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# The importance of soil education to connectivity as a dimension of soil security

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ABSTRACT

The connectivity concept within soil security posits that people need to have a connection to soil in order to properly value it. Showing how soil is important in everyday life can create connections to soil, because people care about things they see as impacting their quality of life. Education can demonstrate these connections and may take place in either formal or informal settings and over a wide range of age groups. Creating an effective educational environment is critical, which involves understanding the specific group being addressed, including their existing knowledge of and interest in soil. Soil scientists increasingly teach to student groups that need to know about soils within their chosen careers but are not necessarily training to be soil specialists. Within this formal setting, education that demonstrates the various functions that soils provide in support of human well-being may be important to connectivity because it clearly demonstrates the impact of soils on peoples' lives. In less formal settings, it will be important to identify concepts that will resonate with the public or stakeholders, such as terroir, soil health, or soil security, and to effectively reach these groups with a message built around these concepts. Social marketing, social media, storytelling, soil apps, and soil games are all approaches that have promise to deliver the desired message, therefore creating connections between people and soil.

## 1. Introduction

Soil scientists are constantly seeking ways to better connect non-soil scientists to soil issues. Several ideas have been proposed to accomplish this, including the terroir concept, soil health, soil quality, and soil security (Brevik et al., 2019a), as well as demonstrating the importance of soil in meeting major policy goals such as the sustainable development goals (Keesstra et al., 2016) or zero net land degradation by 2030 (Brevik et al., 2015). Soil security was proposed, in part, to create a bridge between scientists and policy makers (Koch et al., 2013). Other security concepts, such as food security, water security, and energy security already enjoy wide acceptance among many policy makers around the world, so soil security has been viewed as a way to take advantage of this "security" recognition to advance needs within soil science (McBratney et al., 2014).

Five dimensions of soil security have been proposed to assess the various parameters that make up this concept, one of these is connectivity. As envisioned by McBratney et al. (2014), connectivity brings a social aspect to the soil security concept, the idea that people need to have a connection to soil in order to properly value soil. More specifically, connectivity incorporates the knowledge and resources necessary to properly manage soil, views soil management as a long-term commitment that involves many generations, and raises the possibility that we need a soil ethic. These aspects of connectivity have strong links to soil knowledge, which means they would be supported by well-considered educational strategies. The goal of this paper is to show how soil education is important in creating connectivity between people and soils within the concept of connectivity as one of the five dimensions of soil security. This was achieved through a review of the soil education and soil security literature.

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## 2. Soil concepts linked to connectivity

People generally will not be concerned about something, like soil, unless they see its importance in their own lives (MacEwan et al., 2017; Brevik et al., 2019a). There are several places where the importance of soils to everyday life can easily be demonstrated. The most obvious of these is probably food production (Pozza and Field, 2020), and classes in soil and agronomic sciences often make this connection quite clear. However, as discussed later in the paper, classes that cover soils are not a regular part of education for students from about 6 to 18 years old (henceforth referred to as primary and secondary education) in many countries, and soil science is not a regular part of most university level programs. Other places where soils are important to modern society include (but are not limited to) provision of medications/pharmaceuticals, building materials, and clothing (Brevik et al., 2019b) as well as water storage and purification (Neary et al., 2009) and landslide prevention (Xiao et al., 2017). While most people would probably agree these are important to providing a good quality of life, they are probably less likely to associate these ecosystem services with soils than with food production. Regardless of the actual level of current recognition, demonstrating the importance of soils in providing ecosystem and societal services, such as those mentioned, offers opportunities to make connections (i.e., address the connectivity dimension of soil security) with people.

It has also been well demonstrated that degrading our soils leaves them less capable of providing ecosystem services (Baude et al., 2019), something that is routinely covered in soils and agronomic classes. Also, some aspects of soil degradation (e.g., erosion) can be easily demonstrated even to the relatively untrained eye. Dealing with such problems reinforces the importance of soil stewardship. Therefore, there are ample opportunities to increase soil connectivity with people by engaging in some basic soil science education. To this point the major challenge soil scientists have faced is establishing a place within the educational system to regularly engage people in soil education.

## 3. Current education practices that support connectivity

Soil science is a unique discipline characterized by the interactions between fundamental research and its applications (Bouma, 2001). It is also a highly interdisciplinary field that has its origins in other related fields. Biology, chemistry, geology and physical geography all contributed to the early development of soil science and continue to be fundamentally linked to soil science (Brevik and Hartemink, 2010). The complexity of many present-day issues further emphasizes the need for interdisciplinary soil science research and education (Zhuang et al., 2015). Therefore, education needs to provide students with the opportunities to gain disciplinary knowledge and skills, to be able to make connections between soil science fundamentals and their applications in a variety of ecosystems, and to communicate effectively with a range of stakeholders, including the public, government officials, and others (Field et al., 2017).

Many undergraduate soil science programs, similar to other interdisciplinary disciplines (e.g., environmental science), must devote a substantial proportion of their curricula to supporting subjects. Finding the proper balance between supporting coursework and soil science specific coursework is not an easy thing to accomplish, and postsecondary institutions are implementing a wide variety of approaches to address this issue (Brevik et al., 2020a). Assuming that the five classical subdisciplines [soil genesis and morphology (pedology), soil biology, soil chemistry, soil mineralogy, and soil physics] are central to soil science (Churchman, 2010), a well-designed soil science curriculum would include study in each of these areas; and in the most straightforward approach this would give a minimum of five courses. Alternatively, these subjects could be covered in other ways that do not require stand-alone courses. For example, soil genesis and morphology and soil chemistry courses could cover concepts from soil mineralogy since soil mineralogy is a major part of understanding both these other topics. Some of these five disciplines could be covered in other courses focused on providing specific direction to a soil science curriculum depending on the type of career a student wants to pursue or the particular area that a given university wants to focus in (e.g., agronomy, forestry, natural resource restoration). Examples of such courses that are commonly taught include (but are not limited to) environmental soil science, soil health/quality, soil management and/or conservation, soil biogeochemistry, and urban soils. While these courses may not represent the central core of the field, each of them uses concepts from some combination of the five classical subdisciplines and directs them to specific applications within soil science.

Alternatively, the approach may shift from properties to functions, which would require a different organization of content. Approaching soils through separate subdisciplines has led to the loss of an integral and integrated understanding of the soil and its functioning (Vogel et al., 2018). Recent studies have found that universities in several countries around the world have experienced a shift from teaching soil science to disciplinary soil science majors to teaching students of related disciplines such as environmental science, renewable natural resources, geography, and geology (Diochon et al., 2017; Brevik et al., 2020b). Hence, a considerable portion of soil science teaching is delivered to non-soil science majors, presenting instructors with a challenge to balance teaching in-depth soil science concepts with creating interest and a sense of wonder about the soil and its roles in various global issues, in other words, to create connectivity with soil. To tackle issues such as environmental and soil degradation and ensure connectivity in soil security, it is important to approach soils as a system, assuming their complexity and dealing with systemic inter-relations (Turner, 2021). This is because soils are complex entities that are very difficult for humans to understand. Taking a systems approach has been shown to result in better understanding of soil issues and improved management choices (Turner, 2021).

Probably the most obvious choice for a course in need of restructuring is the traditional introduction to soil science course to be more interdisciplinary and integrative in its nature (Groffman et al., 1991; Amador and Görres, 2004). This course is not just a fundamental part of many soil science and soil science related programs, but it is also the most common (and sometimes only) soil science course offered at many postsecondary institutions (Diochon et al., 2017). Hence, instead of going over details of the five classical subdisciplines of soil science, a better approach might be to shift the focus of these introductory courses to center them on soil functions, allowing students to gain a perspective of soil as an ecological integrator. The traditional role of introductory soil science courses, or any introductory course in other disciplines, has been to expose undergraduate students at the beginning of their program to their chosen field of study (Druger, 2006). As such, introductory soil science courses have tried to connect students majoring in soil science to their discipline, but in its traditional format introductory soil science courses have not necessarily connected students who are not majoring in soil science to our discipline.

One way forward in restructuring the soil science curricula could be by implementing the emerging concept of '*know*', '*know of*' and being '*aware of*' soil (Field, 2019). This concept is student-centered, and it frames learning environments focused on developing either deep soil science knowledge (*know soil*) or the application of soil science knowledge across a range of subjects where soil science is only part of learning (*know of soil*), as needed in the given student's educational goals. In turn, this allows development of curricula with a system approach built on disciplinary expertise combined with a multidisciplinary learning environment, motivated by real-world issues. This concept requires teachers to have expertise in soil science, reflect on their own development as a teacher, and contribute to innovation in soil education, while being committed to betterment of the soil science curricula in long term. As any good educational practice this requires focus on scholarship, practice, the learner, and knowledge (Field, 2020a). Casting soil

education within the *know soil* or *know of soil* framework encourages connecting students to soil at a level appropriate to their career goals.

The disciplinary approach commonly used in soil science does not fully embrace the need of creating and growing perception and awareness of soils and their importance for the environment and society. The first step is to recognize that educating people means educating about soils, increasing their knowledge and not necessarily about the science of soils. This requires a holistic and open approach to soils related to the meaning and significance it has in people's lives.

Tapping into people's inherent competitive streak is a powerful way to engage with soil. The soil judging competition has a long history beginning with its creation in the United States of America in 1961 (Rees and Johnson, 2020). In 2012, countries such as Australia adopted this approach to engaging with soil and the first international competition was held at the 20th World Congress of Soil Science in Jeju, Korea and has been steadily building globally ever since (Cattle et al., 2014; Field et al., 2020). The benefits of this approach include not just deepening of students' knowledge of soil description and interpretation, but also learning about team building and teamwork. The internationalization of this activity exposes students to the diversity of soil globally and provides opportunities for cross-cultural exchange and building a wider social network exposing students to 'others' understanding, values and ethical priorities of soil and its function. The coaching philosophy that underpins the training and preparation for soil judging makes the experience fun and means this is not limited to those who aspire to be soil experts (i.e., *know soil*), but can also include individuals from other cognate disciplines who will '*know of*' soil (Field et al., 2020).

Convincing postsecondary students that soil science is a viable area of study and profession is an important task with an overarching impact to the whole of society and its capacity to address important global issues. Yet, it is difficult to recruit students to a career if they are not aware that the discipline exists (Chaloupka, 2015; Lawrence, 2021). The integration of soil science into the primary and secondary curricula as well as informal education is important because it addresses the broad issue of the lack of public knowledge about the importance of soils (Ayala, 2004). A recent review of elementary, middle, and high school programs around the world revealed that soil science is explicitly mentioned in the high school curricula of several Canadian provinces, various states in the United States and in South Africa, but not as frequently as other natural sciences such as geology and astronomy (Hayhoe, 2013). Soil science contents are also part of the primary and secondary curricula in Brazil, as stated in the national curriculum governmental guidelines (Brasil, 2018) for sciences (primary) and biology and geography (secondary).

In the U.K., soil science is not directly part of the primary or secondary curricula. This is further complicated by the devolved nations developing their own national curricula and multiple exam boards delivering examinations in subjects that cover different aspects of the curriculum. In primary curricula in England, soil is explored in allied subjects such as science or geography e.g. "pupils could explore different soils and identify similarities and differences between them and investigate what happens when rocks are rubbed together" (Department for Education, 2013). There is no explicit reference to soil in primary curricula in Scotland, Wales, and Northern Ireland. In secondary curricula in England, soils are covered in geography, but appear mainly as minor parts of other topics (e.g., Climate and Ecosystems; Forests Under Threat; Weather [soil moisture]). In Scotland and Northern Ireland soils are taught in more depth in the secondary curriculum in environmental science but are not covered in geography.

Despite these encouraging examples of the integration of soil science into the primary and secondary curricula, in many instances the depth to which the soil science subject area is explored depends on the teacher's interest and experience as well as the provision of resources that enable them to meet the teaching and learning requirements regulated by their educational authorities (Field et al., 2020b).

Over the last few decades, several papers have pointed out that soil science has been largely overlooked in primary and secondary education systems globally (Bridges and Van Baren, 1997; Diochon et al., 2017). The initiative to incorporate soil science into primary and secondary classrooms cannot solely be left to schoolteachers, as they often lack an in-depth knowledge of the discipline themselves (Landa, 2004). Collaborations among higher education, government, public, and scientific institutions are essential for successful introduction of soil science concepts to primary and secondary classes (Margenot et al., 2016), and it is important that soil scientists become involved in communicating the relevance of our discipline. Some examples of initiatives of soil scientists' engagement in the education of primary and secondary science teachers and students include the "Soil 4 Youth" (https://soil4youth.soilweb.ca/) program in Canada, K–12 Soil Science Teacher Resources (https://www.soils4teachers.org/) in the United States, Science Learning Hub–Pokapū Akoranga Pūtaiao in New Zealand (https://www.sciencelearn.org.nz/), Soils in Schools supported through Soil Science Australia (https://www.soilscienceaustralia.org.au/training/soils-in-schools/), the Tea Compost for Schools (https://teacomposition.sydney.edu.au/about/), and On the Cutting Edge Professional Development Program for Geoscience Faculty (https://serc.carleton.edu/NAGTWorkshops/about/index.html). Other examples include involvement with extracurricular educational programs that focus on natural resources education (e.g., Envirothon, Science Olympiad) and collaboration with not-for-profit organizations such as museums and local and national associations of primary and secondary science teachers. The *Mão na massa* Project and the more than 70 soil education initiatives in Brazil have developed different ways to tackle soil education in schools as well as teachers' training and professional development (Lima et al., 2020), and the Ministry of Education in Japan decided to include the words "soil grains" in elementary and junior high school textbooks as one of the factors relieving sediment-related disasters after heavy rain events (starting in 2020). This was an outcome of many years of effort by soil scientists communicating with education sectors.

Another avenue to enhance understanding of the public about the importance of soil for food production is through urban agriculture. An increase in the popularity of community gardens and urban farms has been observed in many cities around the world (Turner et al., 2011), and school gardens have also become more common. For example, several high schools across Canada use their school gardens to teach students about the importance of soil texture and organic matter for soil water-holding capacity and plant available nutrients (Krzic et al., 2020). By allowing students to collect soil samples, which are then sent to a commercial laboratory to test for nutrients and other soil properties, students are engaged in data interpretation, observing how the nutrient requirements vary for different crops and different soils. This information can, in turn, be extended into mathematics to develop a budget for costs and potential revenues. These activities are also intended to instill a sense of stewardship of the land, to promote beneficial management practices in soils (Krzic et al., 2020).

## 4. Challenges to enhancing connectivity & some examples of how to overcome those challenges

### 4.1. Improving communication with different stakeholders

One of the main objectives of soil education in the modern era is arguably to effectively encourage stakeholders (people who are benefiting from soil functions, which is probably all of humanity) to act towards the improvement of soil security. Primary stakeholders related to soil security include policy makers to farmers, and many other consumers who might not understand how they are connected to soil security.

Over the last few decades, many soil scientists around the world have been actively advocating to policy makers to regulate soil-related issues (Koch et al., 2012). The "International Year of Soils", developed by the Food and Agriculture Organization of the United Nations (http://www.

fao.org/soils-2015/en/), which was followed by the "International Decade of Soils" (https://www.iuss.org/international-decade-of-soils/), by the International Union of Soil Sciences, and the concept of the "4 per 1000″ initiative (https://www.4p1000.org/) are examples of global activities related to soil security that have been advocated for by soil scientists. These activities have achieved a number of results, but many soil scientists had to do more than just publish papers with "soil security" as one of their keywords. The soil scientists involved in these activities need to understand the processes regarding the establishment of international agreements and legislation, as well as the efficiency of policy designs (Brown et al., 2021). In other words, for soil scientists to be effective in creating connectivity to soil, they need to understand different ways of creating those connections to people of different backgrounds.

Farmers are also important stakeholders regarding soil security issues and effective communication with farmers needs to be based on the understandings of their motivation. Farmer motivation towards environmental activities vary depending on factors such as the subsidy systems (Mills et al., 2018), farmer engagement in research (Salvia et al., 2018), and in social movements. Also, whether farmers will engage in environmental activities often depends on the availability of appropriate machinery (e.g., reduced tillage) and labor, thus soil scientists who communicate with farmers need to have the skills to comprehensively grasp the business side of farming.

Farmers rights to their land (securing land tenure) are now recognized as one of the keys for the sustainable use of soil, and soil scientists may need to be trained in this area. Particularly in many developing parts of the world, many farmers do not have a legally registered title to their land and this often leads to a soil security related issue. Farmers who own land are often assumed to use a broader number of management strategies and adopt best sustainable management practices earlier than farmers who rent their land (Fraser, 2004; Baxter, 2017). Even though insecure land tenure is a real obstacle to long-term soil conservation, it is not possible to assume that long-term leases will substitute for land ownership as other confounding variables such as crop history, governmental policy, and adoption of short-term management practices also play a role (Fraser, 2004; Baxter, 2017). For example, soil scientists need to have skills to come up with a program that pays farmers to use grassland set-asides, even for just one to four years, that over-rides the effect of insecure land tenure and creates incentives for owner-operators and tenant farmers alike to use crop management that protects soil quality in the long term.

To train soil scientists with good communication skills who can think in "different stakeholders' shoes", scientific communication courses can be an important inclusion in modern or future soil science degree programs. For example, consumers often link food security to soil security (Pozza and Field, 2020). Soil scientists need communication skills to link their choice of diet (or what to buy in shops) and soil security. Soil science education may include courses on human nutrition as well as basic environmental sciences (e.g., environmental labeling on food), it is important that we think about how much soil science courses should cover regarding such matters (Brown et al., 2020; Muller et al., 2019). However, these courses should not hinder the development of basic knowledge of soil science itself.

Many current soils students will pursue careers in fields other than soil science (environmental science, land management, agronomy, ecology, engineering, geosciences, urban land, etc.). Consequently, students' skills should be adaptable (Havelin et al., 2010), and undergraduate soil science education should enable students not just to acquire disciplinary knowledge, but to also develop interpretive and critical thinking skills and learn how to communicate contextual solutions to relevant stakeholders (Field et al., 2011). Several studies have reported that the level of knowledge in the soil science field is not the concern (Field et al., 2011; Masse et al., 2019), but graduates are lacking the necessary interpretive field experience and have poor communication (written and verbal) and critical thinking skills (often referred to as soft skills) (Havelin et al., 2010; Lobry de Bruyn et al., 2017; Masse et al., 2019). In order to improve soil science education at the undergraduate level, curriculum development should evolve as the soil science discipline evolves and encompasses new fields of study. Education should also focus on how soil science is integrated into many aspects of other disciplines and vice versa (Hartemink and McBratney, 2008). Reflecting on the feedback from stakeholders and those who teach, as well as from those who are learning, is important to maintain and adjust the level of skills necessary for a career with a soil science focus (Brevik et al., 2018; Hartemink and McBratney, 2008; Krzic et al., 2015).

### 4.2. Overcoming the academic silo structure

A notable decline in enrollment in agronomy and crop science programs in North America and elsewhere occurred during the late 1990s and early 2000s (Baveye et al., 2006; Collins, 2008) with corresponding declines in the enrollment of students in soil science courses. These declines were triggered by reductions in university budgets as well as several other interrelated issues. Many Faculties of Agricultural Sciences responded to the budget cuts by rebranding themselves as Environmental Sciences, Renewable Land Resources, Land and Food Systems, etc., and this also involved re-labeling of some of the soil science courses. In addition, budget cuts also forced university administrations to focus on the majors of greatest popularity (i.e., enrollment) and undergraduate soil science majors traditionally had a low enrollment. Consequently, many soil science programs and courses ceased to exist. The traditional university structure of housing disciplines in specific faculties (a.k.a. silos), accompanied with a financial structure that allocates funding to faculties based on the number of students taught by each faculty, makes it difficult for soil science courses to attract students from other units. In order to enhance student enrollment in soil science courses and also allow students from non-soil science majors to know of soils as Field et al. (2020) have indicated, the rigid academic structure, driven by a financial model that favours the silo approach, needs to change.

One potential way to bring this change is through the collaboration of soil instructors from different institutions and sharing of their ideas and reflections about education. Such collaborations involving reflections by individuals, between groups, and within postsecondary institutions bring new opportunities to question and break away from the entrenched way of thinking about teaching process (Fullan, 1999; Hoban and Hastings, 2006). To strengthen these collaborative efforts, one should also create opportunities to consult and reflect on feedback from external stakeholders and industry (Field et al., 2013). For example, an external advisory board can be used to provide annual reviews of degree programs. Similarly, it is not uncommon to find instructors with soil science expertise in multiple departments on a university campus, such as agriculture/agronomy, biology, engineering, forestry, geography/geology, etc. (Brevik et al., 2020b). Many environmental science programs, for example, operate on an interdisciplinary model that brings together faculty from multiple departments to offer the degree program, and soil science, at least at some universities, may need to consider a similar interdisciplinary, multi-department model to provide strong training to future students.

Also, soil scientists themselves might need to break their traditional idea of research and actively take leadership roles in starting multidisciplinary projects. Many large-scale projects require scientists to meet the sustainable development goals (SDGs) and directly link to policy making as well as the involvement of stakeholders (often in addition to publishing scientific papers with high impact). To achieve these rather contrasting goals, soil scientists should collaborate more with, for example, social scientists who research public awareness and consensus among stakeholders, and engineers who are studying sensing devices such as satellites to microsensors. Many universities have "research administrators" who should be linking the different "silos". Communicating with the research administrators to help them understand soil

security can be one of the first things done by many soil scientists to overcome the academic silo structures.

### 4.3. Lack of awareness about the importance of soil & finding ways to better connect to society

#### 4.3.1. Create meaningful communication about soils. The meaning of soil to different groups

Soil is an academic term that has different meanings to different disciplines and little meaning and significance for many people in general. In scientific fields of study and research the term soil is described differently from geologists to agronomists, from engineers to biologists. In most cases it encompasses the idea of a substrate, a basis, a mineral material, which leaves out a major characteristic of soil, that is, its biology. Soil only is soil because its dynamics and functions are driven by a multitude of organisms. On the other hand, the public in general uses a variety of terms to refer to soil and those terms result from a social construction related to people's life experiences, history and contexts. Research by Muggler et al. (in press) showed that the words used to describe soil by people from different origins, urban, rural or rur-urban, are distinct and are more numerous for the two last groups. Moreover, the words have associated meanings related to belonging, place of origin and ancestry, showing their natural connection to the soil. Conversely, words used by urban people are more related to mud, dirt, impure and waste while not related with the place where food is produced, showing more detachment than connection. Research on soil health gives similar results, with regional variations in the words used to describe a healthy soil (Lobry de Bruyn and Abbey, 2003; Krzywoszynska, 2019a).

These findings show that much needs to be done to reach the connectivity dimension to make soils secure and keep them healthy and functional for the future. A first approach is to look at the cultural and social aspects of soils that are meaningful to people. Soil science communication and outreach can then be adjusted to connect to them, establishing a dialog between types of knowledge. Another important aspect is to start communication with common sense, so-called empiric to scientific knowledge, in a way that engagement with the science of soils is obtained step by step, starting from the context and understanding of the stakeholder. Furthermore, it is important to consider that awareness is a personal characteristic, so it is rooted in emotions and subjective aspects that are usually discarded or devalued in science, despite the fact they are the roots of any commitment and connectivity, even to science.

#### 4.3.2. Concepts the public connects to

People care for things that they value (Underwood and Morrison, 2011). With this in mind, the big question for soil scientists becomes, how do we get people who do not study soil to care about soil (e.g., Krzywoszynska, 2019b)? Brevik et al. (2019a) proposed concepts such as terroir, soil health, soil security, and food security as ways to potentially accomplish this. The underlying idea in each case is to tie soil to something that people outside of the soil science world care about. The concept of terroir has been quite successful at connecting people to the land that their food comes from for several speciality products such as wine, cacao, coffee, olive oil, and others (Vaudour et al., 2015). For those who are very connected to their food, such a concept may also help connect them to the soil their food grew in. Similarly, soil health and food security both have wide-spread acceptance from and meaning for many farmers, agribusiness executives, and policy makers (Harris and Bezdicek, 1994; Santiago-Brown et al., 2015; Carlisle, 2016), so tying these concepts to soil may help create connections between soil and the non-soil science community. In many ways soil security incorporates aspects of these concepts into its overall structure but also extends beyond them, particularly with respect to the social aspects of soil (Brevik et al., 2019a). Between this and the ties to other security concepts (e.g., energy, food, and water security), soil security offers a good possible way to link the public to soil.

Concepts that non-soil scientists might relate to, such as soil health, soil security, etc., are only one part of the total picture. The next step is being able to reach people with the information we want to communicate. This has traditionally involved marketing efforts through media such as radio, television, or print, which can be quite expensive. However, in the modern world there are many new options available, with varying advantages and disadvantages (Fig. 1, Table 1).

#### 4.3.3. Social marketing

Traditional marketing focuses on selling a product, good, or service. Social marketing seeks to change people's behavior in a way that would be beneficial to society (Kotler, 2008). Social marketing techniques could be used to encourage behaviors that would improve soil security as part of a connectivity strategy within the soil security concept. These efforts could be direct, such as discouraging soil contamination through changed behaviors, or indirect, such as taking advantage of some consumers' willingness to pay premium prices for food products that are produced in ways that build soil security, thus encouraging farmers to produce their crops in a way that gets those premium prices (Chen, 2017). The major drawback to social marketing is time and expense. The target audience needs to receive the social marketing message repeatedly, sometimes over a period of years, for it to work, which requires a major investment of time and can become quite expensive (CCHD, 2018).

#### 4.3.4. Media and social media

Several high-profile documentaries with leading public figures and celebrities have highlighted the climate, biodiversity and environmental crises (e.g., An inconvenient truth, 2006; There's something in the Water, 2019; Blue Planet, 2017). Environmental films and documentaries are primarily used to raise public awareness and engagement in environmental issues (increase connectivity), with calls to action to motivate a movement around a campaign that can translate into social and/or behavioral change. Many documentaries have successfully raised awareness and concern for environmental issues, some cite the "Attenborough effect" where single use plastic declined in the UK in response to the call to reduce marine plastic in the documentary Blue Planet (Hilderbrand, 2020). However, documentaries have not necessarily resulted in wide-spread social change in the behavior of individuals or a policy change (Nolan, 2010; Dunn et al., 2020). In addition, those watching such documentaries will usually have an underlying interest in nature or the environment, so detecting a behavior change can be confounded by this bias.

Most environmental films or documentaries focus on emotive issues such as animal extinction, biodiversity loss, climate heating and plastics, yet there are very few mainstream features commissioned on soil. Dirt! The Movie (http://www.dirtthemovie.org/) was released in 2009, Symphony of the Soil (https://symphonyofthesoil.com/) came out in 2013, and the Soil Science Society of America (among others) financially supported Between Earth and Sky (https://betweenearthandskymovie.com/), which was produced in 2016. More recently a documentary on soil heath and regenerative agriculture (Kiss the Ground, 2020) featuring Woody Harrelson (the Hollywood actor) has received nearly 10 million trailer views. However, to our knowledge there are no evaluations of the impact of these movies on public perception or awareness of soil or changing behaviors. These documentaries are also made with the best of intentions, but they do not always provide realistic views regarding how meaningful changes can be achieved (Amundson, 2021).

Celebrities have become advocates for environmental issues and have been used to endorse campaigns in environmental conservation (Olmedo et al., 2020), yet there is little specific evaluation of the effectiveness of the endorsement on achieving the campaign objectives. The selection of the celebrity is also important when considering the audience one wishes to reach, to ensure a connection of the target audience to soil through this celebrity 'mediator'. In many cases familiarity with the public figure or celebrity ensures connectivity to the

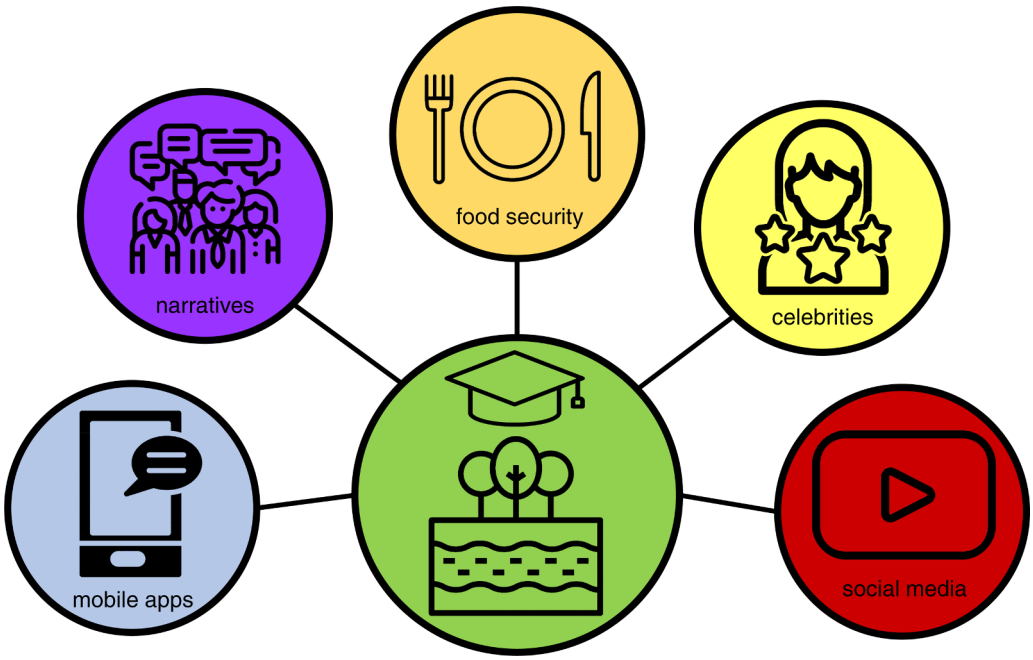


**Fig. 1.** Methods for soil connectivity. Icons created by Tippawan Sookruay, Dinosoft Lab, P Thanga Vignesh, Symbolon, Noura Mbarki, Sumit Saengthong from the Noun Project.

cause, such as using recognizable ambassadors, often well-known actors, models or socialites. This familiarity can also be extended toward 'ordinary people', where adults in the U.S.A who were most familiar with Greta Thurnberg showed an increased willingness for action against climate change; the "Greta Thurnberg effect" (Sabherwal et al., 2020). Familiarity, authenticity, and shared values are key components of connectivity between the audience and celebrity or public figure, and the advocated environmental cause. Could we utilize this celebrity effect to advocate for connecting (or reconnecting) people and soil?

Social media platforms, rather than 'legacy media' (TV, newspapers), are used for knowledge exchange in soil science. The most viewed content related to soil on YouTube ("soil") and Instagram (#soil) are linked to gardening, growing or agriculture. Thus, the content is aimed primary at connecting audiences engaged with these practices, and not the wider public. YouTube also serves as a complementary online platform for agricultural extension activities, primarily focused on soil health and regenerative agriculture (e.g. https://www.youtube.com/user/NDSUSoilHealth/ or https://www.youtube.com/user/TheUSDANRCS). For the farming community, peer-to-peer networks have always been important and trustworthy sources of information and advice. This has also been demonstrated on social media, where Twitter was used to increase farmer-to-farmer information flow on the adoption of no-till in the U.K. (Skaalsveen et al., 2020).

#### 4.3.5. *Storytelling and narratives*

Storytelling has long been recognised as a tool in science communication to non-expert audiences though narratives, anecdotes and personal experiences (Dahlstrom, 2014). For increased connectivity to soil we should be making soil information relevant and engaging for the public. This connectivity can be achieved through sharing soil information as a narrative that has emotional and cultural affinity with the public, rather than just presenting facts and figures. A number of popular books frame soil within experiences of rural life, farming and regenerative agriculture that utilize personal experiences and stories (Montgomery, 2017; Brown, 2018). Yet these are focused on audiences already interested in farming and agriculture and not directed at those completely unfamiliar with soil. Teaching science through children's stories is a well-established method to provide meaningful context to classroom activities (Monhardt and Monhardt, 2006), with many books now published about soil for younger readers. However, there are no specific studies that have evaluated the student's connectivity with soil immediately after reading these books, or in later years.

Creating narratives outside learning environments is another way to connect people with soil through shared narratives and stories. The Soil Voices (https://soilvoices.org/) project provides a space to collect stories and memories of people's connection, perception and knowing of soil. This project discovers narratives from non-scientific perspectives that document a personal connection with soil, and thus have meaning and relevance to non-specialists potentially discovering alternative routes to soil connection. This form of communication can create shared meanings and 'meaning- making' rather than knowledge exchange, making the soil connection personally meaningful for the individual. Creating fictional narratives can be an effective method for narrative persuasion, when presentation of scientific facts is not effective or engaging. Fictional stories can change attitudes and behaviours (Moyer-Gusé and Dale, 2017) through transportation into a fictional world and creating vivid imagery. A long-running BBC Radio4 drama 'The Archers', about a fictional rural village community, has run stories on soil health and soil erosion that were woven into the lives of the fictional community. Another example is the FAO children's books about soils (https://www.iuss.org/international-decade-of-soils/the-iuss-goes-to-the-school/). It is not necessarily the acquisition of scientific knowledge that changes public attitudes towards science, but rather the cultural meanings or connections of science, which can be evoked using fictional narratives (Davies et al., 2019).

#### 4.3.6. *Easy to use soil apps and games*

Apps tend to be focused on specific stakeholder groups (researchers, farmers and practitioners) requiring specific information about soils or to record observations or make soil management decisions (e.g. Hydric Soil, SoilWeb, Soilscapes, Soilmentor, Soilmapp. iSDAsoil, mySoil, SIFSS). These apps provide immediate information about the soil at the geolocation of the user, commonly describing the soil type and key soil properties summarised from national Soil Survey data. The information presented in these apps is often aimed at agricultural specialists and is technical in content, thus is not appropriate for a non-specialist to digest

**Table 1**
Methods for increasing soil connectivity with the public.

| Method | How it works /examples | Advantages | Disadvantages |
|---|---|---|---|
| Environmental concepts | Broad familiar frameworks (soil health, food security, soil security) | Widespread acceptance by certain sectors (e.g., farmers, policy makers) | Conceptual or global in context therefore little relevance for individual |
| Social Marketing | Marketing concepts to elicit social change | Successful campaigns can create meaningful change | Campaigns can be lengthy and expensive |
| Media and social media | Documentaries | Widespread accessibility to media and social media platforms | Targeting right celebrity for right audience |
| | Celebrity ambassadors/ endorsement | Familiarisation with celebrity and their values | Little evidence for social change after viewing/ engaging with popular content |
| | Social media platforms (YouTube, Twitter, Instagram) | Widely used, inexpensive way to reach large numbers of people | Response to messages rely more on the sender (the one who forwards it) than the content of the message |
| Storytelling and narratives | Storytelling and narrative content rather than facts and figures | Making content relatable and personal<br>Can potentially discover new routes for connectivity | Fictional storytelling can become persuasive narrative and cause issues in ethics<br>Soil stories often focus on agriculture or farming |
| Soil apps | Mobile apps, usually location based | On-the-go access to soil information<br>Educational games to increase soil knowledge | Soil information often only relatable to specialists<br>Limited to agricultural sector |

and immediately connect with the soil. Games that involve soil are also often aimed at people with an interest in agriculture or farming and therefore may not connect or engage with others outside these areas. However, the Starting with Soil app is an interactive animated platform aimed at engaging children with soil, where they can plant a seed, discover how long it takes for soil to form and drag a microscope over the soil. Other app games also involve soil and are related to agriculture, where players can take soil samples and soil data for precision farming (Farming simulator). The animated game approach has been demonstrated to be effective at communicating complex soil concepts in educational studies (Ulery et al., 2020).

## 5. Takeaway lessons

This literature review brought us to the following conclusions:

1 There probably is not a "one size fits all" approach to connecting non-soil scientists to soil. People of different backgrounds will likely respond to different approaches. Soil health has found an audience amongst many farmers and urban gardeners, terroir connects wine and other food aficionados to the land, including the soil, that produced the products they love, and soil security targets policy makers who are familiar with other security concepts (e.g., energy, food, and water security). Selecting a concept that resonates with a given group and shows the relevance of soil to their lives will increase the likelihood of achieving connectivity through soil education efforts.

2 Educating soil science specialists who can connect non-specialists to soil will require training in more than just soil and related sciences. It will be important to provide soil science students with training in the soft skills as well. Taking a systems approach to soil education has also shown promise for achieving greater connectivity to soil.

3 Education that accounts for the level of soils knowledge an individual is seeking to achieve (*aware of, know of*, or *know* soil) could also help form increased connectivity. We do not all need to be soil specialists, and in fact attempting to engage to the level of a specialist may turn some people off soils. However, engaging people with soils at a level that corresponds with their own interest levels could allow for the development of a sense of wonder about soil among more people, and thus increased connectivity.

4 Including soils in primary and secondary education curricula, museums, and other educational and outreach settings that reach many people who are not and will not become soils specialists has potential to increase soil connectivity; they may be sensitized and awakened to soils and its importance for life and society.

5 There are many modern opportunities beyond traditional educational options to make connections with non-soil specialists. These include social marketing, media, social media, apps, and digital games. All these options are relatively new, and it is important that their effectiveness be evaluated.

## 6. Concluding thoughts

Soil education is very important to connectivity, because it provides answers regarding why soil is important in our everyday lives. In seeking to educate people about soil, it is important that we make soil information more palatable and digestible to non-specialists. We can do this through both formal and informal education using a range of approaches, tools and techniques. Focusing on soil functions in formal education, and using fun digital tools, platforms, and other forms of engagement in both formal and non-formal education could be helpful. It is important that soil scientists be aware of the different connections that exist between soils and various stakeholders, and that soil scientists be prepared to engage with stakeholders in ways that connect with each stakeholder group. If key soil concepts and modes of communications outreach can be identified, soil security can be greatly advanced through soil connectivity driven by education.

## 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.

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