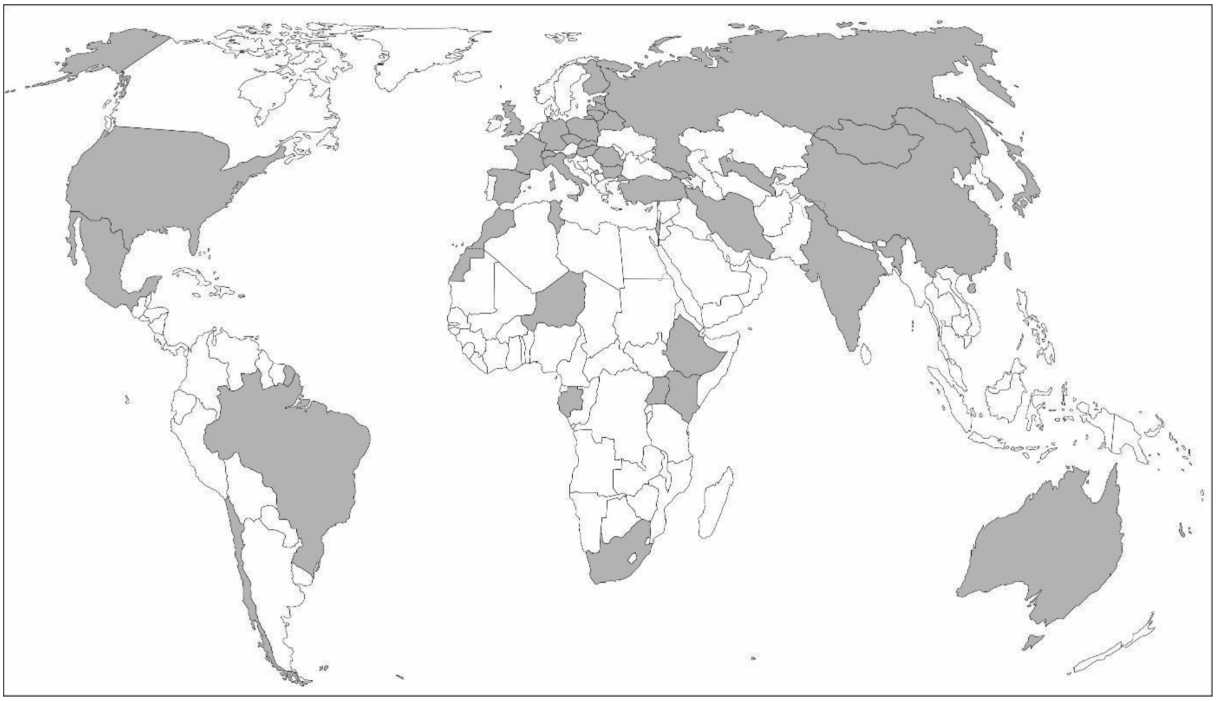

Fig. 1. Participating countries from which data was collected (see also Table 2).

analysis of school textbooks (ISCED 3rd level). Due to the Covid-19 pandemic, there were a number of challenges, including school and library closures as well as limited contacts with relevant contributors. Similarly, it was not possible to include a number of countries where political, ideological or language factors presented insurmountable logistical problems. Potential participants in more than 50 countries were invited to cooperate, and 43 of these were able to obtain and contribute information. A tool that evaluates textbook content (a list of analyzed textbooks from all countries with an indication of the educational level is available in the Supplementary Material 1) was addressed to soil scientists who were asked to assess and characterise the soil science knowledge contained in their country's school textbooks, as well as to consult with teachers responsible for soil science education. The tool for evaluating textbook content was designed so that any soil scientist could complete it, given the appropriate information. Due to the necessity of obtaining the opinion of experts in soil science from around the world, a purposive sampling method was used to select the respondents.

The evaluation tool (Table 1) was compiled regarding the implementation of soil education. It comprised 25 questions covering general information pertaining to textbooks, schools, and students. The most important information related to the detailed characteristics of individual soil concepts discussed in the country's often-used textbooks. In most countries, several available textbooks at different levels within secondary/high education were analyzed. The data were averaged in order to obtain complete information about the soil science knowledge provided over the entire cycle of teaching at a given level, regardless of the textbook. Soil concepts referred in particular to soil genesis, soil profiles, soil processes, soils of the country, world soils, soils management, soil degradation and protection, soil functions, agricultural usefulness, and climatic-soil-vegetation zones. The content of the textbooks was analyzed in terms of the above-mentioned concepts: Are they present? If yes, what level of detail does the content provide? Are there appropriate graphics, maps, and charts? Is any relevant or important information omitted?

Information with regard to whether soil knowledge in the analyzed textbook was up-to-date was also considered. In addition, the soil scientist from each participating country provided a description of their particular education system (Table 1). In some countries, for example

Table 1
Evaluating tool regarding soil science education and education systems.

No.	Textbook information
1.	*Country*
2.	*Is soil knowledge present?*
3.	*School level*
4.	*Grade*
5.	*Student age*
6.	*Textbook authors*
7.	*Textbook title*
8.	*Pages concern soil knowledge from … to …*
9.	*How many pages?*
Topics	
10.	*Soil genesis*
11.	*Soil profile*
12.	*Soil processes*
13.	*Soils of country*
14.	*World soils*
15.	*Soil management*
16.	*Soil degradation and protection*
17.	*Agricultural usefulness*
18.	*Soil functions*
19.	*Climatic-soil-vegetation zones*
20.	*Other*
Additional information	
21.	*Is the information up-to-date?*
22.	*Comments*
23.	*What soil classification was used to describe world soils?*
24.	*Is soil classification up-to-date?*
25.	*Additional remarks*
Description of the education system - questions	
1.	*What is the geographic education based on?*
2.	*What does this document include? Is it compulsory for each school?*
3.	*How many stages of geographic education are available?*
4.	*Is geographic education compulsory?*
5.	*What is the most popular publishing house offering textbooks?*
6.	*Who chooses the textbook?*
7.	*Additional information*

the USA, Germany and Switzerland, national education systems relate to a federal structure. There are no national requirements or science education standards officially endorsed by the United States government, but guidelines and recommendations are periodically written and recommended. In 2013, the National Research Council (NRC), the National Science Teachers Association (NSTA), the American Association for the Advancement of Science (AAAS), and other nongovernmental organizations worked with state-level education departments to develop the Next Generation Science Standards (NGSS). Twenty states and the District of Columbia now use the NGSS for their schools. Twenty-four other states have adapted the NGSS for use in their schools, often with minimal changes. Currently about 71 % of US students are in schools with syllabi based on these standards and recommendations. The American textbooks analyzed were based on the requirements specified in the standards, and the results were averaged. In the case of Switzerland, topics and learning targets are stipulated for every school-level separately in a curriculum. Since 2016 the German speaking cantons (21) have developed a common document. The exact number of years in every school level, school books, curricula and specific requirements for qualifications vary between cantons. Therefore, instead of an overview of soil education in Switzerland, the canton of Bern was used in this study as representative of the Swiss system. In Germany education is not centrally regulated by the national government. Education is the official responsibility of each of the sixteen individual federal states. Hence, education affairs are diversely administered, although the basic structure and most standards are aligned across the states. In this research, we focused on the federal state of Lower Saxony and, specifically, lower, and upper secondary schools (high school level) which qualify for university admission. In other countries, educational programs and core curricula are standardised and centralised based on government guidelines, so the soil science content in textbooks is the same for the whole country.

2.1. Data analysis and statistics

Data and statistical analyses were conducted using the Paleontological Statistics Software Package for Education and Data Analysis - PAST (Hammer et al., 2001). The descriptive data were analyzed, compared, and contrasted. In particular, soil knowledge concepts (vide supra) were analyzed, and the descriptive data converted into a quantitative form: 0 points - no information, 1 - scanty information, 2 - some information, 3 - complete information. Each country could potentially receive a maximum of 30 points. The correlation between the figures was tested, and an attempt was made to cluster individual components ($p = 0, 05$). This was carried out using the k-means, the classical, and the neighbor-joining methods. Average scores on specific soil science concepts in all countries were grouped using the classical clustering method (hierarchical). Unweighted pair-group average (UPGMA) was applied where clusters were joined based on the average distance between all members in the two groups (Euclidean similarity index). The hierarchical clustering routine produces a 'dendrogram' showing how data points can be clustered. The same data were grouped using the k-means method representing the group of non-hierarchical algorithms. It was necessary to specify the number of clusters in advance. Based on previous results of classical clustering, three clusters were determined for this method. Neighbor joining clustering was an alternative method for hierarchical cluster analysis of the average scores on specific soil science concepts. Bray-Curtis similarity index and bootstrap replicate of 1000 were used for this clustering analysis.

The data provided for the listed soil concepts were converted into quantitative values: 1 - no information, 2 - scanty information, 3 - some information, 4 - complete information. The relationships between particular concepts were calculated by dividing the sum of points into individual categories (group of analyzed soil concepts). In relation to the educational operational goals: *knowledge* (*the student knows*), *comprehension (student understands), application (student is able to)*, (Krathwohl, 2002), the soil concepts presented in the textbooks were divided into groups corresponding to the implementation of individual goals: knowledge (*soil genesis, soil profile, soils of the country, world soils* and *climatic-soil vegetation zones*), understanding (*soil processes, soil functions* and *agricultural usefulness*), and ability (*soil management, protection, and degradation*), (Fig. 2). Objectives that describe intended learning outcomes as the result of instruction are usually framed in terms of a description of what is to be done with that content. Thus, statements of objectives typically consist of a noun - the subject matter content - and a verb - the cognitive process (Krathwohl, 2002). Therefore: the student *knows* - the student was expected to be able to recall or recognise soil science *knowledge*, the student *understands* - the student was expected to interpret, classify, compare, and explain soil science processes, the student is able to - the student is expected to execute and implement previously acquired soil science knowledge.

The student *knows* represents a basic educational goal. Soil concepts such as *soil genesis, soil profile, soils of the country, world soils*, and *climatic-soil vegetation zones* available in the textbook provide the student with elementary knowledge about soils. However, the factual knowledge (theoretical soil concepts) is likely to be quickly forgotten by students if they do not *understand* the relationships and processes occurring in the soil. *Understanding* (another educational goal) allows the combining of known facts into a complex context. Showing *understanding* is the role of the following concepts: *soil processes, soil functions,* and *agricultural usefulness*. Following on from this, if students do not understand, they will not *be able to* put the relevant knowledge and skills into practice. In short, they will be unlikely to appreciate the applicability of soil education. To achieve this, students need to be familiar with the following concepts: *soil management, protection*, and *degradation*. The values of these three educational goals were the basis for assigning "scores" within each type of goal: a) knowledge – multiplied by 1 point, b)

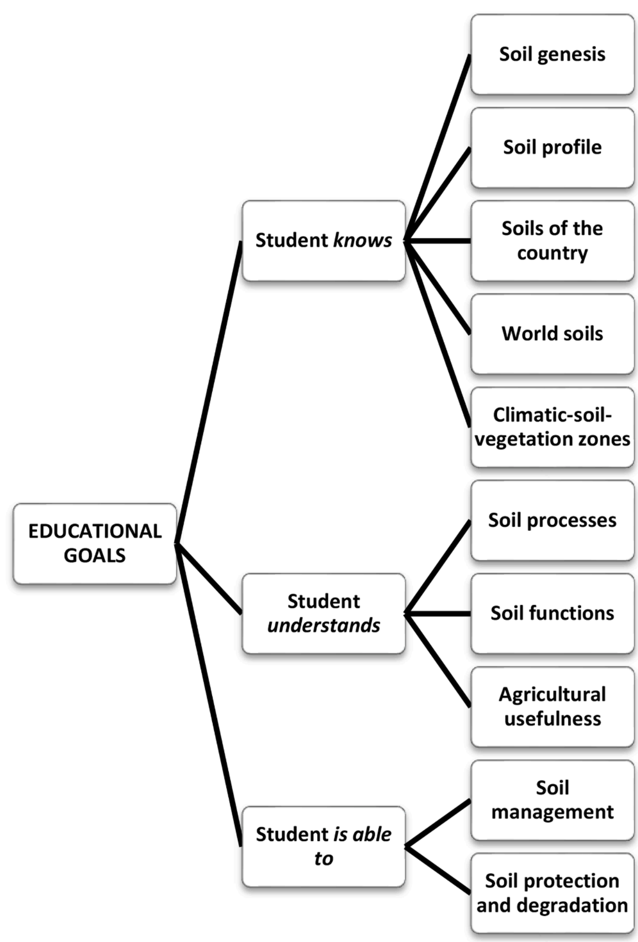

Fig. 2. Soil concepts presented in textbooks in relation to the three groups of individual educational goals.

understanding - multiplied by 2 points, c) ability - multiplied by 3 points.

2.2. Soil information coefficient (SIC)

A soil information coefficient (SIC) was created to further evaluate the combined effect of the calculated scores. This was undertaken with the aim of providing quantitative information regarding the effectiveness of textbooks in contributing to the achievement of the three, primary educational goals (Fig. 2).

The SIC was calculated according to this formula:

$$SIC = \sqrt{\frac{S_w}{S_{w^{max}}}} \times S_w \times S_{w^{max}}$$

Where:

S_w is the weighted sum of scores related to particular goals;

$S_w$max is the maximum weighted sum of scores related to particular goals.

3. Results and discussion

3.1. Review of textbook analysis and statistics

Fig. 3 reflects soil science topics analyzed in textbooks from the investigated 43 countries worldwide. The mean value for overall content score was 16.1. The highest scores were achieved by Mongolia (28 out of 30), Turkey (26), Niger (25), and Uganda (25). Unfortunately, soil education in these countries is often presented as an optional subject. General analyses of individual topics discussed in the textbooks (given numerical values) are presented in Table 2. Issues related to *soil genesis* and *soil profile* were discussed in the most detail in textbooks (scores of 2.2 and 2.0 respectively), whereas *world soils* (1.2) and *agricultural usefulness* (1.2) received the lowest coverage. The remaining issues received scores ranging from 1.3 to 1.9.

The ten soil science concepts were clustered into three groups for further analysis (k-means). Specifically, cluster 1 included the topics which received the most attention; cluster 2 included topics receiving a moderate amount of attention; and cluster 3 included the least discussed topics (Table 3). *Soil genesis, soil profile, world soils, soil degradation and protection and climatic-soil-vegetation zones* (cluster 1) are the most discussed topics, whereas *soil processes* and *soil of country* (cluster 3) are the least discussed, with *soil management, agricultural usefulness and soil functions* (cluster 2) falling between the most and least discussed. These results agree with the sum of points obtained from the individual concepts (Table 1).

A further analysis concerned the grouping of countries in relation to the soil science concepts taught in schools. As is evident from clustering results (Supplementary Material 2), the groups of countries demarcated by the classical and k-means method clustering are similar with regard to their approach to soil science concepts taught in schools. Few differences in the results of the neighbor joining method were observed. Further analyses were performed based on clusters obtained from classical and k-means methods. Cluster 1 included countries where numerous clearly visible gaps in soil science education from textbooks and core curricula were observed. Countries with some gaps in soil science education are included in cluster 2**,** whereas cluster 3 included countries where soil topics were best represented. It should be noted that the group of higher scoring countries included countries where soil science education at the secondary/high school level is non-compulsory or optional and may involve a relatively small number of students (e.g., Ethiopia, Uganda, Kenya, Niger, and the USA).

In the overall analysis, the knowledge concepts (listed above) were the most commonly represented (mean 68 %). This percentage represents the sum of individual soil issues included in category: the student *knows* (Fig. 4).

While Turkey, Niger, and Uganda rate relatively highly according to all three educational goals, the student audience reached is not necessarily a broad one, because soil science education is not compulsory in these countries (Fig. 4). Interestingly, Poland, Belarus, and Latvia are European countries showing, in terms of soil science education, similarities in their attainment of the three goals. The three countries share similar historical and political backgrounds (long-term socialist systems). In these countries, education is compulsory up to the age of 18 and is provided to all citizens. In terms of its overall achievement against all three goals (Fig. 4), special mention can be made of Mongolia - a country where compulsory education lasts 11 years. Ninety-eight percent of young Mongolians are enrolled in primary schools, and eighty-five percent continue education in secondary schools (lower and higher). High school (high secondary) education is interrupted almost halfway through by means of an exam, and compulsory schooling ends at this stage (https://www.scholaro.com/pro/Countries/Mongolia/Education-System). Despite this challenging situation, Mongolia scored highly on the above list (90 %). On the other hand, the lowest result in the category student *knows* were observed for Australia, Iran, and India (30–40 %). Nevertheless, in this case, the lowest is *not the*

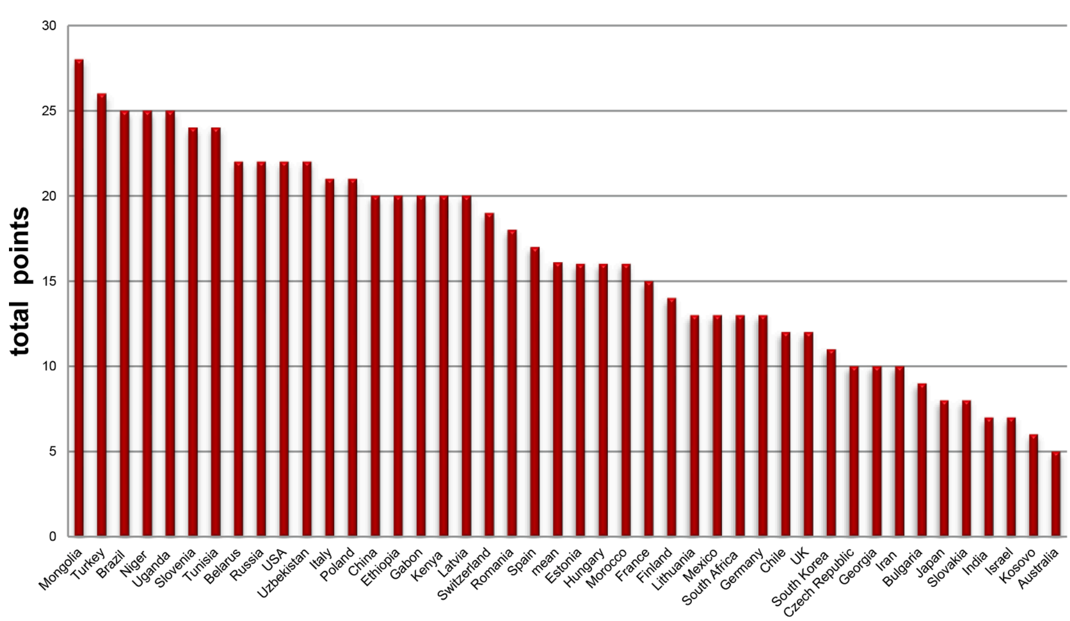

Fig. 3. Soil science concepts: total points for individual countries regarding the presence and depth of the listed soil science concepts.

Table 2
Analysis of individual soil science concepts discussed in textbooks, scored from 0 (no information) to 3 (complete information).

Country	Soil genesis	Soil profile	Soil processes	Soils of country	World soils	Soil management	Soil degradation and protection	Agricultural usefulness	Soil functions	Climatic-soil-vegetation zones	Sum
Australia	1	0	1	0	0	1	0	1	1	0	5
Belarus	3	3	3	3	2	1	3	0	1	3	22
Brazil	1	3	2	2	3	3	3	2	3	3	25
Bulgaria	2	2	0	3	1	0	0	1	0	0	9
Chile	0	0	0	3	0	0	3	3	3	0	12
China	2	3	3	3	0	3	2	2	2	0	20
Czech Republic	2	1	2	3	0	0	1	0	1	0	10
Estonia	3	3	3	3	1	0	1	0	1	1	16
Ethiopia	3	0	2	3	1	2	2	1	3	3	20
Finland	3	1	3	3	0	3	1	0	0	0	14
France	3	1	2	0	0	2	2	2	3	0	15
Gabon	3	3	3	3	3	0	2	2	1	0	20
Georgia	1	2	1	2	0	0	1	1	1	1	10
Germany	1	1	1	2	1	1	3	1	1	1	13
Hungary	3	3	0	1	2	1	3	1	0	2	16
India	0	3	2	0	0	0	0	1	1	0	7
Iran	3	0	0	0	0	2	3	0	2	0	10
Israel	1	1	1	1	1	0	1	1	0	0	7
Italy	3	3	1	1	0	3	3	3	3	1	21
Japan	1	0	0	0	2	0	1	1	0	3	8
Kenya	2	2	2	2	2	2	2	2	2	2	20
Kosovo	2	0	0	1	0	0	2	0	0	1	6
Latvia	3	3	2	3	3	0	3	1	0	2	20
Lithuania	3	1	2	2	0	3	1	0	1	0	13
Mexico	3	2	1	0	1	0	2	0	1	3	13
Mongolia	3	2	3	3	3	3	3	3	3	2	28
Morocco	2	2	3	0	2	2	3	0	1	1	16
Niger	3	3	3	3	2	2	3	1	2	3	25
Poland	3	3	3	3	3	1	1	1	1	2	21
Romania	3	3	0	0	3	0	3	1	2	3	18
Russia	3	3	2	2	0	3	3	1	2	3	22
Slovakia	0	0	0	2	0	0	2	1	1	2	8
Slovenia	3	3	3	1	3	1	2	2	3	3	24
South Africa	3	3	0	1	2	1	3	0	0	0	13
South Korea	1	2	2	0	0	0	2	1	2	1	11
Spain	2	3	2	3	2	1	0	1	0	3	17
Switzerland	2	2	3	1	0	3	2	2	1	3	19
Tunisia	3	3	3	3	0	3	2	3	2	2	24
Turkey	3	3	3	3	3	3	2	1	2	3	26
Uganda	3	3	3	3	2	2	2	2	2	3	25
UK	0	1	2	0	1	2	2	1	0	3	12
USA	2	3	2	2	3	2	2	3	2	1	22
Uzbekistan	2	2	3	1	2	3	2	3	2	2	22
Statistics											
N	43	43	43	43	43	43	43	43	43	43	
Min	0	0	0	0	0	0	0	0	0	0	
Max	3	3	3	3	3	3	3	3	3	3	
Sum	92	84	76	74	53	58	81	52	58	65	
Mean	2,2	2	1,8	1,7	1,2	1,3	1,9	1,2	1,3	1,5	
Median	3	2	2	2	1	1	2	1	1	2	

Table 3
K-means clustering (average scores on specific soil science concepts in all countries).

Item	Cluster
Soil genesis	1
Soil profile	1
World soils	1
Soil degradation and protection	1
Climatic – soil – vegetation zones	1
Soil processes	2
Soil of country	2
Soil management	3
Agricultural usefulness	3
Soil functions	3

worst. The same countries scored higher in the category *understanding* (India, Australia) and *ability* (Iran). The previously discussed comparison relates to knowledge-based concepts. Finland, a model of education in many respects, is below the average (60 %) but, as shown by the subsequent results, this does not have much of an impact on the acquisition of skills by Finnish students. Over the years, Finland has initiated a number of simple changes that have completely revolutionised their educational system. Finland outranks the United States and Eastern Asian countries because of common-sense practices and a holistic teaching environment.

The student *understands* - the achievement of this educational goal is responsible for the degree of implementation of the following topics: *soil processes, soil functions,* and *agricultural usefulness*. These concepts help to clarify the functioning of soils and their role in the environment. This

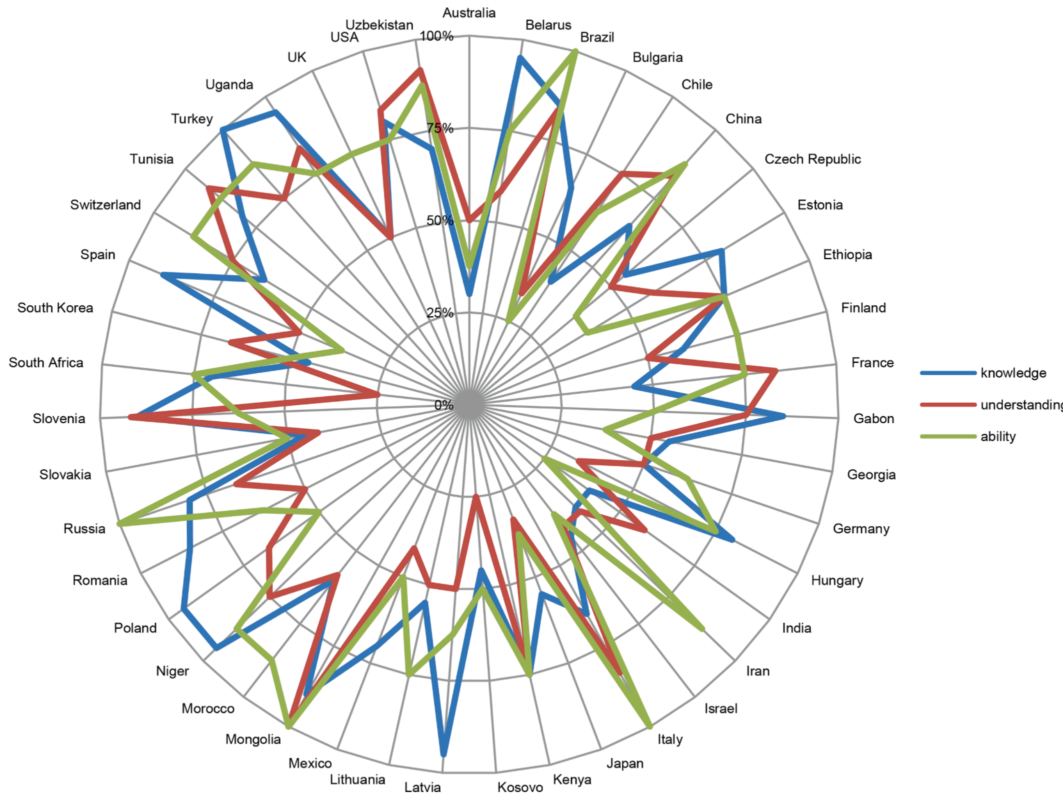

Fig. 4. Achievement of three educational goals (student *knows*, *understands* and *is able to*) in soil science education in 43 countries.

category was the most poorly represented (Fig. 4). The best results were achieved by Mongolia, Slovenia, Tunisia, and Uzbekistan. In Uzbekistan soil education is, as with Mongolia, not compulsory at the high school level. The other countries with high scores are Tunisia, Uganda, and the USA (where, as mentioned, soil education is optional, and policy-dependent in each state). In Brazil, geography is a compulsory curricular component in elementary school (1st to 9th grade). Currently, it is a mandatory subject in high school (1st to 3rd year), however, Brazil is in a process of curricular reorganization, and, with the implementation of the "New High School," geography will no longer be mandatory at this stage. In Slovenia, China, Italy, and France this education is compulsory and, the goal of *understanding* was best achieved (80–90 %). In the group of countries where the results of *understanding* were the lowest (South Africa and Kosovo) or below the average (61 %), there were also countries in which the category student *knows* was the highest rated (Latvia, Estonia, Romania, and Hungary).

Two topics are undoubtedly of an applied nature: *soil management* and *soil protection and degradation.* These concepts were used to determine the achievement of the educational goal: the student *is able to.* Among the countries that achieved the best results were Brazil, Italy, Mongolia, and Russia (Fig. 4).

The average score in the category student *is able to* was 65 %. Higher

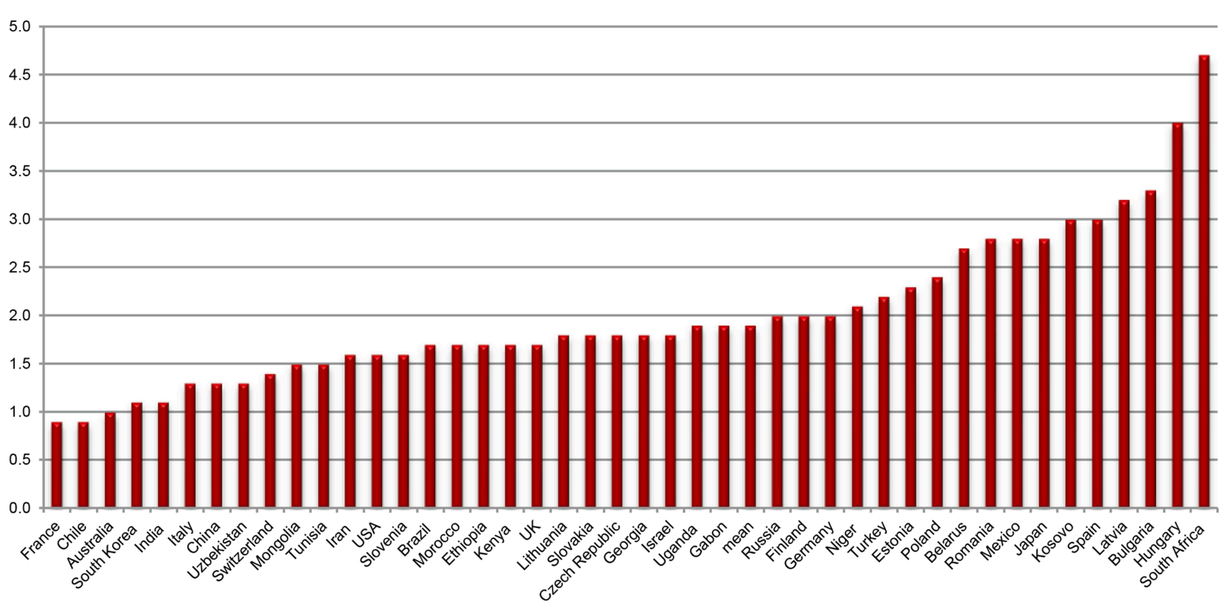

Fig. 5. Knowledge-understanding balance.

results in this category were achieved by countries which, in the previous combination of educational goals were at a medium or low level (Belarus, Finland, Hungary, and Lithuania).

By comparing the categories, the student *knows* and the student *understands*, a knowledge-understanding balance can be calculated by dividing the summed points of the respective categories. A higher number mean that the student *knows* more than *understands* (Fig. 5). Students *know* a lot in Bulgaria, Latvia, Hungary, and South Africa but do *not necessarily understand* as much, so they may forget quickly (Bui and McDaniel, 2015; Kang, 2016; Sekeres et al., 2016). In France, Chile, Australia, and South Korea, the emphasis is on concepts that shape the process of understanding the environment. Poland, Estonia, Turkey, Niger, Germany, Finland, Russia, Gabon, Uganda, Israel, Georgia, Czech Republic, Slovakia, and Lithuania were near the average score (1.9) which implies a knowledge-understanding balance.

The next indicator assessed whether students see the practical application of the knowledge they have already acquired. For this purpose, the topic soils *of the country* was compared with the topic *soil management;* a mean value of 1.2 (Fig. 6) was observed. Theoretically, the higher the index, the more questionable the knowledge-understanding balance in soils education because, while students know which soils occur in their surroundings, this knowledge is simply abstract, with no practical dimension (Latvia, Gabon, Chile, Czech Republic, and Estonia). In the UK, Morocco (optional education), Iran (optional education), and France students know little about their country's soils, but they know how to manage various soil resources. These countries do not take advantage of teaching on familiar examples. Therefore, a ratio below 1.0 was unfavorable. The group of countries with an index oscillating around 1.0 indicates correctly balanced proportions between knowledge, understanding and skills: India, Slovenia, Turkey, Kenya, USA, Tunisia, Mongolia, China, South Korea, Romania, México, Japan, Finland, South Africa, and Hungary. Soil education in high/secondary school is mandatory in Slovenia, China, South Korea, Romania, Japan, Finland, and Hungary.

Another indicator determining the ability to apply knowledge may be an understanding of *soil functions* and the concepts of *degradation and protection of soil resources*. A low mean value (0.9) was observed (Fig. 7). Countries with lower rates were characterised by a greater emphasis on degradation and protection issues than familiarity with soil functions. In Hungary, Latvia, South Africa, Finland, Switzerland, and Russia (all scored < 0.9), the student knows that soil should be protected and they are aware of soil degradation, but they do not know why and to what purpose because their understanding of soil functions is inadequate (Fig. 7). In Australia, India, France, and Slovenia, understanding soil functions seems to be a more important goal than understanding soil degradation and conservation. It can be argued here that the student is aware of how important soil is but is not necessarily aware of soil problems and what can be done to protect soil resources. Ideally, this emphasis on soil functions and soil protection and degradation should be in equilibrium. In the case of Italy, Russia, Romania, Uzbekistan, Brazil, Lithuania, South Korea, China, Mongolia, Tunisia, USA, Turkey, and Uganda (result 0.8–1.0) this indicator appears well balanced, however, it should be noted how poorly the concept: *soil functions* scored in each country. Typically, one or two soil functions were mentioned in textbooks: "providing food" and "habitat for animals". In the case of soil protection, there was usually little information on soil degradation and even fewer details regarding its protection, a significant issue that requires addressing in the near future.

3.2. Soil information coefficient (SIC) and teaching forms of soil science

General access in textbooks to educational implementation of three goals were assessed by SIC (vide supra). Textbooks from Mongolia, Brazil, Turkey, Tunisia, Niger, Uganda, Uzbekistan, and Italy achieved the highest scores, achieving 50 points for their SIC score (Fig. 8). Conversely, Japanese, Israeli, Indian, Bulgarian, Kosovarian, and Australian textbooks proved to be inadequate, with a SIC below 20.

Comparing the educational goals the student *knows*, *understands*, *is able to*, and the interdependencies between their implementation, it can be argued that Finland, Italy, Russia, and Mongolia offered what might best be described as *optimal* soil education. Balanced proportions between individual soil science topics, equal emphasis on achieving the most important goals and paying special attention to the need to develop students' ability to perceive facts, threats, and benefits related to soil management put these countries in an elite position regarding soil science education. Additionally, the attractive graphic design of textbooks, as well as encouraging students to use modern, digital approaches to the educational process, further improved the performances of these countries in SIC terms (Fig. 9).

It should be noted that although the extent to which textbooks are

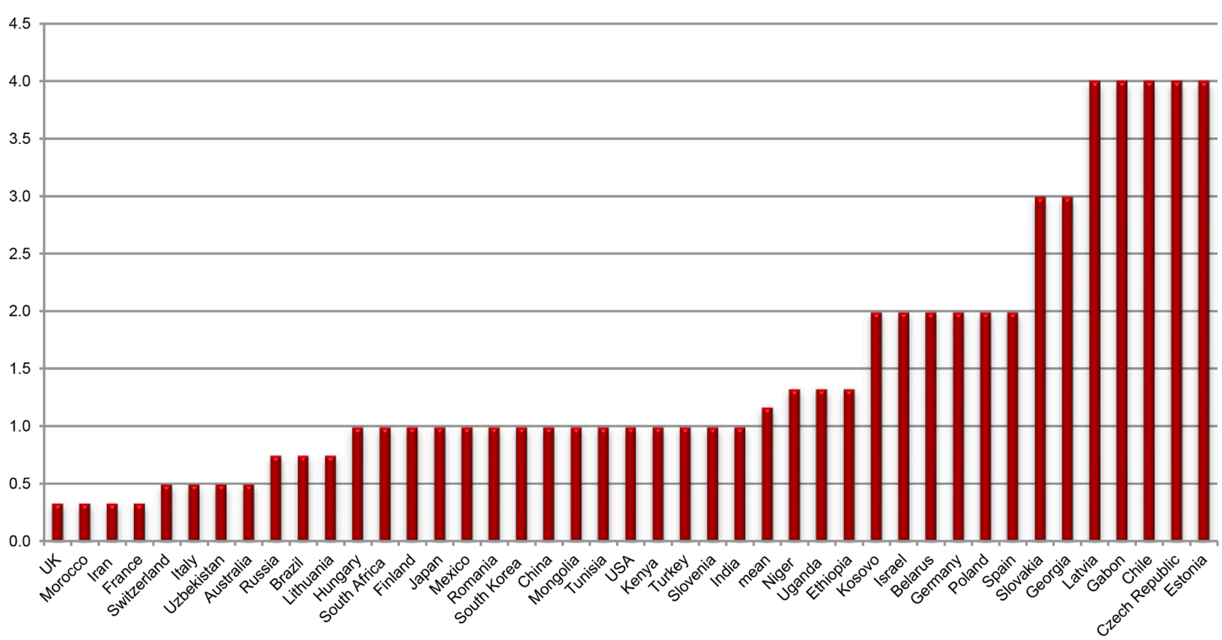

Fig. 6. Knowledge-practice balance: soil of country/soil management.

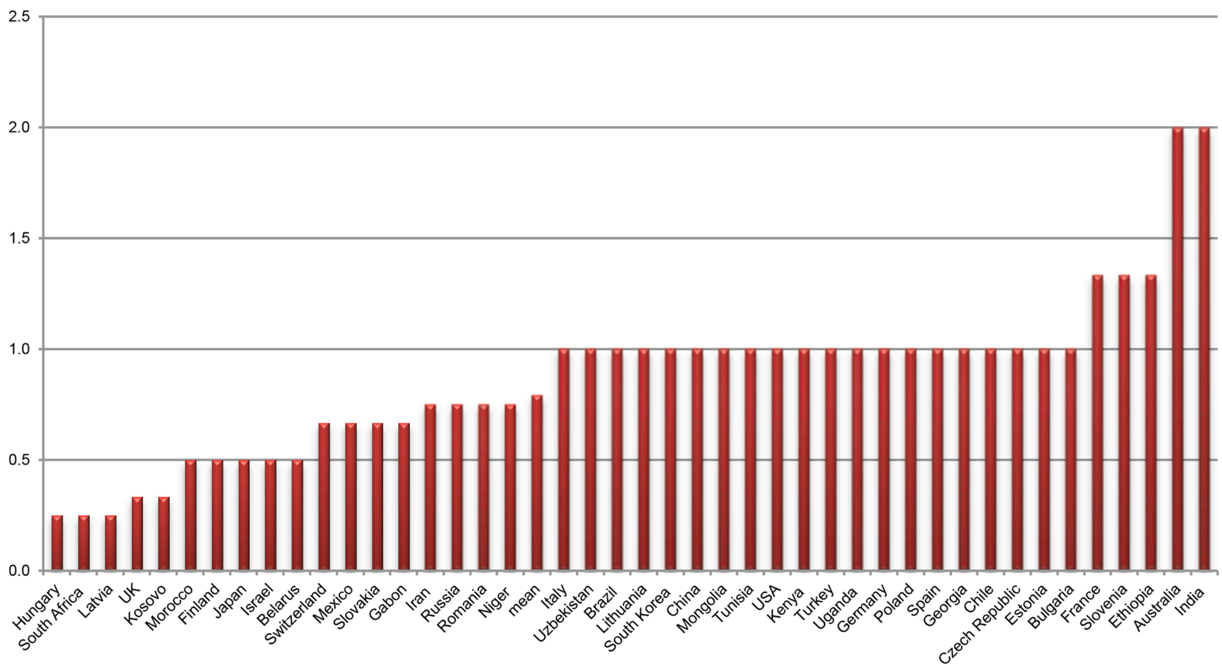

Fig. 7. Knowledge-practice balance: soil functions/soil degradation and protection.

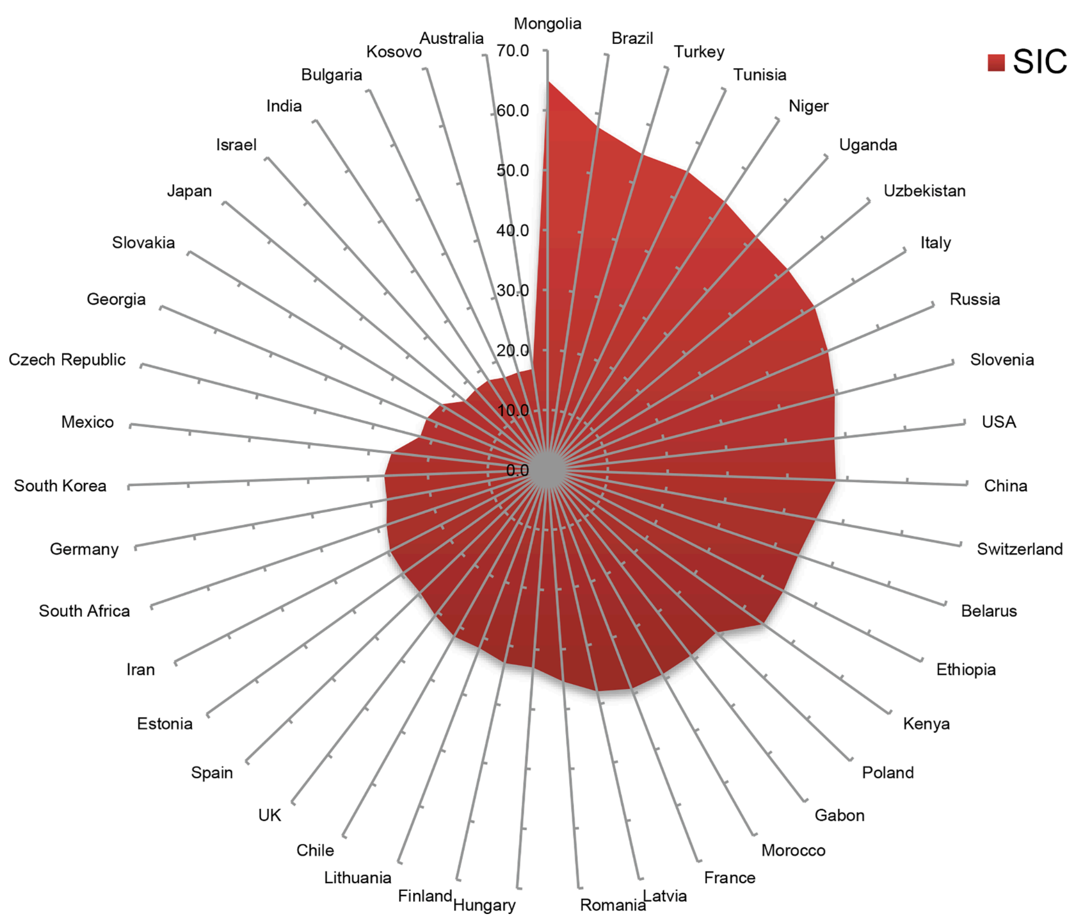

Fig. 8. Soil Information Coefficient (SIC) in investigated textbooks.

used varies (depending on the teacher and subject and class), there is little doubt that textbooks are an extremely important instruction medium utilised by teachers. Care should therefore be taken to make them attractive and tailored to the needs of the student/recipient.

Not only do indicators differ from country to country, but also between educational systems. In most countries, geographic education is

Fig. 9. Soil-related graphics included in: 1 – Finnish, 2 – Italian, 3 – Mongolian, 4 –Russian textbooks (note that these are simply included as examples of soil-related graphics and have not been assessed or evaluated *per se)*.

based on the core curriculum compiled and structured by experts in their ministry or department of education and which stipulates a compulsory set of teaching goals, content, and skills. These are prescribed in the form of general and specific requirements for knowledge and skills that a student should have after successfully completing an appropriate educational stage. In some countries (USA, Germany, Switzerland) there are no national requirements or science education standards officially endorsed by the government. However, guidelines are periodically written and recommended. Topics and learning targets (as well as competences of students) are often stipulated for every school-level separately.

Soil science education is not always combined with geographic education. Soil education elements are written into the core curricula or educational guidelines of various subjects. In South Korea, for example, soil science education is part of geological education, and in Uzbekistan, the USA and Germany, soil science education is incorporated within various subjects (from geography and biology to earth science). The geography curriculum and education in Italy is based on the "annual plan of activities" (APA). This must be approved by the School Director, based on proposals coming from the "collegial bodies" represented by all the teachers (regardless of their curriculum) belonging to the school. The approved curriculum must be based on both basic (mandatory) and additional activities. The latter are not mandatory but, frequently, teachers decide to include them because they focus on more applicative aspects. The APA can be modified at any time, even during the course of a scholastic year, but this must be done only after following the same previously reported procedure.

Generally, governments have exclusive legislative responsibility for the "general rules on education" and for the determination of the essential levels of services that must be guaranteed throughout the national territory. In most countries there are two to three stages of geographic education (primary, middle/secondary, and high school) but sometimes geography is available as an optional one-year course in high school (for example, in Brazil). Often geography content is incorporated into social studies classes and is not physical science-based.

Geography and environmental science are included as compulsory subjects in most countries with some significant exceptions, such as in the USA. Textbooks are most often chosen by teachers or a school district from several options offered by various publishing houses (Watt, 2004, 2009). In most countries there is plenty of supplementary material; examples include experiment sheets, activity kits, videos, lesson plans, and accompanying websites. In Finland, field trips into the natural and built environment, as well as the use of digital learning and spatial information are an integral part of geography teaching.

The mean years of schooling also has an impact on educational results. Countries with the highest SIC do not always top the list of this mean (Fig. 10). The annual Best Countries Report, conducted by US News and World Report, BAV Group, and the Wharton School of the University of Pennsylvania, reserves an entire section for education. This report surveys people across 78 countries, and ranks those countries based upon the surveyees' responses. It compiles scores from three equally-weighted attributes: a) a well-developed public education system, b) would consider attending university there, and c) provides top-quality education. Therefore, it can be concluded that some countries with lower SIC (Australia, Germany, the United Kingdom, and the USA) and excellent educational outcomes, "catch up" at the tertiary stage. However, the focus of the analysis was not on education systems but on the soil science content of level 3 textbooks that apply to the majority of the population (not only to those who decide to continue their education). The number of persons at a given age who are enrolled in education is also differentiated. Percentage of 15- to 29-year-olds enrolled in school, by selected levels of education, age, and country as well as percentage of children of a given age who are enrolled at an education level compatible with their age or enrolled at a higher education level are presented in Table 4. Data for individual countries come from different sources and refer to different indicators, as it was not possible

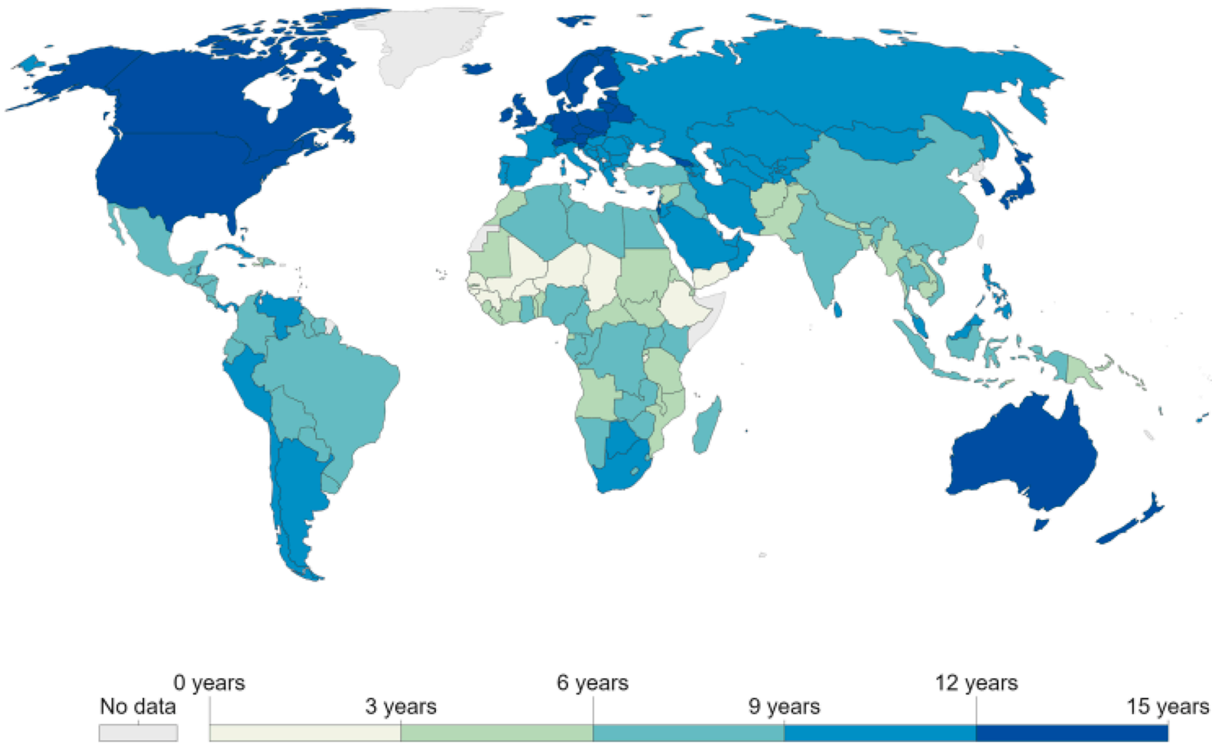

Fig. 10. Average number of years of total schooling across all education levels for the population aged 25 + in 2017 (https://ourworldindata.org/global-education).

to find corresponding data for all countries. The data in the table indicate the importance of education (including soil science education) at level 3. In most of the OECD (Organization for Economic Cooperation and Development) countries analyzed, 70 % of students attend secondary school and only 27 % go on to further education. Except for some African countries (Niger, Uganda, Ethiopia, Gabon) the percentage of children of a given age that are enrolled at an education level compatible with their age is also high (above 75 %). Therefore, the 3rd educational level should present the type of information which will facilitate the development of an environmentally conscious graduate.

One more issue raised major concerns. Most countries declared that no soil classification was mentioned in their textbooks (Fig. 11) and the soil science information was, in 38 counties, not up-to-date. The implication is that the names of soils, their types and locations do not correspond to the current state of knowledge (often these are classifications from 20 to 30 years ago - valid at the time of initial publication of a particular textbook, and then simply repeated in the following editions). The transfer of current, cutting-edge soil science knowledge is slow and, typically, reaches the intended recipients (students at secondary school level) after a considerable delay. This is understandable due to the procedures accompanying the preparation of textbooks. However, the question must be raised as to whether this should really take a decade or even longer. Admittedly nowadays the option of releasing textbooks via open-source content management systems is possible, and that process takes much less time, but it is still problematic because of the need to get ministry (or local government in the case of some countries) approval. Similarly, many developing countries do not have the resources to produce quick-release, online, open-source material. In many, if not most countries, the printed textbook still comprises the backbone of resource material in soil science education. All too frequently, soil science knowledge in textbooks is out of date, with little or nothing being done to bring it up to date.

In spite of the concerns flagged above, a number of positive aspects were identified in the core curriculum in many countries. In Chile, for example, the curriculum included deeper concepts such as the relevance of soil for human health development, the negative effects of intensive/mono-biotic agriculture in biodiversity preservation and soil functionality, causes and consequences of soil pollution, soil degradation, erosion and desertification as universal threats, soils as principal reservoirs of nutrients and organisms, and the influence of soil in social transformations. At this time, many countries are considering or implementing educational reforms and changing their core curricula as well as recommended teaching methods. Contemporary teaching methods consider the life experiences of the students, internationality, and cooperation with out-of-school bodies.

3.3. Learning from mistakes: Challenging proposals for improving future soil science teaching.

As previously noted, problems with inadequate soil science knowledge topics result from incomplete information on soils available to students. In addition to concerns about a decline in student participation in learning science, in particular soil science programs and courses (Baveye et al., 2006; Hartemink et al., 2008), the key challenge as to how best to effectively engage and address student deficiencies in soil education remains.

Although the content of soil science is situated between the natural sciences and professional practice (Philip, 1991), and a unique aspect of soil science is the interaction between basic research and its application (Hartemink et al. 2014), this aspect is neglected in most countries. Soil degradation has become a global problem whereas among the soil concepts worst taught are “soil functions”, “soil management”, and “agricultural usefulness”. The concept “soil degradation and protection” usually covers only the degradation part without addressing its protection. Emphasizing the importance of providing examples of improvements to degraded soils because of their pivotal role in sustainable development is necessary. Similarly, the limited examples of solutions to soil degradation issues leads young people to believe, incorrectly, that little or nothing can be done to resolve such issues. Textbooks lack examples of specific actions taken to address soil conservation and degradation. No mention is made of reports produced by international expert teams, such as the unprecedented report of the

Table 4
Percentage of students enrolled in schools and attending an education level compatible with their age (based on OECD Online Education Database and UNICEF Global Database, (https://data.unicef.org/topic/education/overview/), (Organization for Economic Cooperation and Development OECD, 2022), (https://ourworldindata.org/global-education).

Percentage of 15- to 29-year-olds enrolled in school, by selected levels of education, age, and country: 2018			
Country	All levels of education[1] 15 to 19 years old	20 to 29 years old	Secondary education[2] Total
Australia	83.7	36.3	64.7
Chile	81.5	28.9	64.4
Czech Republic	90.3	23.7	85.1
Estonia	88.2	24.4	82.4
Finland	86.7	40.1	83.8
France	87	22.6	66.2
Germany	86.4	34.1	75.1
Hungary	83.3	22.5	73
Israel	66.2	20.3	61.4
Italy	85.3	24.6	76.4
Japan	no data	no data	57.9
Korea	84.3	28.9	55
Latvia	93	28.3	84.2
Lithuania	93.7	28.4	80.4
Mexico	62.5	18.6	51.5
Poland	92.6	28.4	83.7
Portugal	88.9	23.2	73.2
Russian Federation	87.3	18.7	46.9
Slovak Republic	83.8	17.6	77.4
Slovenia	94.3	33.5	82.5
Spain	87.2	31.5	69.4
Switzerland	84.9	27.7	81
Turkey	70.9	42.2	59.9
United Kingdom	83.3	20.1	66.1
United States	83.7	24.4	64.2
Percentage of children of a given age that are attending an education level compatible with their age or attending a higher education level: 2021[3]			
Belarus			88
Brazil			65
Bulgaria			86
China			60
Ethiopia			8
Gabon			16
Georgia			85
India			64
Kenya			36
Mongolia			87
Niger			4
Romania			90
South Africa n/c			85
South Korea			95
Tunisia			59
Uganda			8
Iran			no data
Morocco			no data
Uzbekistan			no data

[1] In addition to secondary and postsecondary education, may include enrollment in International Standard Classification of Education (ISCED) 2011 level 1 (primary or elementary education).
[2] Refers to ISCED 2011 level 2 (lower secondary education) and level 3 (upper secondary education). Secondary education generally corresponds to grades 7–12 in the United States.
[3] Household survey data from the past 10 years are used for the calculation of completion rate. For countries with multiple years of data, the most recent dataset is used.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Scholes et al., 2018).

There are many functions of soil which could and should be presented in greater detail. Understanding of all relevant functions may be difficult for students but brief mentions of such functions can be included in textbooks as a foundation for higher education (Mori et al., 2020). In turn, soil management is essential for sustainability. According to The International Union of Soil Sciences (IUSS, 2016) the key to achieving the Sustainable Development Goals (SDGs) is the protection of soil resources and education for its conservation (Reyes-Sanches, 2020b).

Agricultural usefulness is one such feature that emphasises the basic function of the soil: supplying food, fiber, and fuel. Insufficient or inadequate knowledge in this area may have serious consequences for the future. Many educational programs lack the ability to demonstrate to students that the food which sustains their lives depends on soil, as well as making them aware of the daily efforts of farmers and other agricultural practitioners (Hirai and Mori, 2020). In many countries there is a lack of soil science content and the lack of enquiry teaching materials for schools (Moebius-Clune et al., 2018). Equally, there are insufficient field activities to present students with appropriate practical skills.

According to Field (Field et al., 2013; Field et al., 2017) students will benefit from the interplay of teaching and research, and field-school (practical abilities) is much more effective than traditional lecturing. Field lessons are one of the most effective techniques in teaching soil science (Kasimov et al., 2013; Hartemink et al., 2014; Al-Maktoumi et al., 2016, Urbańska et al., 2019; Smith et al., 2020). Siebe et al. (2017), site three aspects which should be considered in order to increase awareness about soils. In the human psyche, there should be a desire for "soil care", the participation of the body should be provided by experiences ("learning by doing") and spiritual connections to soils create emotional links to them. All three aspects can be perfectly fulfilled with field lessons (Urbańska and Charzyński, 2021).

A separate problem is inadequate soil training for those teachers who have often not taken any soil science courses at university level (Huang et al., 2014; Huang et al., 2015; Huang and Hseu, 2020). The teachers in the countries which formed the focus of this research held qualifications on many different levels. In Tunisia teachers have a license or bachelor's degree in natural sciences. Teaching licensure requirements differ in each state in the USA. The board of education in each state determines the necessary requirements for obtaining a teaching license. Typically, at high school level, teachers must have an undergraduate degree in a related subject (a few states require a graduate degree), complete a teacher preparation program, and pass several standardised exams. In Italy as well as in many other countries (for example, Russia and Poland) teachers typically possess inadequate skills for soil science teaching. Many schools (for example, Estonia, Mexico, Brazil, Argentina, Germany, and Poland) have resolved this issue with the help of different projects in collaboration with universities. Teachers actively use workshops, worksheets, practical exercises in real life, as well as utilizing using modern IT tools. Capra et al. (2017) proposed the use of soil songs in teaching activities as a powerful means of communication; several teachers coming from different disciplines (for example ecology and climate science) already use songs, and music in general, in their activities (Turner and Freedman, 2004; Bucchi and Lorenzet, 2008; Huang and Allgaier, 2015). Recognizing the intrinsic ability of music to share emotions, intentions, and meanings, even among people with different backgrounds, can prove to be advantageous (Miell et al., 2012). Xylander (2020) suggested that soil science education should be experienced with all the senses (for example, in school gardens). Stirring the viewer's imagination can also be done through storytelling, which is what happens during soil exhibitions at the Senckenberg Museum für Naturkunde Görlitz (Xylander, 2020). During the summits in Tbilisi (1987), Rio de Janeiro (2000) and Johannesburg (2002), both the UN and UNESCO emphasised the importance of building teacher capacity so as to enable teachers to teach and support the education of children and young people (Reyes-Sanches, 2020b). This in turn will prepare the next generation to contribute meaningfully towards the solving of present and future environmental problems.

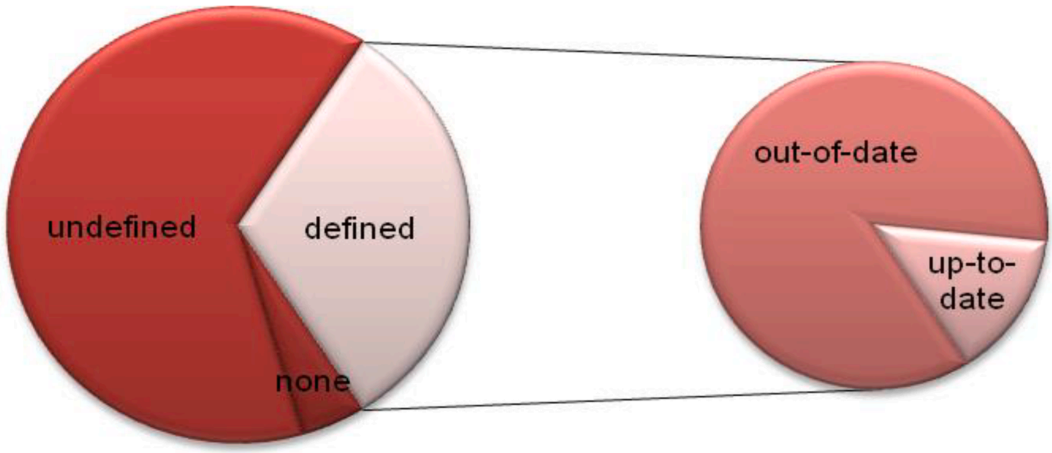

Fig. 11. Type of soil classification used in textbooks.

4. Summary and conclusions

Globally, there are many problematic issues and disparities in textbooks at the high school level. Soil scientists need to be aware that the current generation of students in many countries are unaware of the importance of soil. Universities offering soil science courses should appreciate that it might well be extremely difficult to recruit students to soil science as most are unaware that the discipline even exists (Brevik et al., 2020). There is a need to develop appropriate methodological and instructional guidelines to make future generations aware of the study of soil science at more than just a superficial level. This process should not only concern a particular country but should become an international goal for everyone with an interest in soils. Soil science societies could develop common guidelines for global soil science education and even create educational platforms with soil science content delivered in a form that caters to the needs of young audiences. It should also be remembered that young people respond favorably to modern, digital teaching methods. Role playing and spatial data applications may well increase students' motivation, interest in learning, and improve digital literacy (Urbańska et al., 2019). Teachers should provide students with the opportunity and time to develop their own thinking, creativity, and action; only the combination of such methods with appropriate soil science content in textbooks, supported by field lessons, can shape a "new" citizen of the world who is ready to face the future challenges facing our planet. From this perspective, the German concept of "from idea to action" (Xylander and Zumkowski-Xylander, 2018) should be applied in more countries worldwide. Some educational solutions will help to achieve this goal. For instance, theoretical issues in the field of *knowledge of facts* (soil profile, soil genesis, country, and world soils, etc.) should be discussed in connection with the issues based on the *understanding* of processes and the ability to *apply* this knowledge in practice (minimizing the forgetting of factual data). Much greater emphasis needs to be placed on educating students about the functions of soils and the role that soils play in the environment (a key aspect due to the multitasking nature of the soil cover). Students should be able to draw conclusions and notice the relationship between soil types and their management (increasing the conscious management of soil resources). Field lessons (with the participation of soil science specialists) should be an integral part of high school soil education ("learning by doing"). Much work has yet to be done, but this should not be seen as a deterrent but, rather, as a fresh challenge for soil science academics and scholars worldwide. Without an improvement in the main issues around soil science teaching highlighted in this paper, soil scientists will be unlikely to solve all the outstanding issues affecting the fragile, non-renewable soil resource on their own. It must be emphasised that several positive examples have been identified globally, thus presenting a fundamental foundation for further improvements. Educating young people, starting at the compulsory school level, and bridging the gap in terms of knowledge between higher and lower educational levels, can be seen as one of the most effective solutions. It is often said, but now truer than ever, that future generations will be faced with, and will be required to solve significant challenges in terms of soil resource protection and management. Can soil science have a future without facing the *educational* aspects surrounding these issues?

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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