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Teaching and Researching in Soil Science

Issue Editors

Cristina Lull Noguera
Universitat Politècnica de València, Spain

Héctor Moreno Ramón
Universitat Politècnica de València, Spain

Luis Roca Perez
Universitat Politècnica de València, Spain

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Teaching and Researching in Soil Science

This Special Issue was open to teachers and researchers from any country, presenting experiences and reflections on research and teaching in soil science, with the possibility of relating both aspects, and/or showing teaching initiatives having close contact with research, trying to stimulate the initiation of students in tasks related to the first steps in research on soil science.

The Spanish Journal of Soil Science welcomed reflections on how to promote soil science globally, from different points of view and with different approaches.

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Table of contents

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Layla M. San-Emeterio,
Swedish University of Agricultural Sciences, Sweden

*CORRESPONDENCE
Cristina Lull,
clull@upvnet.upv.es

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Editorial: Teaching and researching in soil science

Cristina Lull[1]*, Héctor Moreno[2] and Luis Roca[3]

[1]Research Group in Forest Science and Technology (Re-ForeST), Research Institute of Water and Environmental Engineering (IIAMA), Universitat Politècnica de València, Valencia, Spain, [2]Department of Plant Production, Universitat Politècnica de València, Valencia, Spain, [3]Departamento de Biologia Vegetal, Facultat de Farmàcia, Universitat de València, Valencia, Spain

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Editorial on the Special Issue
Teaching and researching in soil science

Introduction

Soils are considered one of the fundamental natural resources for the development and sustenance of life on Earth. Soils are essential for the production of a wide variety of goods and services and for human wellbeing (FAO, 2015). It is essential that the study of soil – as the foundation of food production, a component of ecosystems, a habitat for diverse living organisms, a regulator of water resources, and a carbon sink – along with its conservation and degradation, be included in all levels of education. In this regard, the European Soil Charter of 1972 reminds that "Soil conservation principles must be fully included in teaching programs at all levels as an element of environmental education as such: at primary, secondary and university levels".

It is essential to introduce soils early in school curricula, underscoring their importance and raising awareness (Margenot et al., 2016; Črnec and Vrščaj, 2026). As Margenot et al. (2016) stated: *Curricula standards are a potential constraint and entry point for soil science*. However, the study of soils in compulsory education remains marginal in many regions (Tseng and Lai, 2025; Margenot et al., 2016; Virto et al., 2019), despite their central role in terrestrial systems. In primary and secondary education, students should understand and value the many functions of soil. A major challenge in teaching about soil is ensuring that young people understand the degradation processes that affect soil and learn about soil conservation measures. Moreover, young students should acquire not only knowledge but also skills and attitudes relating to caring for and respecting the environment in which they live, including the soil. In the field of soil science education, the book *Soil Sciences Education: Global Concepts and Teaching* (Kosaki et al., 2020) is particularly noteworthy, as it outlines the concepts, philosophy, and key principles for designing soil science education curricula across all levels, from preschool to adult learning.

In the article "The joy of teaching soil science" (Hartemink et al., 2014), Megan Balks mentions "The joy (and serious responsibility) of teaching soil science is to see some students awaken to the fascination, intrinsic beauty, and importance of our soil resource, . . .”. To promote and teach soil science, we need teachers who possess the necessary knowledge, confidence, and motivation (Brevik et al., 2022). The teacher’s job is to provide a solid foundation, spark curiosity, and equip students with conceptual and methodological tools that enable them to delve deeper on their own, ask questions, analyse data, and apply soil science to real agricultural and environmental problems. Therefore, a key point in teaching soil science is training teachers responsible for imparting knowledge about soil, mainly at the primary and secondary levels. Not all teachers at these educational levels have in-depth knowledge of soil.

Aran from the University of Lorraine points out that soil is virtually absent from school curricula and from the training of future schoolteachers. Therefore, to raise schoolchildren’s knowledge and awareness of soil, their teachers should receive training. Aran has written an article describing the use of project-based learning to help future primary school teachers explore soil science and learn how to teach it. These teachers are enrolled in a multidisciplinary bachelor’s degree in education. As part of this approach, the author explains how students design and implement an educational activity on soil in an elementary school classroom.

Turning now to the teaching and learning of soil science at the university level, for a soil scientist, teaching this subject involves some challenges. Among them, align soil science with sustainability. Al-Ismaily et al. argue that soil science curricula at university level should be redesigned from a sustainability perspective. This implies fostering in students a holistic understanding of soil systems as integral components of socio-ecological landscapes, and preparing them to contribute to interdisciplinary research, community action, and policy engagement. They address the urgent need to transform soil science education to ensure its alignment with the United Nations Sustainable Development Goals (SDGs). Soils contribute directly to at least 14 of the 17 SDGs, including those relating to food security (SDG 2, SDG 15 and SDG 13), water purification (SDG 6) and climate regulation (SDG 13). Their article provides guidance for educators who wish to prepare students to tackle the challenges of global sustainability through soil science. This study proposes a shift from viewing soil merely as a technical physical medium to understanding it as ‘natural capital’ and as a dynamic agent of sustainable transformation. The authors, drawing on case studies from the Bachelor of Science in Soil Sciences at Sultan Qaboos University (Oman) and Moscow State University (Russia), propose a forward-looking soil science curriculum focused on sustainability, systems thinking and real-world engagement. They also consider global stakeholder insights and integrative frameworks, such as One Health, Soil Security and the Pedometrics Challenges. Furthermore, the article highlights pedagogical innovations such as inquiry-based learning, debates and community projects. These tools aim to foster students’ interdisciplinary and systems thinking skills. Moreover, the authors call for a comprehensive curriculum reform that positions soil science not as a technical sub-discipline, but as a strategic catalyst for a sustainable planet.

Why is it important to understand soil? It is an essential resource for life on Earth and, moreover, is directly linked to global issues such as food security, access to water, biodiversity, and climate change. This is the perspective from which Reyes-Sánchez, in her article “An Educational Gaze From the International Union of Soil Sciences”, argues that the deterioration of soil resources generates environmental, social, and economic problems, leading to poverty, inequality, and resource conflicts. Therefore, in this situation, state soil science societies and, more specifically, the International Union of Soil Sciences (IUSS) have a moral obligation to promote soil protection through education and public awareness, as these are key tools to achieve the SDGs. However, although soil is essential to almost all the SDGs, the author emphasises that its importance is not explicitly recognised, reinforcing the need for transformative education worldwide that focuses on soil as a resource. It is not enough to transmit technical knowledge; it is necessary to cultivate values, attitudes, and environmental awareness about soil from an early age, thereby proposing a methodological shift beyond traditional teaching. More specifically, she speaks of a systemic approach in which soil acts as an integrating element for different disciplines. The IUSS presents two main priorities as its specific objectives: (1) halting soil degradation and (2) focusing educational efforts on children and young people, who will be the future stewards of this resource. To achieve these objectives, it proposes training students, scientists, and teachers to foster the ability to communicate science in an accessible way. It also raises the need to professionalise the teaching of soil science, integrating digital technologies and promoting the participation of governments, educational institutions, and civil society. A prime example is the “The IUSS Goes to School” project (Reyes-Sánchez, 2019), launched in 2019, whose main objective was to bring soil science to children and young people through educational materials, activities, and digital resources. Children’s stories, cultivation fact sheets developed by scientists, the publication of educational books in several languages, the organisation of competitions, and collaboration with international organisations such as the FAO were the main avenues of dissemination in this project, which aimed to promote practical application. As a main conclusion, Reyes-Sánchez calls on scientists and educators to move from words to action, actively engaging in the education of new generations.

Final remarks

Although a considerable body of literature has been developed on soil science education, much remains to be done to further raise awareness of soil science and its teaching across all sectors of society. It is necessary to promote and reinforce sustainable lifestyles among young people, which entails responsible and sustainable soil management. This will help ensure that future generations are aware of the need to take care of soil. Soil science education is evolving alongside new teaching methodologies, recent advances in soil science, and the integration of artificial intelligence in schools and universities. This requires rigorous educational research. Thanks to the International Decade of Soils (2015–2024), proclaimed by the IUSS, there has been a significant rise in awareness of soil health. During this period, various educational and outreach projects aimed at improving ‘soil literacy’ have been funded, such as LOESS, CURIOSOIL, etc. Other projects, such as PREPSOIL, aim to encourage teachers to incorporate soil-related topics into their teaching; to this end, the project identifies and

promotes innovative examples of soil education. We would like to express our gratitude to all the authors who have contributed to this Special Issue, as well as to the reviewers and the editorial team for their dedication to upholding the scientific quality of the published works.

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References

Brevik, E. C., Krzic, M., Muggler, C., Field, D., Hannam, J., and Uchida, Y. (2022). Soil science education: a multinational look at current perspectives. *Nat. Sci. Educ.* 51 (1), e20077.

Črnec, K., and Vrščaj, B. (2026). Raising soil awareness in primary and secondary schools through indoor workshops—designs and lessons learned. *Land* 15 (2), 206.

FAO (2015). *Revised World Soil Charter. Global Soil Partnership*. Available online at: https://openknowledge.fao.org/handle/20.500.14283/i4965e (Accessed March 10, 2026).

Hartemink, A. E., Balks, M. R., Chen, Z. S., Drohan, P., Field, D. J., Krasilnikov, P., et al. (2014). The joy of teaching soil science. *Geoderma* 217, 1–9.

Kosaki, T., Lal, R., and Reyes Sanchez, L. B. (2020). *Soil Sciences Education: Global Concepts and Teaching*. Stuttgart, Germany: Schweizerbart Publishers.

Margenot, A. J., Alldritt, K., Southard, S., and O'Geen, A. (2016). Integrating soil science into primary school curricula: students promote soil science education with dig it! the secrets of soil. *Soil Sci. Soc. Am. J.* 80 (4), 831–838.

Reyes-Sánchez, L. B. (2019). "The IUSS goes to the school®," in *The IUSS General Educative Project*. Available online at: https://www.iuss-goes-to-school.org.mx/booklets/ (Accessed March 10, 2026).

Tseng, W. Y., and Lai, H. Y. (2025). The feasibility of implementing a soil education framework in compulsory schools: a case study in Taiwan. *Soil Secur.* 20, 100195.

Virto, I., Imbert, B., Peralta, J., de Soto, I., González-Tejedor, I., Antón, R., et al. (2019). Oinez Basoa: Using school-managed afforested land for soil education in Navarre, Spain. *Span. J. Soil Sci.* 9 (3), 180–198.

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From Soil Pits to Global Goals: Pedagogical Innovations for a Sustainability-Oriented Soil-Science Curriculum Aligned With the Sustainable Development Goals

Said Al-Ismaily[1]*, Aminat Umarova[2] and Johan Bouma[3]

[1]Department of Soils, Water and Agricultural Engineering, College of Agricultural and Marine Sciences, Sultan Qaboos University, Muscat, Oman, [2]Soil Science Faculty, Moscow State University, Moscow, Russia, [3]Emeritus Professor of Soil Science, Wageningen University, Wageningen, Netherlands

Soil science stands at a critical juncture, facing both mounting global environmental crises and transformative possibilities in education. This study advocates a bold re-envisioning of soil science pedagogy, aimed at cultivating the inter- and transdisciplinary competencies essential for achieving the 2030 Sustainable Development Goals (SDGs). Drawing on in-depth case studies from Sultan Qaboos University (Oman) and Moscow State University (Russia), along with global stakeholder insights and integrative frameworks, such as Soil Security, One Health, and the Pedometrics Challenge, we propose a future-facing curriculum focused on sustainability, systems thinking, and real-world engagement. This study showcases pedagogical innovations—including inquiry-based learning, SDG-aligned outcomes, debate-based reasoning, and community-engaged research—that foster core skills in transdisciplinary problem-solving. Supported by empirical findings and curriculum analysis, this study demonstrates that reframing soil-science education around ecosystem services and natural capital can empower students to become solution-oriented professionals. Ultimately, we call for a global curricular reform that positions soil education as a dynamic catalyst for sustainability transformation rather than as a technical subdiscipline.

Keywords: ecosystem services, inquiry-based learning, interdisciplinary competence, soil science education, sustainable development goals

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Cristina Lull Noguera, Universitat Politècnica de València, Spain

****Correspondence***
Said Al-Ismaily,
esmaily@squ.edu.om

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INTRODUCTION

As global challenges intensify, ranging from climate change and biodiversity loss to land degradation and food and water insecurity, the urgency to cultivate a new generation of soil-literate professionals has increased. Soil science—an interdisciplinary field by nature—is fundamental to understanding and mitigating multifaceted environmental and societal threats. However, the prevailing paradigms of higher education remain inadequate to prepare students for the sustainability-driven futures that they are poised to inherit. Higher education institutions (HEIs) are uniquely positioned to produce graduates who can integrate scientific knowledge with practical, policy-relevant, and technological solutions (Kwok, 2018).

The United Nations' (UN) Sustainable Development Goals (SDGs) provide a timely and globally endorsed framework for soil-science education. Several SDGs, including SDGs 2 (Zero Hunger), 6 (Clean Water and Sanitation), 13 (Climate Action), and 15 (Life on Land), are directly dependent on the stewardship of soil resources.

The imperative to realign higher education with the SDGs necessitates a fundamental transformation in academic policy, curricula, and teaching methodologies. Accordingly, the UN and the United Nations Educational, Scientific and Cultural Organization (UNESCO) have positioned education at the heart of global sustainability efforts, emphasizing its pivotal role in fostering a more equitable and ecologically responsible world (Annan-Diab and Molinari, 2017; United Nations, 2015).

HEIs serve as catalysts in the transition toward sustainable societies by shaping individuals' capacity for critical reflection, ethical reasoning, and problem-solving (Sipos et al., 2008; Wiek et al., 2011). Specifically, SDG 4.7 calls for all learners to acquire the knowledge and skills needed to promote sustainable development by 2030 (United Nations, 2015), while UNESCO's (2020) Roadmap for Education for Sustainable Development *2030* provides strategic direction for integrating Education for Sustainable Development across higher education systems. Recent studies have confirmed this institutional responsibility. Avelar et al. (2023) highlighted that the strategic integration of SDGs within university curricula, research, and partnerships is critical to achieving sustainability outcomes. Similarly, Weiss et al. (2021) emphasized the structural and cultural patterns that influence curriculum reform processes, warning that superficial or fragmented integration risks undermine the transformative potential of sustainability education.

Soil is deeply interwoven with global sustainability imperatives, contributing directly to at least 14 of the 17 SDGs (Lal et al., 2021; Swan et al., 2024) by nutrient cycling, carbon storage, water purification, and biodiversity conservation.

Given the centrality of these ecosystem services—provisioning, regulating, supporting, and cultural—it is imperative that soil-science curricula be restructured to equip students with the interdisciplinary knowledge and practical skills needed to engage with these sustainability pillars holistically. Soil should not be taught merely as a physical medium or scientific construct but rather as a dynamic agent of sustainable transformation. This pedagogical shift requires framing soil as a form of natural capital—an asset that provides essential contributions to a continuous flow of ecosystem services essential for achieving the SDGs (Adhikari and Hartemink, 2016; Mikhailova et al., 2024). Soils contribute to ecosystem services in a multi- and transdisciplinary context; indeed, the definition of soil health by the European Union (2023) emphasizes "the continued capacity of soils to contribute to ecosystem services."

To facilitate meaningful integration, curriculum design should employ instructional models that explicitly connect soil properties and functions to sustainability outcomes. Matrix-based pedagogical frameworks have proven especially effective in this regard. These models enable educators to systematically map key soil attributes such as texture, cation exchange capacity, and saturated hydraulic conductivity that help define ecosystem services in line with specific SDGs. This approach not only enhances conceptual understanding, but also fosters students' ability to apply scientific principles in addressing real-world sustainability challenges (Mikhailova et al., 2024).

Furthermore, structuring curricula around soils' ecosystem services enables students to grasp the interdisciplinary significance of soil vis-à-vis both natural and socioeconomic systems. Thus, soil science education transcends disciplinary boundaries and empowers future professionals to engage in the SDG agenda as informed and responsible global citizens.

Bouma (2014) underscored the necessity of transitioning soil science from an inward-looking discipline to one that engages in transdisciplinary contexts. In doing so, soil science has become more relevant to key sustainability concerns, such as food, water, climate, and biodiversity. This approach supports the SDGs not as isolated targets, but as interconnected goals requiring integrated land management strategies. Bouma (2014) called for soil scientists to become "knowledge brokers" capable of linking scientific knowledge with local and policy-based action—an imperative that should be reflected in how we educate future soil professionals. An educational effort along these lines was a student challenge organized in 2021 at Wageningen University, the Netherlands, with the theme, "Make all soils healthy again." The challenge was conducted in the form of a game in which one team would win. After providing basic information, 18 teams worked for half a year on this theme and produced highly original and creative reports of high quality, indicating the intellectual potential of students that may not find a suitable outlet with classic topdown traditional lectures.[1] The Dutch Secretary of Agriculture addressed the students at the final session. The same element of competition is found in the soil judging contests in the USA, where teams from different states compete, which are now also introduced in Europe. Rather than producing soil profile descriptions, such efforts could also be focused on determining soil health and its functions within a particular landscape.

Similarly, Adhikari and Hartemink (2016) highlighted that soil scientists have been slow to adopt the language of ecosystem services, despite their work being inherently linked to it. Their global review illustrated that while provisioning and regulating services are commonly researched, cultural and supporting services remain underexplored. Moreover, the spatial dimensions of soil properties critical for services such as water purification and carbon sequestration are underutilized in teaching and policy engagement. Therefore, pedagogical models must emphasize ecosystem service thinking and its applicability across all dimensions of soil science practice. Recent reports by the European Union (2024) and European Commission (2025) on the future of agriculture support this approach (see also Bouma, 2025), emphasizing "the need for sustainable farm management and harmonization of methodologies for on-farm sustainability assessment," with

[1] https://shorturl.at/j1mke

"common metrics and indicators" aiming at the objective "to determine where each farm stands." In addition, there is a need to "provide quantifiable ecosystem services using robust indicators" in the context of "an agro-food system that is economically, socially and environmentally sustainable." This would involve "contributions to climate mitigation, providing clean water and air, soil health and biodiversity preservation."

Mikhailova et al. (2024) provided a compelling case for using matrix-based learning in soil-science education to directly link soil properties and ecosystem functions with the relevant SDGs. Their findings showed that students exposed to SDG-integrated soil curricula developed a heightened appreciation of soil's role in sustainability, particularly in regulating services such as climate control and water filtration. This supports the inclusion of practical problem-based learning, where students assess soil characteristics (e.g., texture and hydraulic conductivity) within the context of real-world environmental challenges. Such experiential learning allows students to internalize soil's role as natural capital, contributing directly to SDG outcomes.

Additionally, educational research by Zamora-Polo et al. (2019) and Serafini et al. (2022) confirmed that students' awareness of SDGs remains uneven, while their capacity to link disciplinary knowledge to global development frameworks is limited. This gap supports the embedding of SDG-specific competencies into soil-science pedagogy. Students must not only understand soil science but also develop the systems thinking, evaluative judgment, and ethical reasoning necessary to frame soil functions within broader socio-environmental goals. However, many academic programs continue to operate within disciplinary silos, lacking the integration of systems thinking, socio-environmental awareness, and cross-sectoral approaches (Heldal et al., 2024; Watkins et al., 2012).

There is a critical need to redesign the tertiary-level curricula to better reflect the complexity and interconnectedness of contemporary soil-related challenges. Embedding SDG-aligned learning outcomes such as socioecological systems analysis, participatory stakeholder engagement, sustainability impact assessment, and ethical reasoning can shift educational paradigms from traditional content-based instruction to transformative competence-oriented learning models (Mikhailova et al., 2024). Pedagogical experts call for embedding sustainability principles, critical thinking, and stakeholder communication within soil science curricula (Ross et al., 2012). These platforms not only validate empirical findings but also serve as crucibles for the development of pedagogical frameworks that emphasize integrative and applied learning.

Practical strategies for implementing these reforms include Living Lab environments, also advocated by European Union (2024); capstone projects centered on community-based sustainability challenges, and participatory research involving stakeholders such as farmers, environmental planners, and local communities. Brevik et al. (2022) advocated for student-centered innovations—flipped classrooms, problem-based learning, studio-integrated labs, and virtual soil explorations—that replicate real-world dynamics and foster collaborative problem solving. These experiential methods promote learner agency, critical reflection, and adaptive thinking (Brevik et al., 2022).

Structural curricular reform must also be underpinned by interdisciplinary collaboration. Integrating soil science with disciplines such as environmental science, agronomy, engineering, public health, and socioeconomics enhances transdisciplinary learning and mirrors sustainability challenges' systemic nature (Bouma, 2023; Lal et al., 2021). This integration will foster a holistic understanding of soil systems, ethical foresight, and innovation capacity among future professionals.

This call for transformation is supported by recent empirical data. A comprehensive stakeholder survey conducted by Veenstra et al. (2024) across 24 European countries (n = 669) revealed persistent gaps in soil-science education, particularly in systems thinking, stakeholder communication, and integrated understanding of soil within the One Health paradigm. Stakeholders ranked "a scientific basis of soil functioning" and "the ability to mobilize agronomic drivers to protect soils" as the most critical competencies. With 84% of the respondents working in soil-related fields and 67% self-identifying as experts, the data reflect a strong sectoral engagement and consensus on educational priorities.

Complementing this, Field et al. (2011) outlined 11 foundational soil science teaching principles developed through a stakeholder-driven multi-institutional process. These principles emphasized contextualized learning, cross-subdisciplinary integration, and the cultivation of metacognitive and communication skills. Grounded in constructivist and experiential learning theories, this pedagogical model provides a scaffold for reform that supports both dynamic environmental problem-solving and active professional engagement.

Despite the promise of integrating the SDGs into higher education, particularly in STEM fields such as soil science, numerous pedagogical and institutional challenges remain. One major obstacle is the SDGs' broad and often abstract nature, which can impede the design of specific actionable learning outcomes (Mikhailova et al., 2024). This lack of clarity often results in ambiguous instructional objectives and difficulty in understanding SDGs' relevance to the academic discipline. Such problems can be overcome by focusing on specifically defined ecosystem services that are in line with certain SDGs.

Furthermore, the subject-specific orientation of SDGs' content requires careful adaptation; however, most curricula are not structured to accommodate crosscutting themes. This lack of coherence can render SDG integration superficial or disconnected, particularly in isolated courses or modules (Mikhailova et al., 2024). Students' unfamiliarity with SDGs also presents a pedagogical barrier: nearly 80% of the students surveyed were unaware of basic SDG facts, while many continued to misunderstand key soil–SDG linkages, even after instruction.

Time constraints in academic scheduling further hinder deep engagement with the SDGs' content. As Cottafava et al. (2020) noted, short modules limit sustained exploration and shared language development across disciplines. Consequently, student learning may remain at the surface level, while innovative ideas seldom progress beyond conceptualization.

Moreover, student projects, while often imaginative, frequently lack feasibility due to gaps in managerial competencies, such as economic planning, feasibility analysis, and stakeholder involvement, resulting in what has been described as "SDG-washing" (Cottafava et al., 2020). It should also be noted that students often lack the necessary skills to present their projects in front of an audience that may include potential users of their work.

Institutionally, systemic inertia and resource limitations impede efforts toward mainstream SDG education. Without curricular integration, administrative support, or funding, such initiatives struggle for legitimacy and long-term impact. Further, traditional lecture-centric instruction constrains the adoption of transformative pedagogies, even though hands-on approaches, such as laboratory work and reflective writing, have been shown to deepen students' understanding of SDGs' relevance (Mikhailova et al., 2024). However, the lack of individualized assessments such as paired pre- and post-tests limits the evaluation of student progress.

Meanwhile, despite its central role in environmental sustainability, soil remains underrepresented in SDG documentation and discourse. This omission risks further marginalizing soil science in both the educational and policy arenas (Mikhailova et al., 2024). This underrepresentation can be overcome by demonstrating—through specific examples—the crucial role of soils in contributing to ecosystem services, in line with certain SDGs.

Nevertheless, soil science curricula are uniquely positioned to bridge the gap between scientific knowledge and sustainability strategies. As a STEM discipline that inherently intersects with planetary health, soil science provides a robust interdisciplinary platform for SDG-based education. Embedding soil ecosystem services into coursework, framed around provisioning, regulating, and cultural ecosystem service categories, facilitates conceptual linkages to the SDGs (Adhikari and Hartemink, 2016; Mikhailova et al., 2024).

Matrix-based instructional approaches, which align specific soil properties with individual SDGs, have shown promise in enhancing conceptual clarity and real-world applicability. For instance, linking soil texture with water filtration and nutrient retention fosters an understanding of its relevance to SDGs 6 (Clean Water and Sanitation) and 2 (Zero Hunger) (Mikhailova et al., 2024).

Meanwhile, transdisciplinary pedagogies focusing on systems thinking, open learning environments, and stakeholder collaboration are essential for cultivating the leadership skills required for sustainability transitions (Cottafava et al., 2020). The University of Torino exemplifies this approach by engaging students in applied problem-solving within local sustainability contexts.

Additionally, HEIs, with mandates for teaching, research, and outreach, are strategically positioned to lead this educational transformation. The institutional integration of SDGs—from curricula to management practices—could amplify their societal impact (Zamora-Polo et al., 2019). However, challenges persist in operationalizing these ambitions without clear, discipline-specific instructional frameworks (Mikhailova et al., 2024).

In summary, there is a compelling need to reimagine and revisit soil science programs to more deliberately align them with the SDGs (Noguera et al., 2021). As sustainability challenges become increasingly complex and interconnected, higher education must evolve to provide students with disciplinary expertise and the capacity for critical, systems-based thinking. According to the UN and UNESCO, transformative changes in educational policy, curricula, and pedagogy are indispensable for addressing sustainability across the social, environmental, and economic domains (Annan-Diab and Molinari, 2017; United Nations, 2015; UNESCO, 2020). As previously stated, soil science has a unique relevance across at least 14 of the 17 SDGs, given its foundational role in ecosystem services that support Earth-system sustainability (Bouma et al., 2019; Keesstra et al., 2016).

However, traditional approaches to soil education often remain narrowly focused on sub-disciplinary content and technical modeling—what some have termed a "soil pit" perspective (Bouma et al., 2019). This insularity inhibits engagement with broader transdisciplinary contexts, and reduces the visibility of soil science in addressing global sustainability objectives. To overcome this problem, soil-science curricula must be reframed through the lens of sustainability. This entails training students to see soils not just as physical and chemical entities but also as dynamic systems embedded within socio-ecological landscapes, thereby fostering the competencies necessary to engage with policy, community-based action, and interdisciplinary research (Sipos et al., 2008; Wiek et al., 2011).

Embedding SDG-relevant knowledge into soil-science education requires a strategic curriculum design. Avelar et al. (2023) emphasized that sustainability's integration into higher education should extend beyond isolated courses and instead permeate teaching, research, and institutional partnerships. Similarly, Weiss et al. (2021) highlighted that effective curriculum change demands coordinated institutional efforts rather than *ad hoc* or symbolic reforms. The SDGs—particularly SDG 4.7—call for educational systems to ensure that all learners acquire the knowledge and skills needed to promote sustainable development (United Nations, 2015). The *ESD Roadmap 2030* by UNESCO (2020) provides further guidance on how HEIs can operationalize these aims.

A transdisciplinary approach that links soil functions to ecosystem services and quantifies their contributions to specific SDG is essential (Keesstra et al., 2016). Such models not only reinforce the scientific relevance of soil processes but also contextualize them within human development frameworks, making the learning experience more meaningful and socially impactful. In doing so, soil-science education can cultivate a generation of professionals who are not only technically adept, but also ethically and systemically oriented toward sustainability transitions.

OBJECTIVES OF THIS STUDY

Building on the urgent call for pedagogical reform outlined in the introduction, this study seeks to contribute to the evolving discourse on integrating soil-science education with the SDGs. This is accomplished by aligning curriculum design, instructional

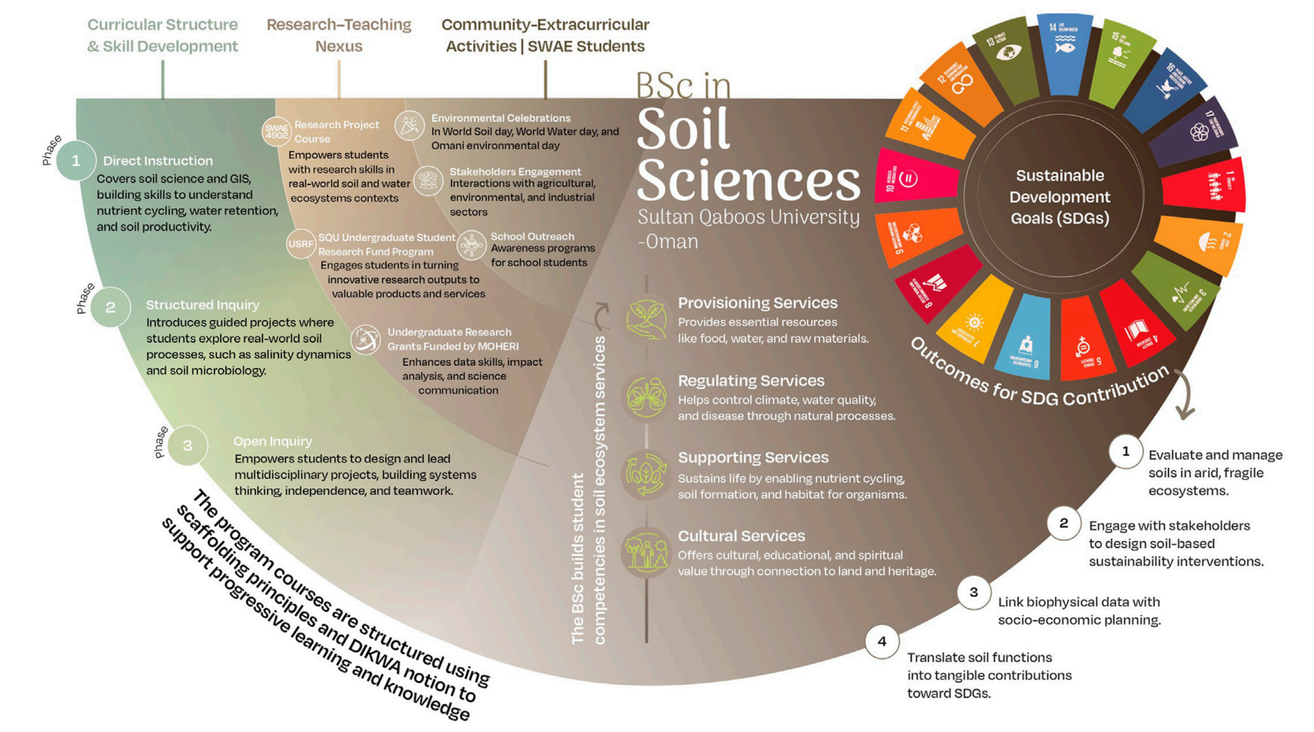

FIGURE 1 | Infographic visually encapsulating the comprehensive and sustainability-driven structure of the BSc in Soil Sciences program at Sultan Qaboos University (SQU), Oman.

strategies, and professional competencies with global sustainability challenges. The specific objectives of this study are as follows:

a) To document and analyze the curriculum tuning of undergraduate soil-science programs at Sultan Qaboos University (SQU; in Oman) and Moscow State University (MSU; in Russia), focusing on enhancing student competencies related to soil ecosystem services, interdisciplinary knowledge, and SDG-relevant outcomes.
b) To present selected case studies and experiential learning practices implemented within these programs, aiming to illustrate how specific pedagogical approaches such as project-based learning, community engagement, and ecosystem services mapping can equip students with practical skills aligned with the SDG targets.

TRANSFORMING SOIL-SCIENCE EDUCATION AT SQU

The Bachelor of Science (BSc) in Soil Sciences at SQU is the only undergraduate degree dedicated to agriculture and soil science in Oman (**Figure 1**). Offered by the Department of Soils, Water, and Agricultural Engineering (SWAE) at the College of Agricultural and Marine Sciences, this four-year program (126 credits) blends foundational sciences with applied instruction in soil and water systems. Delivered in English and aligned with national accreditation standards, the curriculum emphasizes Oman's unique arid and saline landscapes, such as mountain terraces and traditional *aflaj* irrigation systems, providing students with regionally tailored and globally relevant education (Al-Ismaily et al., 2018).

The program was scaffolded across three progressive phases of inquiry, reflecting the complexity of soil ecosystem services and promoting sustainability-oriented education. Phase I, Direct Instruction, lays the scientific groundwork, focusing on core topics, such as Introduction to Soil and Water, Environmental Soil Chemistry, Environmental Soil Physics, Hydrology, and Geographic Information Systems (GIS). Students develop the foundational knowledge necessary to understand nutrient cycling, soil-water retention, and biological productivity, which are crucial to providing and supporting ecosystem services. These competencies contribute directly to SDGs 2 and 6. In Phase II, Structured Inquiry, students engage in guided projects that examine real-world soil processes such as salinity dynamics and soil microbiology. This phase strengthens their ability to interpret data and address regulatory services such as pollution mitigation and climate control, aligned with SDG 13 (Climate Action). Finally, Phase III, Open Inquiry, empowers students to lead multidisciplinary projects, such as urban soil health assessments, holistic hydropedological understanding and modeling of soilscapes, land-use planning, enhancing water conservation, and resilience to water scarcity in challenging soil environments. This encourages systems thinking and collaborative problem solving essential for landscape-scale decision-making and contributes to SDG 15 (Life on Land).

The central pillar of the BSc in Soil Sciences at SQU is its robust research-teaching nexus, which actively integrates student learning with applied scientific inquiry. This integration is most evident in the three key platforms that scaffold undergraduate research. The Research Project Course (Research Projects in Soil, Water, and Agricultural Engineering–SWAE4902) offers structured opportunities for students to apply classroom theories to field-based investigations of soil and water systems. Through this course, students develop critical competencies in experimental design, environmental data analysis, and scientific reporting. Second, the SQU's Undergraduate Student Research Fund Program offers competitive grants and structured mentorship, empowering students to undertake both independent and team-based research projects that align with national development goals, particularly in the areas of arid-land sustainability and soil-salinity management. An important dimension of this initiative is its emphasis on generating innovative research outputs with the potential to be transformed into value-added products, sustainable processes, and practical services, thereby bridging academic inquiry with real-world applications and socioeconomic impacts (For the Undergraduate Student Research Fund Program at SQU, see [2]). Third, the program connects students with nationally competitive Undergraduate Research Grants funded by the Ministry of Higher Education, Research, and Innovation, which expand research capacity through support for fieldwork, laboratory experimentation, and stakeholder engagement.

Together, these platforms operationalize the research–teaching nexus by enabling students to obtain real-world insights and contribute meaningfully to soil and environmental science. They cultivate high-level competencies in data interpretation, impact assessment, and science communication and advance broader educational and societal goals, particularly SDGs 4 and 17. This integrative model transforms the undergraduate experience into a trajectory of innovation, civic responsibility, and professional readiness within the context of Oman's fragile but vital soil ecosystems.

The program's aim is to build graduates' capacity to evaluate and manage soils in arid, fragile ecosystems, as well as foster transdisciplinary approaches for sustainable soil-based solutions. Students learn to engage with diverse stakeholders, link biophysical data to socioeconomic contexts, and translate soil functions into actionable strategies that support the SDGs. By connecting theory, inquiry-based pedagogy, and practical applications, the BSc in Soil Sciences at SQU is a model of higher education aligned with global sustainability imperatives and tailored to local ecological realities.

In the classroom, students in the SWAE program at SQU engage in diverse community and extracurricular activities that strengthen their environmental leadership and reinforce the social dimension of soil science. These activities are integral to the program's applied learning philosophy and contribute to the development of cultural and educational ecosystem services. A highlight is the organization and participation in World Soil Day events, where students lead public awareness campaigns, exhibitions, and scientific demonstrations aimed at increasing soil literacy across Omani society. Additionally, students regularly conduct outreach workshops at local schools and engage young learners in interactive lessons on soil health, irrigation, and sustainable land use. These events foster early environmental awareness and position the SWAE students as ambassadors of sustainability education.

By extending their community footprint, students are also involved in student-led field courses that simulate professional environments by combining technical skills with stakeholder interactions. These experiences are often framed within student clubs and environmental societies that support collaborative initiatives such as tree planting, urban garden assessments, and field-based conservation practices. Through these initiatives, the students gain practical experience in teamwork, public engagement, and environmental stewardship. These activities not only complement academic learning but also help build soft skills, such as communication, leadership, and civic responsibility, thereby aligning with the broader mission of SDGs 4 (Quality Education) and 13 (Climate Action). By embedding community engagement in the academic journey, the SWAE program cultivates well-rounded graduates equipped to act as agents of positive change in both local and global environmental contexts.

The BSc in Soil Sciences curriculum at SQU is fully in line with the rapid advancement of modern instrumental methods in soil research, which has transformed soil science into a data-driven, digital discipline (Brevik et al., 2022). This evolution requires proficiency in diverse technological domains, including big data analytics, mathematical modeling using HYDRUS-1D, Internet of Things for irrigation, remote sensing, GIS, among others. These competencies are becoming increasingly critical for effective soil monitoring, environmental planning, and sustainable land management (Lomonosov, 1763; Mikhailova et al., 2018).

SOIL-SCIENCE EDUCATION AT MSU

The educational approach of the Soil Science Faculty at MSU is characterized by a systematic framework that integrates soil science with broader biosphere and societal functions. Key elements include (1) a systemic perspective on soil as a dynamic component of natural and anthropogenic processes, (2) interdisciplinary instruction spanning the natural and social sciences, and (3) the incorporation of modern research methodologies, including experimental analysis, statistical evaluation, and mathematical modeling.

This model reflects both the historical roots of soil education at MSU and the guiding principles of the Russian higher education system, which emphasizes foundational knowledge and its practical applications. The curriculum is also shaped by the mandatory inclusion of humanities and physical development courses to ensure a holistic education.

MSU's soil science tradition dates back over two centuries, preceding the formalization of the discipline by Dokuchaev. M.V.

[2]https://l1nq.com/z28M9

TABLE 1 | Undergraduate curriculum in soil science at MSU.

Disciplinary area	Course	Academic units	Contact hours	Faculty
General (Social Sciences)	Economics	4	72	Faculty of Economics
	Sociology	2	54	Faculty of Sociology
	Law	2	36	Faculty of Law
	Philosophy			Faculty of Philosophy
	Fundamentals of Land Law	2	36	Faculty of Law
	Land Use and Management	2	36	Soil Science Faculty
	Food Security	3	36	Soil Science Faculty
	Sustainable Development	3	36	Soil Science Faculty
	Life Safety	2	24	Soil Science Faculty
	Russian Language and Speech Culture	4	60	Faculty of Teacher Education
Mathematics	Introduction to Calculus	8	156	Faculty of Mechanics and Mathematics
	Informatics	4	90	Faculty of Mechanics and Mathematics
	Mathematical Statistics	4	120	Soil Science Faculty
	GIS	2	48	Soil Science Faculty
Chemistry	General Chemistry	3	90	Faculty of Chemistry
	Physical Chemistry	2	72	Faculty of Chemistry
	Colloidal Chemistry	2	54	Faculty of Chemistry
	Organic Chemistry	3	72	Faculty of Chemistry
	Soil Chemistry	2	48	Soil Science Faculty
	Agrochemistry	5	144	Soil Science Faculty
Physics	Physics	5	120	Faculty of Physics
	Soil Physics	4	132	Soil Science Faculty
	Erosion and Soil Protection	2	60	Soil Science Faculty
Geography	Geology	2	60	Faculty of Geology
	Cartography & Topography	3	36	Faculty of Geography
	Geomorphology	3	36	Soil Science Faculty
	Soil Cartography	2	48	Soil Science Faculty
	Soil Geography	3	72	Soil Science Faculty
	Mineralogy	4	36	Faculty of Geology
Agronomy and Soil Science	Agriculture	3	72	Soil Science Faculty
	Fundamentals of Soil Science	5	72	Soil Science Faculty
	Soil Reclamation	3	90	Soil Science Faculty
	Soil Science	2	60	Soil Science Faculty
	Crop Production	2	60	Soil Science Faculty
	Soil Properties and Processes	2	54	Soil Science Faculty
	Paleosoil Science & Evolution	3	30	Soil Science Faculty
	Land Resource Assessment	3	36	Soil Science Faculty

Lomonosov's (1763) publication "On the Layers of the Earth" laid the groundwork by conceptualizing soil as a product of geological and biological interactions. In the early 19th century, pioneering faculties such as P.I. Strakhov conducted empirical soil research, while A.A. Prokopovich-Antonsky established the Moscow Society of Agriculture. By 1823, soil and agricultural education had been formally recognized as a scientific discipline through Pavlov's work. The Department of Agronomic Chemistry (now the Department of Agrochemistry and Plant Biochemistry) was founded in 1863, and Dokuchaev advocated for soil science departments in universities by 1895. In 1906, soil science was officially introduced as a natural science course at the MSU.

Throughout the 20th century, structural reforms, including temporary shifts away from faculty-based systems, eventually led to the consolidation of soil science as an academic focus. In 1973, the Faculty of Biology and Soil was split, leading to the creation of the independent Faculty of Soil Science. Today, the Faculty employs 344 staff members, including 75 faculty members and 83 researchers, and boasts of a legacy that spans collaborations with multiple faculties, such as those of Physics, Geography, Biology, and Geology.

The Faculty's educational philosophy is rooted in rigor and clarity, a perspective articulated by Professor Vladychensky (Shein and Umarova, 2008), who emphasized the delivery of essential scientific knowledge, the development of analytical thinking, and the importance of self-directed learning. The curriculum aims to foster fundamental competencies across disciplines including mathematics, physics, chemistry, biology, geography, and soil science. Students are expected to develop general and specialized professional skills that allow them to conduct research, engage in applied science, and meaningfully contribute to land management, agriculture, environmental protection, and education.

The MSU operates on a credit-hour system, according to which one credit equals 36 academic hours (45 min each). **Table 1** shows the main courses of the Bachelor's degree program in soil science at MSU. The bachelor's program spans 4 years of full-time study, totaling 240 credits divided into a basic core module (137 credits), a variable module (27 credits), practical and research training (39 credits), and a final certification (9 credits). Courses are delivered by faculty holding professorial ranks across multiple departments to ensure interdisciplinary exposure.

The undergraduate program in soil science at MSU was founded on a comprehensive and interdisciplinary educational framework. It integrates a well-balanced mix of the general sciences, natural sciences, technical disciplines, and applied soil studies. The curriculum is organized into five core disciplinary domains: general (social sciences), mathematics, chemistry, physics and geography, and agronomy and soil science, each contributing critical knowledge and skills that support both theoretical foundations and practical applications in soil science.

This interdisciplinary design ensures scientific depth and promotes an integrated understanding of soil ecosystem services, including nutrient cycling, water retention, carbon storage, and biodiversity support. By embedding sustainability concepts throughout the coursework, the program effectively prepares students to contribute to global priorities, particularly those outlined in SDGs 2 (Zero Hunger), 6 (Clean Water and Sanitation), 13 (Climate Action), and 15 (Life on Land).

Students follow a uniform curriculum for the first two years before choosing a specialization in the third year. The faculty houses 10 departments, including agrochemistry, soil biology, soil geography, soil chemistry, physics and recreation, and radioecology, each offering tailored courses. Specializations include agroecology, soil biology, land resources and functioning, soil physics and erosion, and soil chemistry. Students are assigned supervisors for their research activities starting in their third year.

The program is designed not only to prepare soil science experts, but also future researchers, educators, and policymakers. Approximately 70% of graduates pursue master's degrees, while 40% continue to pursue PhDs. Alumni work in agriculture, environmental agencies, governmental bodies, universities, and international institutions such as Michigan State University (USA), the University of Alberta (Canada), and the National Autonomous University of Mexico (Mexico).

Practical training is integral and includes nearly 4 months of summer fieldwork. Courses in geology, botany, topography, and soil science are supplemented with training in soil cartography, erosion control, and zonal soil surveys. The communication, teamwork, and research designs are developed through conferences and group projects. Students also participate in outreach events such as "Science Days," "Soil Science Day," and summer schools that engage local communities.

MSU's emphasis on applied learning is supported by a pedagogical approach that encourages problem-solving, ethical collaboration, and scientific communication. Despite criticism of the rigidity of the Russian education system, MSU's soil science program fostered the development of soft skills through laboratory work, team-based field assignments, and participation in public science events.

Group projects, field training, and oral presentations reinforce soft skills. Students develop competencies in scientific reasoning, experimental design, data analysis, and ethical execution of collaborative work. These experiences position graduates in roles that demand interdisciplinary insight and evidence-based decision-making.

Students specializing in physics, land recreation, and soil erosion have gained expertise in physical soil processes, degradation assessment, and remediation. They studied both core and elective subjects tailored to their focus areas, gaining hands-on experience with laboratory instrumentation and field-survey equipment.

INTEGRATING SOIL-SCIENCE EDUCATION WITH SUSTAINABLE DEVELOPMENT: COURSE-LEVEL PERSPECTIVES FROM SQU AND MSU

The following section presents a pedagogical analysis of selected courses and instructional practices from the BSc in Soil Sciences at SQU and MSU. These examples were chosen to illustrate how the program translates its broader educational strategies into specific learning experiences that equip students to understand and support soil ecosystem services within the framework of the SDGs. The selected courses (i, ii, iii, and iv from SQU and v from MSU) included the following:

(i) A theoretical course for junior-level students—Soil and Water Conservation (SWAE3304).
(ii) A field-intensive experiential course, Soil and Water Winter Tour (SWAE4110).
(iii) An advanced capstone-level course integrating lectures and hands-on applications—Hydropedology for Soil–Water–Landscape Interactions (SWAE4111).
(iv) Final year research project: Research Project in Soils, Water, and Agriculture. Engineering (SWAE4902).
(v) Advanced theory–practice integrated course: Soil physics.

Next each course will be examined through the lens of its pedagogical design, learning outcomes, and the specific competencies it fosters, particularly those related to ecosystem service thinking, interdisciplinary integration, and sustainability problem-solving.

Soil and Water Conservation (SWAE3304): Building Foundational Competence in Sustainable Soil Stewardship

The Soil and Water Conservation (SWAE3304) course provides junior-level students in the BSc in Soil Sciences at SQU with essential theoretical grounding and an applied understanding of soil and water as finite and life-sustaining natural resources. Through a combination of lectures, interactive debates, and continuous assessment, the course is structured to bridge the disciplinary foundations in soil physics, hydrology, and environmental science with real-world conservation strategies.

Pedagogical Design

The course leverages a multi-modal teaching approach encompassing (**Figure 2**):

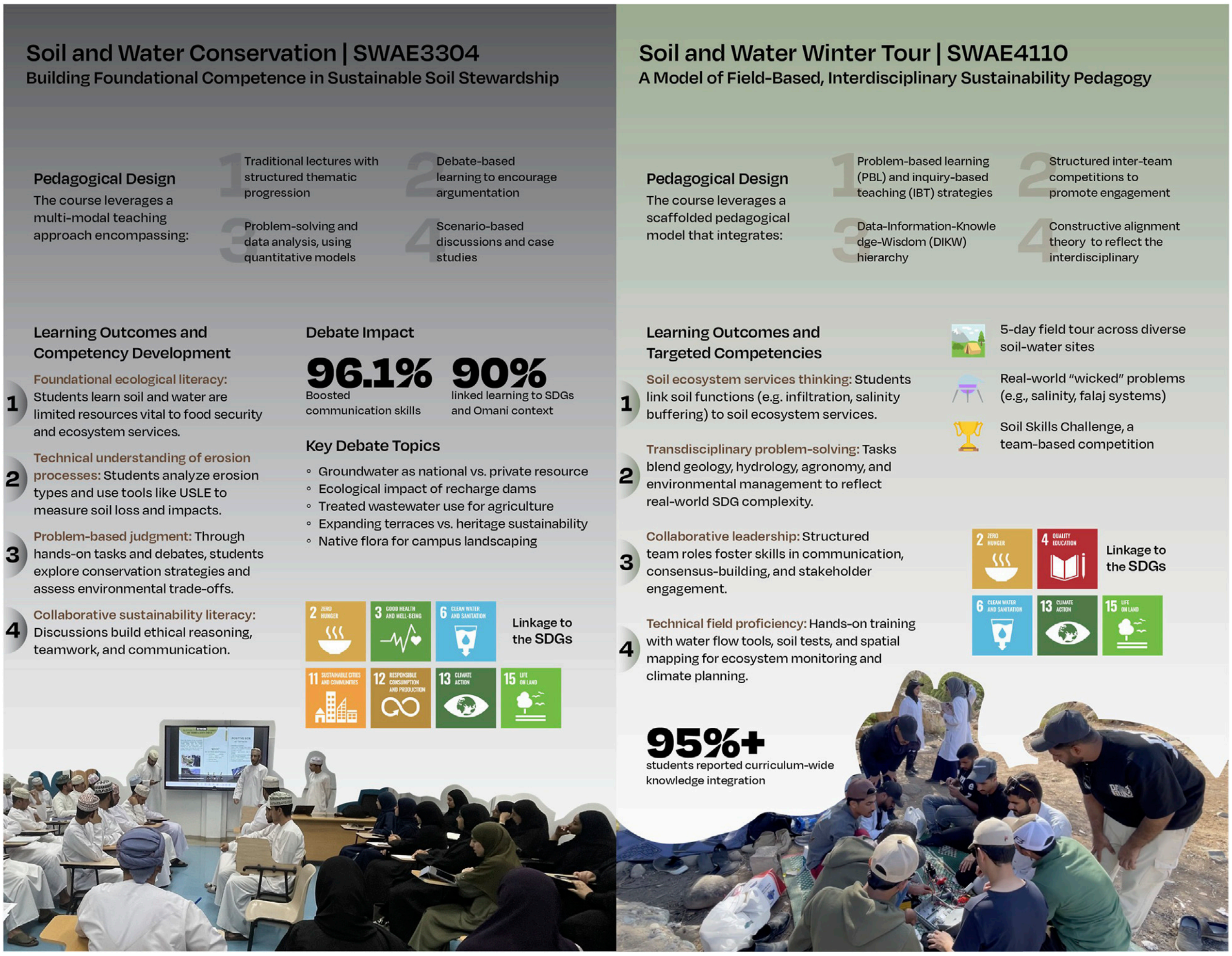

FIGURE 2 | Infographic highlighting two integrated courses: SWAE3304 uses lectures, debates, and modeling to build foundational skills in soil and water conservation, while SWAE4110 offers field-based, interdisciplinary learning focused on ecosystem services, technical fieldwork, and SDG-linked problem-solving.

- Traditional lectures with structured thematic progression.
- Debate-based learning, which encourages argumentation, evaluation, and synthesis of knowledge regarding controversial soil- and water-management issues.
- Problem-solving and data analysis using quantitative models such as the Universal Soil Loss Equation.
- Scenario-based discussions and case studies that contextualize soil degradation and conservation within Oman's unique arid ecosystem.

This scaffolded design supports active engagement while fostering systems thinking and the ability to diagnose and intervene in soil-degradation scenarios.

Learning Outcomes and Competency Development

The course systematically nurtures the following skill sets:

- Foundational ecological literacy: Students comprehend soil and water as non-renewable environmental assets whose degradation threatens food security, water availability, and long-term land productivity, contributing to a foundational understanding of the support and regulation of soil ecosystem services.
- Technical understanding of erosion processes: Students analyze geological, water, and wind erosion dynamics and learn to apply predictive tools (e.g., the universal soil loss equation) to quantify soil loss, linking physical processes to environmental degradation and restoration potential.
- Problem-based judgment: Through practical exercises and group debates, learners explore diverse conservation practices, compare remediation strategies, and critically engage with topics such as salinization, irrigation inefficiencies, and chemical pollution, which are essential for evaluating the tradeoffs among environmental solutions.
- Collaborative sustainability literacy: Debates and peer discussions promote ethical reasoning, communication skills, and teamwork, thus enabling students to

TABLE 2 | Debate topics: Soil ecosystem services and SDG relevance.

Debate topic	Key controversy	Relevance to soil ecosystem services	Relevant SDGs
Should groundwater in Oman remain private property or become a national resource?	A clash between traditional rights and public sustainability	Affects soil-water interactions, recharge zones, and access equity—impacts provisioning and regulating services	SDG 6, SDG 15, SDG 12
More recharge dams in Oman: A smart investment or an ecological misstep?	Balancing water security with environmental concerns	Alters hydrological cycles, infiltration, and sedimentation—directly affects regulating and supporting soil services	SDG 6, SDG 13, SDG 15
Is Oman ready to embrace treated wastewater as a source of drinking water?	Necessity vs. public perception and health	Impacts soil health and microbial balance if reused in agriculture—ties to pollution control and soil filtering services	SDG 6, SDG 3, SDG 12
Expanding mountain terraces in Oman: reviving heritage or misusing resources?	Heritage conservation versus cost and climate adaptation	Reduces erosion, improves soil stability and water retention—supports regulating and supporting services	SDG 2, SDG 15, SDG 11
Is replacing exotic flora with native species a viable water conservation strategy for SQU?	Aesthetic landscape vs. ecological responsibility	Enhances water-use efficiency, supports native soil biodiversity and nutrient cycles—boosts supporting and habitat services	SDG 6, SDG 15, SDG 13

participate effectively in multi-stakeholder conservation efforts.

The student debate initiative is structured around a robust framework of guidelines, procedures, and timing protocols that ensure academic rigor, fairness, and effective skill development. Central to this framework is the formal nomination and assignment of Student Debate Coordinators entrusted with the end-to-end logistical and procedural management of the debate process. Their responsibilities include scheduling with instructors, assigning teams, facilitating topic selection through class voting, ensuring timely communication of rules and deadlines, managing presentation materials, and moderating debate sessions to uphold procedural compliance.

The debate format is designed to foster analytical thinking and communication skills by engaging two teams—Proposition and Opposition—to present and defend contrasting viewpoints. Each team comprises 5–6 members, and debates topics that must be both controversial and intellectually stimulating. To ensure contextual relevance, selected topics should align directly with course themes (e.g., soil, water, and conservation) and be linked to broader objectives such as the SDGs. **Table 2** depicts examples of debate topics for the 2025 fall semester, outlining key environmental issues in Oman, each framed by a central controversy. These topics are directly linked to soil ecosystem services (e.g., water regulation, erosion control, and biodiversity) and align with the relevant SDGs. Whenever possible, emphasis is placed on regional relevance, especially concerning Oman and other arid or semi-arid regions, thereby enhancing the applicability and depth of student engagement.

The procedural timeline is structured meticulously to promote equity and clarity. A total of 25 min is allocated to each debate session. This includes 10 min for initial problem statements (5 min per team), followed by a 12-min rebuttal phase spanning three rounds (2 min per team, per round). Each team then delivers a 1-min closing statement, and an additional minute is reserved for transitions and setup. This tightly managed schedule reinforces time discipline, while providing ample opportunity for critical argumentation and structured dialogue.

To uphold academic integrity and constructive engagement, the debating process is governed by a set of formal rules. The participants must demonstrate mutual respect, avoid interruptions, and adhere strictly to the allotted time. The arguments should be logical, clearly articulated, and supported by credible data, sources, and case studies. Teams are also expected to listen and respond directly to opposing arguments, fostering a dynamic and evidence-based dialogue. Citing sources when referencing studies or data is not only encouraged but required, thereby reinforcing critical scholarship and accountability.

Figure 3 shows a stacked bar chart illustrating how a cohort of 51 students evaluated their level of agreement with 17 reflective statements following their participation in a classroom debate. The responses are categorized on a five-point Likert scale, ranging from "strongly disagree" (indicated in red) to "strongly agree" (indicated in blue). This visual representation offers a concise overview of student perceptions of the various cognitive, communicative, and collaborative outcomes associated with debate activities. Overall, the responses demonstrate a high degree of positive engagement, with most students selecting either "agree" or "strongly agree" for most statements. This pattern reflects a broadly favorable reception and confirms the effectiveness of the debate format in promoting active learning and reflection.

Among the highest-rated outcomes were "improved teamwork and communication" with 96.1% of students expressing agreement, and "more engaging than lectures," with 58.8% of students selecting "strongly agree." Furthermore, statements related to debate topics' relevance to the SDGs and Oman-specific issues also received strong endorsement, with over 90% agreement, thus highlighting the success of the activity in fostering contextual awareness and real-world applications.

The students also reported notable developments in key academic skills. These included enhanced public speaking confidence, improved research and evidence-based reasoning, and a deeper appreciation of interdisciplinary connections and outcomes that aligned well with the course's intended learning objectives.

However, only a few areas presented opportunities for enhancement. Statements such as "linked to sustainability" and "understanding Oman's conservation issues" elicited relatively lower levels of strong agreement and included a higher proportion of "neutral" or "disagree" responses. This indicates

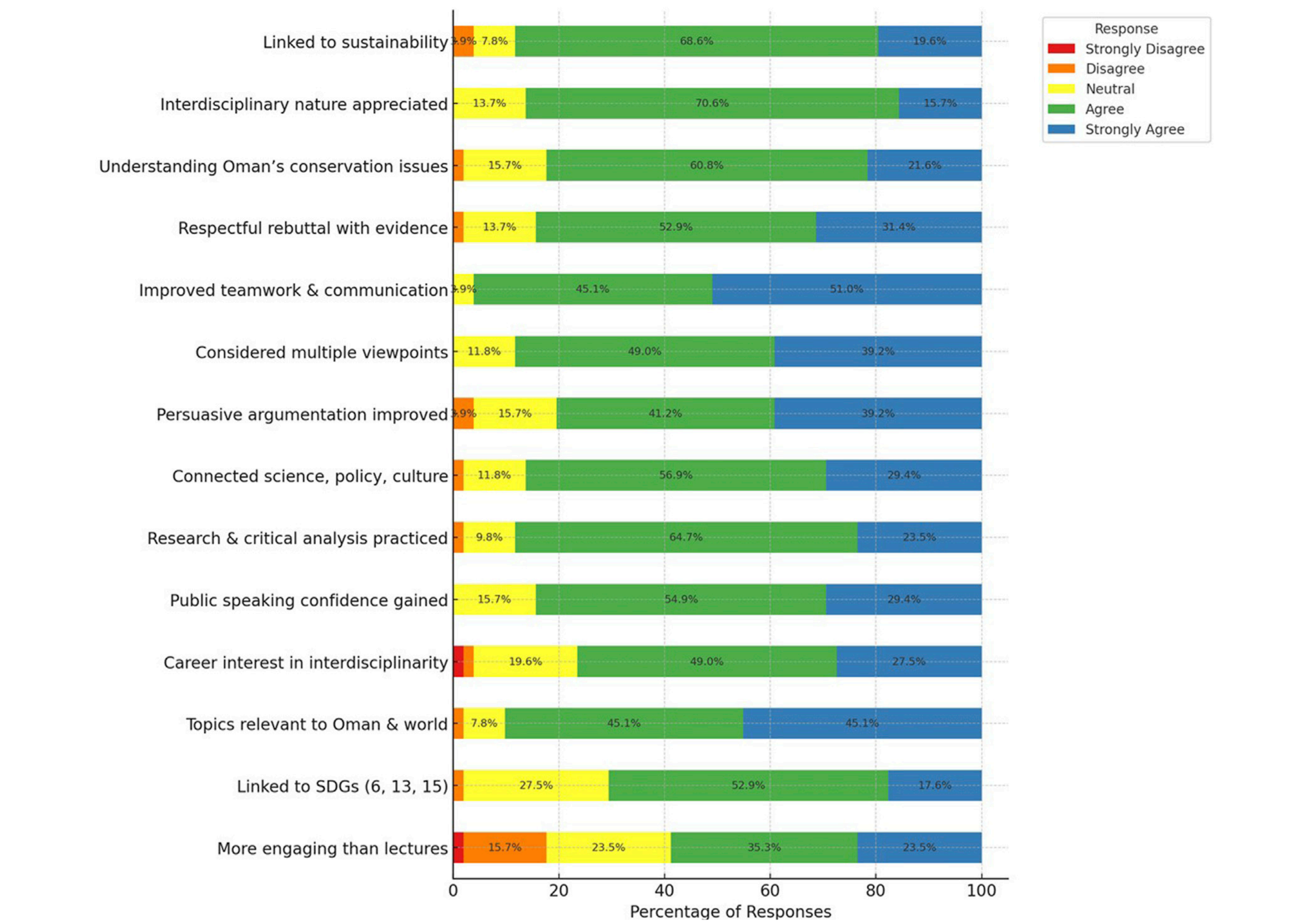

FIGURE 3 | Student reflections on debate-based learning outcomes.

that these themes may benefit from a greater instructional emphasis or clearer integration within the debate structure.

When students were asked to reflect on their debate experiences, their responses revealed a strong appreciation for both the academic and personal benefits of the activity. Many identified the most valuable aspect as the opportunity to enhance their argumentation and rebuttal skills, especially through the use of evidence and real-time reasoning. Students also noted gains in confidence, public-speaking skill, and the ability to communicate ideas clearly. Working in teams fostered collaboration, while engaging in complex sustainability topics helped them explore diverse perspectives and apply critical thinking.

Regarding improvements, the students overwhelmingly requested more time for preparation, delivery, and rebuttals. Several studies have suggested reducing or removing the presentation segment to allow for a deeper discussion. Others have recommended structured feedback, rubrics, and smaller teams to ensure equal participation. Suggestions for improvement also include using interactive formats (e.g., fact-checking and audience Q&As), advanced topic briefs, and better timing within the academic calendar to reduce pressure.

In their final comments, students expressed gratitude, calling the debate enriching, enjoyable, and unique, compared with traditional class activities. Many wished that it would continue in future courses, while a few proposed a more professional setup with clear rules, competitive rounds, and expert involvement. Overall, the responses reflected a deep appreciation of the activity's value in building essential skills, and a strong desire to see it grow and improve.

Soil and Water Winter Tour (SWAE4110): A Model of Field-Based, Interdisciplinary Sustainability Pedagogy

The Soil and Water Winter Tour (SWAE4110) represents a flagship experiential course within the BSc in Soil Sciences at SQU, designed to embody the pedagogical values of active learning, interdisciplinary integration, and ecosystem service-based education (Al-Ismaily et al., 2021; Al-Ismaily et al., 2023). The course is delivered as a five-day immersive field experience and culminates in the Soil Skills Challenge, a structured team-based competition that blends technical soil

FIGURE 4 | Infographic illustrating two complementary upper-level courses: SWAE4111 emphasizes system modelling and experimental hydropedology through integrated lab–field modules, while SWAE4902 engages students in interdisciplinary, research-driven projects tackling real environmental challenges with clear SDG alignment.

science tasks with real-world environmental problem solving (**Figure 4**).

Pedagogical Design

The course architecture leverages a scaffolded pedagogical model that integrates:

- Problem-based learning and inquiry-based teaching strategies.
- Structured inter-team competitions to promote engagement and critical reasoning.
- The data-information-knowledge-wisdom hierarchy (Ackoff, 1989) guides students from data collection to decision making.
- The constructive alignment theory ensures that assessments reflect a course's interdisciplinary and skill-based objectives.

Field scenarios are deliberately complex and often "wicked" in nature—for instance, they involve addressing secondary salinization in arid home gardens or installing precision irrigation systems—requiring students to synthesize competencies from hydrology, soil chemistry, landscape interpretation, and agroecology.

Learning Outcomes and Targeted Competencies

The course delivered various targeted learning outcomes that served both soil-science education and the broader goal of environmental sustainability. These include:

- Soil ecosystem services thinking: Students analyze and interpret the relationships among soil functions (e.g., infiltration and salinity buffering) and their role in delivering regulating, provisioning, and cultural services.
- Transdisciplinary problem-solving: Tasks require the integration of knowledge from geology, hydrology, agronomy, and environmental management, mirroring the multifactorial nature of SDG challenges.

- Collaborative leadership and communication: Through structured team roles and leadership rotations, students build real-world competencies in consensus-building, scientific dialogue, and stakeholder reporting.
- Technical field proficiency: Training includes direct experience with tools for water flow measurements, soil property testing, and spatial mapping, which are vital for ecosystem monitoring and climate-resilient land planning.

Linkage to Ecosystem Services and the SDGs

Through this pedagogy, students not only master disciplinary content, but are also equipped to actively contribute to SDG-relevant areas:

- SDGs 2 (Zero Hunger) and 15 (Life on Land): Investigating soil fertility, salinity control, and sustainable irrigation.
- SDG 6 (Clean Water and Sanitation): Water quality testing and flow analysis in the *falaj* and *wadi* systems.
- SDG 13 (Climate Action): Insights into carbon cycling, soil water retention, and climate adaptation strategies.
- SDG 4 (Quality Education): Embodying experiential, equity-centered pedagogy that emphasizes lifelong, practical learning.

In post-course evaluations, students reported enhanced capacities for problem analysis, communication, and sustainability planning. Over 95% confirmed that the Soil Skills Challenge helped integrate knowledge across the curriculum and connect theory to practice in impactful ways.

Hydropedology for Soil–Water–Landscape Interactions (SWAE4111): Advanced Integration of Soil Physics, Landscape Hydrology, and Sustainability Modeling

The course Hydropedology for Soil–Water–Landscape Interactions (SWAE4111) is a senior-level research-based course within the BSc in Soil Sciences at SQU. Designed as both a theoretical and practical learning experience, the course demonstrates how advanced soil-science pedagogy can align academic instruction with the competencies required to manage soil ecosystem services and respond to the sustainability imperatives articulated in the SDGs.

Pedagogical Design

This course is built in a multi-module format that blends lectures, laboratory experimentation, and field-based modelling (**Figure 4**). It integrates:

- Project-based learning anchored in real-world hydrological modeling scenarios.
- Active application of numerical modeling tools (HYDRUS-1D) for simulating vadose zone processes.
- Hands-on soil column experimentation for analyzing stratified water flow.
- Critical systems thinking links hydrological fluxes to soil formation, water quality, and land use.

The course follows a systems-based framework that emphasizes feedback between pedological properties and hydrological behavior, equipping students to bridge technical insight with environmental design and land management.

Learning Outcomes and Targeted Competencies

The course cultivates several advanced competencies relevant to sustainability-oriented soil science:

- Predictive modeling: Students gain the ability to simulate one-dimensional water and solute dynamics using HYDRUS-1D, a tool widely employed in environmental impact assessments and irrigation planning.
- Interdisciplinary soil-water analysis: Through case-based learning, students explore flow pathways (overland, lateral, and groundwater) and their influence on pedogenic features (e.g., salinity and redox indicators), thereby enhancing their understanding of regulating and supporting ecosystem services.
- Research design and problem solving: Students design and interpret column experiments and, in teams, tackle landscape-scale soil–water challenges (e.g., contaminant transport, irrigation efficiency), integrating experimental hydrology, quantitative analysis, hypothesis-driven inquiry, and collaborative solution-building aligned with community and ecological needs.

Linkage to Ecosystem Services and the SDGs

SWAE4111 plays a critical role in training students to apply soil-science knowledge to real-world challenges in which soil–water interactions drive ecosystem functioning. Its specific contributions to the SDGs include the following:

- SDG 6 (Clean Water and Sanitation): Modeling and mitigation of water contamination and inefficient irrigation through vadose zone simulations.
- SDG 13 (Climate Action): Understanding soil-water dynamics for climate resilience through water retention, infiltration, and root-zone modelling under harsh arid conditions.
- SDG 15 (Life on Land): Assessment of soil landscape heterogeneity and its role in biodiversity, vegetation dynamics, and catchment management.
- SDG 2 (Zero Hunger): Enhanced understanding of moisture redistribution and plant–water interactions across diverse geomorphological landscape features to optimize agricultural productivity in arid environments.
- The course enables students to treat soil not merely as a substrate but as a dynamic interface of biophysical, hydrological, and socio-ecological processes. Graduates are equipped to become integrative professionals capable of applying scientific tools to multiscale sustainability issues.

Research Project in SWAE

Pedagogical Design

SWAE4902 is designed as a capstone research experience that synthesizes theoretical, analytical, and field-based competencies acquired through SWAE programs. The course leverages a flexible yet rigorous independent study format in which students conduct original research under faculty mentorship (**Figure 4**). It integrates:

- Research-based learning grounded in real-world soil, water, and agricultural challenges, allowing students to address environmental and engineering questions.
- Iterative engagement with scientific methods, from hypothesis formulation to data analysis and critical evaluation.
- Hands-on experimentation and/or fieldwork depending on the project scope, with a focus on data generation, interpretation, and technical reporting.
- Cross-disciplinary research framing, blending technical engineering knowledge with socio-environmental insights, and stakeholder relevance.

This project-based framework emphasizes independent inquiry, scientific integrity, and methodological rigor, enabling students to transform abstract classroom concepts into actionable solutions that are aligned with sustainable land, soil, and water management goals.

Learning Outcomes and Targeted Competencies

SWAE4902 develops advanced competencies essential for professional and academic pathways in environmental sciences, engineering, and sustainability. By the end of the course, students are expected to:

- Apply research methods to study environmental systems and integrate interdisciplinary knowledge to solve SWAE problems—from problem definition and hypothesis formation to protocol design and analysis of complex data—with ecological, climatic, and socioeconomic dimensions.
- Develop academic and professional communication skills. Students produce high-quality research output, including technical reports and formal presentations suitable for diverse stakeholders.
- Demonstrate autonomy and scientific integrity. Students manage time-bound projects independently, reflect on research ethics, engage in peer and expert reviews, and enhance their lifelong learning capacity.
- Collaborate across disciplines and cultures. Through opportunities for group or interdepartmental projects, students refine their teamwork, leadership, and intercultural communication skills while tackling real-world sustainability issues.

Linkage to Ecosystem Services and the SDGs

The SWAE4902 equips students with the skills and knowledge to engage in complex sustainability problems in which soil, water, and agriculture intersect with human and ecological systems. This directly contributes to the following SDGs:

- SDG 6 (Clean Water and Sanitation): Students develop research projects addressing water quality, irrigation efficiency, or groundwater management using data-driven approaches.
- SDG 13 (Climate Action): Projects focus on climate-smart soil and water practices to assess the vulnerability and resilience of agriecosystems under variable climate regimes.
- SDG 15 (Life on Land): The program emphasizes land degradation, soil health, and land-use dynamics, thus contributing to preserving terrestrial ecosystems and promoting sustainable agriculture.
- SDG 4 (Quality Education): This course fosters inquiry-based learning and knowledge co-creation, helping develop critical scientific thinking and research skills.
- SDG 9 (Industry, Innovation and Infrastructure): Students explore innovation in agricultural engineering, including precision irrigation, sensor-based monitoring, and sustainable water infrastructure design.

Through SWAE4902, students are not only trained in technical research skills, but also encouraged to become thoughtful practitioners capable of translating academic knowledge into innovative solutions for sustainable development in soil and water resource management.

Table 3 showcases five student investigations illustrating our emphasis on interdisciplinary methods and applied learning, each contributing uniquely to soil ecosystem processes and SDGs. The projects range from the development of biodegradable hydrogels for improved soil moisture retention in arid regions to the AI-powered classification of traditional adobe architecture for cultural preservation (**Table 3**). Other students explore optimal hydrogel application strategies through experimental columns and HYDRUS-1D modeling, evaluate the effects of gravel content on infiltration and drainage in sandy soils, and examine the influence of soil texture on the distribution of native Omani tree species such as Sidr and Ghaf. These projects employ diverse methodologies, including laboratory analyses, numerical simulations, remote sensing, and fieldwork, and cultivate essential skills in data analytics, soil physics, modeling, and scientific communication. Moreover, the research outcomes extend beyond academic knowledge by reinforcing critical ecosystem services, such as water regulation, soil structural integrity, and vegetation support.

Figure 5 shows a vibrant snapshot of student engagement at SQU, where learning extends beyond the classroom. Students are actively involved in a dynamic blend of field experimentation (e.g., soil sampling and infiltration tests), along with sensor-based environmental monitoring and classroom-based hydrological modelling. Practical sessions also included the operation of technical equipment (e.g., drilling rigs and data loggers) to foster familiarity with the professional tools used in environmental research. This immersive, interdisciplinary learning environment bridges theoretical knowledge with real-world applications, thereby cultivating essential competencies in soil physics, hydrology, and environmental engineering.

TABLE 3 | SWAE4902: Selected student research projects summary during the Spring 2025 semester.

Title	Objectives	Activities involved	Skills gained	Link to soil ecosystem services	Linked SDGs
Natural hydrogel for water retention	Enhance soil water retention and antimicrobial activity using a natural hydrogel (sodium alginate + frankincense)	Hydrogel formulation, lab testing (FTIR, TGA), field validation with soil sensors	Polymer chemistry, soil physics, microbial analysis, lab instrumentation	Improves water holding, supports microbial balance, enhances plant water uptake	SDG 6, SDG 13, SDG 15
AI analysis of adobe architecture	Use AI to classify structural features and materials of heritage adobe walls in Nizwa and Izki	Image collection, model training with TensorFlow, classification, real-time Q&A interface	Machine learning, computer vision, cultural heritage analytics, Python programming	Preserves earthen architecture that depends on traditional soil compositions	SDG 11, SDG 9, SDG 15
Hydrogel application methods in sandy soil	Compare effectiveness of different hydrogel application techniques on water dynamics using HYDRUS-1D	Column experiments, modeling (HYDRUS-1D), RETC fitting, water retention and evaporation measurement	Soil-water simulation, lab experimentation, numerical modeling, irrigation management	Reduces water loss, enhances root-zone moisture, supports drought resilience	SDG 2, SDG 6, SDG 13
Role of gravel in water retention and drainage	Quantify how gravel percentages affect infiltration, retention, and hydraulic conductivity	Soil column tests, infiltration and drainage measurement, Ksat analysis	Soil physical analysis, experimental setup, data logging, water budgeting	Optimizes soil structure for irrigation, reduces erosion and nutrient leaching	SDG 2, SDG 6, SDG 15
Soil properties influencing native tree distribution under arid soil ecosystem	Assess how soil texture influences the growth of native trees like Sidr (Ziziphus spina-christi) and Ghaf (Prosopis cineraria)	Soil profile excavation, lab analysis (texture, EC, XRF), field surveys	Field soil analysis, GIS mapping, plant-soil relationship assessment	Supports afforestation, enhances biodiversity, improves root–soil synergy	SDG 15, SDG 13, SDG 2

FIGURE 5 | Students at SQU combining fieldwork, sensor use, modelling, and technical training to link theory with real-world soil and water management.

Soil Physics (Mandatory Course, 4th Semester): Advanced Study of Soil's Physical Behavior and Multiphase Interactions

The soil physics course, a core component of the BSc in Soil Sciences at MSU, is delivered in the fourth semester, following foundational instruction in mathematics, physics, chemistry, and introductory soil science. This course represents a pedagogically integrated approach to teaching that combines theoretical foundations with intensive hands-on experimentation and field-based learning (**Figure 6**). It is designed to teach students to analyze and quantify soil physical properties and regimes, which are fundamental to ecosystem functioning and environmental sustainability.

Integrated Instructional Design

The course architecture strategically combines lectures, seminars, laboratory practicums, and field training to foster a

FIGURE 6 | A comprehensive set of field and laboratory activities during soil science training in Chashnikovo and MSU: From left to right: (1) an experiment using Brilliant Blue dye to trace preferential water flow paths in soil profiles; (2) pressure filtration rate measurements across soil horizons; (3) evaluation of soil gas emissions; (4) morphological description of soil profile; (5) a student-led conference presenting results from hands-on soil physics practice; (6) flooded soil profile inspection after rainfall; and (7) filtration experiments.

comprehensive understanding of soil physical systems. Instruction emphasizes the dual development of foundational theory and applied skillsets, thereby enabling students to diagnose and interpret physical soil characteristics in diverse environmental contexts.

Lecture Delivery and Engagement

A total of 48 classroom hours—comprising 24 lectures—cover essential domains such as solid-phase physics, unsaturated flow and soil water retention, gas and thermal regimes, mass and heat transfer, soil deformation, and introductory mathematical modeling of mass transport. Lectures are designed for interactive learning, involving blackboard-based notetaking, open discussions, and active questioning. Theoretical exposition is augmented by visual media (e.g., slides, photographs, and graphs) to reinforce conceptual understanding and contextual relevance.

Seminar-Based Deepening of Knowledge

Seminars are delivered in small groups (8–12 students), providing a platform for personalized academic engagement. The sessions include problem-solving exercises, theoretical dialogues, and student-led presentations. Advanced topics, such as laser diffractometry and sedimentation analysis, are explored through infographics and technical summaries, thus enhancing both subject mastery and communication skills.

Laboratory Practicum and Experimental Training

Students engage in weekly laboratory sessions (five academic hours), each working with a unique soil sample, to assess its physical properties such as bulk density, porosity, water content, infiltration rate, and compaction behavior. This practicum emphasizes procedural design, methodological selection, and data interpretation, supported by detailed manuals and individualized data cards. Since soil samples for each group are collected from different layers of the same soil profile, students have the opportunity to collectively discuss and evaluate the soil properties and functions in relation to SDGs toward the end of the course. The immersive laboratory experience fosters autonomy, precision, and scientific reasoning.

Assessment and Evaluation Framework

Students' academic progress is regularly monitored during the semester. This includes checking the results of an experimental analysis of soil properties conducted by a student in a laboratory setting. To do this, each student completes an individual workbook that records their findings. Theoretical knowledge is assessed through tests. High-performing students may qualify for exemption from the final examination based on sustained excellence throughout the semester. This incentive motivates students to study consistently throughout the course.

Field Practice and Research Integration

A two-week summer field training session at the Chashnikovo Soil Ecology Center immerses students in real-world terrain featuring diverse soil types and vegetative covers. Students analyze soil profiles and measured physical parameters, including hydrological flow, thermal gradients, gas exchange, and pressure conditions. The instruments are calibrated on-site, and a comparative analysis of the measurement methods is encouraged. Each student group designs and conducts a small research project—ranging from waterlogging impacts to compaction studies—promoting experiential inquiry-based learning.

Capstone Outputs and Communication

Field experiments culminate in detailed student-authored reports, followed by group presentations at student-led conferences. These activities emphasize the synthesis and articulation of findings. Select projects are also presented at the prestigious annual MSU "Lomonosov" student conference and other academic forums, highlighting the course's integration into the university's broader research culture.

Competency Development and Relevance to Ecosystem Services

This course cultivates essential competencies in experimental soil physics, environmental monitoring, analytical reasoning, scientific documentation, and collaborative inquiries. It equips students to interpret physical soil data in the context of land use and ecological stability. It focuses on applying this knowledge to sustain critical ecosystem services, including the following:

- Water infiltration and retention processes.
- Soil structural resilience under mechanical stress.
- Regulation of gas and heat exchange.
- Enhancement of land productivity through informed soil management.
- Selection and maintenance of *suitable foliage* based on the soil moisture regime, compaction level, and aeration capacity.

By training students to assess how soil physical behavior influences vegetation compatibility, the course strengthens their understanding of plant–soil interactions and supports integrated decisions in agroecosystem planning and ecological restoration. The resulting knowledge base enables graduates to contribute meaningfully to sustainable land management, conservation practices, and adaptive responses to environmental changes.

LIMITATIONS AND PRACTICAL CHALLENGES

Despite encouraging outcomes from the pedagogical strategies we have presented, implementation revealed several hurdles. Group-based activities sometimes led to uneven participation and varied individual learning gains—a pattern widely reported in inquiry-based learning contexts (e.g., Beers, 2005; Hupy, 2011). Two factors were most salient: insufficient ongoing evaluation during the project and, in some cases, interpersonal frictions or limited interest among certain students. Although these behaviors can hamper project activities, they are often masked by aggregate group performance. Such challenges are well documented in inquiry-based teaching group work (Beers, 2005). Mitigation approaches include structured peer assessment within teams and an overarching appraisal of each member's contribution by the designated group leader via a direct report to the instructor. Assessing multi-component tasks that span fieldwork, laboratory analysis, modeling, and presentation remained complex. Riga et al. (2017) highlighted similar issues for instructors in evaluating the performance of inquiry-based teaching for multi-component student activities. Field-intensive, research-based courses impose substantial time and logistical demands on both students and staff (Brew and Mantai, 2017). As a result, commitment can wane over time (Spronken-Smith et al., 2011). To alleviate instructor fatigue, in programs, measures could be taken to establish rotation systems for new faculty; recruit graduate teaching assistants; and enlist former students as short-term evaluators and assistants, particularly during field activities. Gaps in scaffolding between phases and courses, as in the Omani case, were evident, with downstream effects on open-inquiry tasks. Student feedback also indicated that links to sustainability and Oman-specific conservation priorities were not always explicit. Analogously, Lazonder and Harmsen (2016) highlighted persistent challenges in linking the three tiers of inquiry-based teaching scaffolding. As preparation for Phase III projects (**Figure 1**), students benefit from a concise refresher of relevant fundamentals from earlier courses. We also recommend circulating recent, topic-aligned research articles prior to fieldwork. Instructors should continually develop novel Phase III project themes to engage new cohorts and avoid repetition across years. As Brew and Mantai (2017) argue, effective inquiry instructors are active researchers who design assignments that are "wicked" authentic and complex yet still comprehensible and manageable within the constraints of time, logistics, and resources. Competition- or research-oriented pedagogies are prone to productivity losses when teams are oversized and tasks lack sufficient granularity—conditions that elevate the risk of "social loafing" (Aggarwal and O'Brien, 2008). In our context, groups of 5–10 students proved sub-optimal: workload distribution became uneven, role ambiguity increased, and attendant frustration emerged, with measurable declines in both group and individual efficiency (see Wheelan, 2009). Optimal team size is contingent on the number of discrete roles and the complexity of assigned tasks; when these are mismatched, idle time is difficult to avoid. Finally, ambiguity regarding authorship and credit occasionally arose in research–teaching outputs (e.g., the Research Projects in Soil, Water, and Agricultural Engineering—SWAE4902). To ensure transparency and academic integrity, sponsoring agencies should adopt clear, public guidelines for publication and award attribution, and universities should promulgate explicit policies defining undergraduate contributors' roles, including criteria for co-authorship on scientific papers and conference presentations (see Rasmussen et al., 2020).

DISCUSSION AND CONCLUSION

Soil science is at a crossroads. As one of the most vital yet underrepresented disciplines in the global sustainability agenda, its educational paradigms must evolve to meet the complexity of 21st-century challenges. Although soils are central to food security, water quality, climate regulation, and biodiversity—the core pillars of the SDGs—soil science education remains largely siloed, technically focused, and insufficiently aligned with sustainability frameworks. This manuscript presents two case studies that illustrate fundamental transformations with regard to how we teach, learn, and apply soil science. The approach presented can help overcome problems identified by a recent European stakeholder survey of 24 countries (Veenstra et al., 2024), showing gaps in soil science education in terms of systems thinking, stakeholder communication, and an integrated understanding of soil science functioning in an inter- and transdisciplinary context. A focus on ecosystem services provides a structural link with the UN SDGs. At SQU (Oman), the BSc in Soil Sciences program was deliberately structured as a whole-of-program reform anchored in graduate attributes, with explicit alignment of learning outcomes and assessments to SDGs articulated through the contributions of soil to ecosystem services in arid Omani contexts. To our knowledge, few (if any) undergraduate soil programs have involved a comparable degree-level redesign rather than piecemeal course revisions, underscoring the distinctiveness of the SQU model. This approach aligns with Spronken-Smith et al.'s (2011) perspectives, who note that "the focus on graduate attributes, together with the holistic consideration of the degree program rather than on a piecemeal course-by-course basis, allowed the development of a coherent program, progressively building skills and knowledge through to graduation." Revitalizing soil-science education is not a supplementary curricular innovation but a strategic imperative. Embedding ecosystem service thinking, systems-based pedagogy, and SDG-linked outcomes into curricula is essential for repositioning soil education as a cornerstone of sustainability science. Training students to assess, manage, and communicate the multifunctionality of soil through interdisciplinary, inquiry-driven, and stakeholder-informed models will cultivate professionals equipped with technical expertise, ethical foresight, a transdisciplinary vision, and action-oriented thinking.

Case studies from SQU (Oman) and MSU (Russia) demonstrate how transformative pedagogy (through debate-based learning, research–teaching integration, hydropedological modelling, and field-based collaboration) can produce graduates capable of translating soil knowledge into policy impacts, community engagement, and resilience-building strategies. These programs show that when soil is framed not merely as a scientific subject, but as natural capital fundamental to planetary health, students emerge as sustainability stewards prepared to drive change across sectors.

To unlock soil science's full potential in service of the SDGs, HEIs must embed soil literacy at the heart of sustainable development education. Doing so will not only elevate the visibility and relevance of soil-science globally but also empower a new generation of professionals capable of safeguarding the Earth's most life-sustaining resource.

To realize soil-science education's transformative potential, various strategic actions are recommended. First, the curricular integration of the SDGs must be prioritized. Programs should explicitly embed SDG 4.7 and related targets into course outcomes, design, and assessment frameworks. Creating course matrices that link soil properties to ecosystem services and specific SDG indicators will enhance the conceptual clarity and applied relevance. Importantly, these transformations must be implemented at the program level (rather than limited to individual courses) to ensure coherence, scalability, and sustained institutional impact.

Second, there is a pressing need to promote interdisciplinary pedagogy. Soil-science curricula should be broadened to include linkages with environmental engineering, public health, economics, and policy studies to reflect sustainability challenges' systemic nature. Simultaneously, stakeholder-informed curriculum development should be actively pursued. Collaboration with farmers, policymakers, urban planners, and non-governmental organizations can ensure that educational content remains locally grounded while addressing complex real-world issues.

Another critical recommendation involves strengthening the research–teaching nexus. Embedding student-led research projects, living laboratories, and community-engaged science in undergraduate programs fosters experiential learning and cultivates scientific agencies. In support of this, institutions should focus on the modernization of tools and technologies by equipping students with skills in HYDRUS modeling, GIS, remote sensing, data analytics, and tools essential for modern environmental decision-making.

Further, students should be prepared to function as policy advocates and knowledge brokers with dedicated training in science communication, sustainability discourse, and participation in policy platforms such as intergovernmental committees. Global collaboration and mobility have a significant potential. Joint degree programs, field exchanges, and cross-institutional teaching partnerships can expose students to diverse soil systems and sustainability strategies.

Faculty development and institutional incentives are essential for sustaining such innovations. Training educators in sustainability pedagogy, transdisciplinary approaches, and co-creation techniques will build instructional capacity, and the recognition of teaching excellence should be institutionalized. Additionally, establishing longitudinal impact assessment frameworks could help monitor the effectiveness of SDG-integrated curricula on graduate skills, civic engagement, and professional success.

Finally, we call for greater visibility of soil in SDG policies and discourse. Advocating the explicit recognition of soil systems in UN documents, national education strategies, and sustainability science literature is vital for positioning soil science as a key discipline for achieving global development goals.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

SA-I and AU made substantial contributions to the study concept/design and drafting of the manuscript. JB revised the manuscript critically for important intellectual content. All authors contributed to the article and approved the submitted version.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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REFERENCES

Ackoff, R. L. (1989). From Data to Wisdom. *J. Appl. Syst. Anal.* 16, 3–9.

Adhikari, K., and Hartemink, A. E. (2016). Linking Soils to Ecosystem services—A Global Review. *Geoderma* 262, 101–111. doi:10.1016/j.geoderma.2015.08.009

Aggarwal, P., and O'Brien, C. L. (2008). Social Loafing on Group Projects: Structural Antecedents and Effect on Student Satisfaction. *J. Mark. Educ.* 30 (3), 255–264.

Al-Ismaily, S. S., Kacimov, A. R., Al-Maktoumi, A. K., and Al-Busaidi, H. A. (2018). Progressing from Direct Instruction to Structured and Open Inquiry-Based Teaching in a Bachelor of Soil Sciences Program: Experience at the National University in Oman. *J. Geosci. Educ.* 67, 3–19. doi:10.1080/10899995.2018.1509571

Al-Ismaily, S., Al-Mayhai, A., Al-Busaidi, H., Kacimov, A., Blackburn, D., Al-Maktoumi, A., et al. (2021). Soil Skills Challenge: A Problem-Based Field Competition Towards Active Learning for Bsc. Geoscience Students. *Geoderma* 385, 114903. doi:10.1016/j.geoderma.2020.114903

Al-Ismaily, S., Kacimov, A., Al-Mayhai, A., Al-Busaidi, H., Blackburn, D., Al-Shukaili, A., et al. (2023). The "Soil Skills" Pedagogical Approach Conjugated with Soil Judging Contests. *Span. J. Soil Sci.* 13, 12081. doi:10.3389/sjss.2023.12081

Annan-Diab, F., and Molinari, C. (2017). Interdisciplinarity: Practical Approach to Advancing Education for Sustainability and the Case of the Brighton Business School. *Int. J. Manag. Educ.* 15 (2), 287–298.

Avelar, A. B. A., Da Silva Oliveira, K. D., and Farina, M. C. (2023). The Integration of the Sustainable Development Goals into Curricula, Research and Partnerships in Higher Education. *Int. Rev. Educ.* 69 (3), 299–325. doi:10.1007/s11159-023-10013-1

Beers, G. W. (2005). The Effect of Teaching Method on Objective Test Scores: Problem-Based Learning Versus Lecture. *J. Nurs. Educ.* 44, 305–309. doi:10.3928/01484834-20050701-03

Bouma, J. (2014). Soil Science Contributions Towards Sustainable Development Goals and Their Implementation: Linking Soil Functions with Ecosystem Services. *J. Plant Nutr. Soil Sci.* 177 (1), 111–120. doi:10.1002/jpln.201300646

Bouma, J. (2023). The Role of Hydropedology when Aiming for the United Nations Sustainable Development Goals. *Vadose Zone J.* 23, e20269. doi:10.1002/vzj2.20269

Bouma, J. (2025). The Increasing Relevance of Soil Science and Soil Security in a Changing Agricultural Policy Environment. *Soil secur.* 19, 100192. doi:10.1016/j.soisec.2025.100192

Bouma, J., Montanarella, L., and Evanylo, G. (2019). The Challenge for the Soil Science Community to Contribute to the Implementation of the UN Sustainable Development Goals. *Soil Use Manag.* 35 (4), 538–546. doi:10.1111/sum.12518

Brevik, E. C., Krzic, M., Muggler, C., Field, D., Hannam, J., and Uchida, Y. (2022). Soil Science Education: A Multinational Look at Current Perspectives. *Nat. Sci. Educ.* 51 (1), e20077. doi:10.1002/nse2.20077

Brew, A., and Mantai, L. (2017). Academics' Perceptions of the Challenges and Barriers to Implementing Research-Based Experiences for Undergraduates. *Teach. High. Educ.* 22 (5), 551–568. doi:10.1080/13562517.2016.1273216

Cottafava, D., Corazza, L., and Cavagliá, G. (2020). "Struggles and Successes of Transformative Learning for the Sdgs: A Case Study," in *Struggles and Successes in the Pursuit of Sustainable Development* (Milton Park: Routledge), 11–22.

European Commission (EC) (2025). "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Commission of the Regions. A Vision for Agriculture and Food Shaping Together an Attractive Farming and Agri-Food Sector for Future Generations," in *COM/2025/75 Final* (Brussels: European Commission).

European Union (EU) (2023). "European Missions," in *A Soil Deal for Europe—100 Living Labs and Lighthouses to Lead to the Transition Towards Healthy Soils by 2030; Implementation Plan* (Brussels, Belgium: European Commission).

European Union (EU) (2024). *Strategic Dialogue on the Future of EU Agriculture. A Shared Prospect for Farming and Food in Europe*. Brussels, Belgium: European Union.

Field, D. J., Koppi, A. J., Jarrett, L. E., Abbott, L. K., Cattle, S. R., Grant, C. D., et al. (2011). Soil Science Teaching Principles. *Geoderma* 167, 9–14. doi:10.1016/j.geoderma.2011.09.017

Heldal, R., Nguyen, N. T., Moreira, A., Lago, P., Duboc, L., Betz, S., et al. (2024). Sustainability Competencies and Skills in Software Engineering: An Industry Perspective. *J. Syst. Softw.* 211, 111978. doi:10.1016/j.jss.2024.111978

Hupy, J. P. (2011). Teaching Geographic Concepts Through Fieldwork and Competition. *J. Geogr.* 110 (3), 131–135. doi:10.1080/00221341.2011.532229

Keesstra, S. D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., et al. (2016). The Significance of Soils and Soil Science Towards Realization of the United Nations Sustainable Development Goals. *Soil* 2, 111–128. doi:10.5194/soil-2-111-2016

Kwok, S. (2018). Science Education in the 21st Century. *Nat. Astron* 2 (7), 530–533. doi:10.1038/s41550-018-0510-4

Lal, R., Bouma, J., Brevik, E., Dawson, L., Field, D. J., Glaser, B., et al. (2021). Soils and Sustainable Development Goals of the United Nations: An International Union of Soil Sciences Perspective. *Geoderma Reg.* 25, e00398. doi:10.1016/j.geodrs.2021.e00398

Lazonder, A. W., and Harmsen, R. (2016). Meta-Analysis of Inquiry-Based Learning: Effects of Guidance. *Rev. Educ. Res.* 86 (3), 681–718. doi:10.3102/0034654315627366

Lomonosov, M. V. (1763). О Слояч Земли *[On the Layers of the Earth]*. Moscow: Gosgeoliizdat.

Mikhailova, E. A., Stiglitz, R. Y., Post, C. J., Pargas, R. P., Campbell, T. M., Payne, K. S., et al. (2018). Teaching Sensor Technology and Crowdsourcing with Reusable Learning Objects. *Nat. Sci. Educ.* 47 (1), 1–18. doi:10.4195/nse2018.08.0015

Mikhailova, E. A., Post, C. J., and Nelson, D. G. (2024). Integrating United Nations Sustainable Development Goals in Soil Science Education. *Soil Syst.* 8 (1), 29. doi:10.3390/soilsystems8010029

Noguera, C. L., Pérez-Esteve, E., Fernández, F. R., Soto, M. S., and Vidal-Meló, A. (2021). "Activities Implemented in Soil Science Subjects to Learn Specific Competencies and Sustainable Development Goals," in *ICERI2021 Proceedings. Barcelona, Spain: IATED*, 4254–4262.

Rasmussen, L. M., Williams, C. E., Hausfeld, M. M., Banks, G. C., and Davis, B. C. (2020). Authorship Policies at US Doctoral Universities: A Review and Recommendations for Future Policies. *Sci. Eng. Ethic* 26 (6), 3393–3413. doi:10.1007/s11948-020-00273-7

Riga, F., Winterbottom, M., Harris, E., and Newby, L. (2017). "Inquiry-Based Science Education," in *Science Education*. Editors K. S. Taber and B. Akpan (Rotterdam, Netherlands: Sense), 247–261.

Ross, M., Van Dusen, B., Sherman, S., Otero, V., Rebello, N. S., Engelhardt, P. V., et al. (2012). Teacher-Driven Professional Development and the Pursuit of a Sophisticated Understanding of Inquiry. *AIP Conf. Proc.* 1413 (1), 327–330. doi:10.1063/1.3680061

Serafini, P. G., Moura, J. M., Almeida, M. R., and Rezende, J. F. D. (2022). Sustainable Development Goals in Higher Education Institutions: A Systematic Literature Review. *J. Clean. Prod.* 370, 133473. doi:10.1016/j.jclepro.2022.133473

Shein, E. V., and Umarova, ABSA (2008). S.A. Vladychenskii as a Teacher. *Eurasian Soil Sci.* 41 (10), 1022–1024. doi:10.1134/S1064229308100025

Sipos, Y., Battisti, B., and Grimm, K. (2008). Achieving Transformative Sustainability Learning: Engaging Head, Hands and Heart. *Int. J. Sustain High. Educ.* 9 (1), 68–86. doi:10.1108/14676370810842193

Spronken-Smith, R., Walker, R., Batchelor, J., O'Steen, B., and Angelo, T. (2011). Enablers and Constraints to the Use of Inquiry-Based Learning in Undergraduate Education. *Teach. High. Educ.* 6 (1), 15–28. doi:10.1080/13562517.2010.507300

Swan, T., McBratney, A., and Field, D. (2024). Linkages Between Soil Security and One Health: Implications for the 2030 Sustainable Development Goals. *Front. Public Health* 12, 1447663. doi:10.3389/fpubh.2024.1447663

UNESCO (2020). Education for Sustainable Development: A Roadmap. Available online at: https://unesdoc.unesco.org/ark:/48223/pf0000374802 (Accessed June 5, 2025).

United Nations (UN) (2015). Transforming Our World: The 2030 Agenda for Sustainable Development. Available online at: https://sdgs.un.org/2030agenda (Accessed June 5, 2025).

Veenstra, J., Coquet, Y., Melot, R., and Walter, C. (2024). A European Stakeholder Survey on Soil Science Skills for Sustainable Agriculture. *Eur. J. Soil Sci.* 75 (2), e13449. doi:10.1111/ejss.13449

Watkins, J., Coffey, J. E., Redish, E. F., and Cooke, T. J. (2012). Disciplinary Authenticity: Enriching the Reforms of Introductory Physics Courses for Life-Science Students. *Phys. Rev. Spec. Top. Phys. Educ. Res.* 8 (1), 010112. doi:10.1103/physrevstper.8.010112

Weiss, M., Barth, M., and Von Wehrden, H. (2021). The Patterns of Curriculum Change Processes that Embed Sustainability in Higher Education Institutions. *Sustain Sci.* 16 (5), 1579–1593. doi:10.1007/s11625-021-00984-1

Wheelan, S. A. (2009). Group Size, Group Development, and Group Productivity. *Small Group Res.* 40 (2), 247–262. doi:10.1177/1046496408328703

Wiek, A., Withycombe, L., and Redman, C. L. (2011). Key Competencies in Sustainability: A Reference Framework for Academic Program Development. *Sustain Sci.* 6, 203–218. doi:10.1007/s11625-011-0132-6

Zamora-Polo, F., Sánchez-Martín, J., Corrales-Serrano, M., and Espejo-Antúnez, L. (2019). What Do University Students Know About Sustainable Development Goals? A Realistic Approach to the Reception of This UN Program Amongst the Youth Population. *Sustainability* 11 (13), 3533. doi:10.3390/su11133533

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Helping Future Schoolteachers Discover and Teach Soil: An Example of Project-Based Learning

Delphine Aran *

Département de Sciences de la Vie et de la Terre, LIEC UMR 7360 CNRS, Université de Lorraine, Metz, France

In addition to fundamental knowledge, the teaching provided at primary school develop children's perceptions of the world, particularly that of the effects of human activities on the environment. However, despite its importance in these issues, soil is virtually absent from school curricula, and even more so from the training of future schoolteachers. In order to provide knowledge about soil and its crucial role in the challenges facing humanity, an educational project has been developed at the University of Lorraine for students on the multidisciplinary bachelor's degree in teaching course during the past 5 years. Over fifty students follow traditional soil science courses and then use their knowledge in an active-learning setting. Within the framework of a project-based learning, they organize and carry out an activity session focusing on soil in a class of elementary school pupils, which is a kind of practice for their future teaching careers. The students follow the different stage in building their project. They design their workshop around a soil-linked theme of their choice, respecting the curriculum expectations. They establish a scientific approach to the chosen question and draw up the timetable for their activity, specifying the learning objectives and the resources to be used. They then carry out their activity session with a class at a partner school. The project is assessed on the basis of the students' concrete achievements, as well as their effective analysis of their work. This type of project-based teaching engages students because it gives them the opportunity to take ownership of the discipline through the production of a tangible output. Building and then carrying out the activity session helps to develop students' independence, creativity, and teamwork while at the same time imposing a framework that they must respect. It also enabled them to create a good quality animation, even though for most of them this was their first introduction to the subject of soils.

Keywords: project-based learning, primary school, teaching soil science, undergraduate student, future schoolteacher

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Luis Roca Perez, University of Valencia, Spain

****Correspondence***
Delphine Aran, delphine.aran@univ-lorraine.fr

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INTRODUCTION

The main objective of primary education is to provide a common foundation of fundamental knowledge and skills. These skills, like reading and writing, should enable pupils to master the language needed for reflection and communication. Likewise, science teaching develops their capacity for reasoning and practice of the investigative approach. At the end of this learning process, pupils should be in a position to continue their studies, consolidating their knowledge and building their personal, professional, and civic futures.

In France, science teaching in "cycle 3" primary schools (corresponding to fourth and fifth grade, i.e., children between 9 and 10 years old) aims to give pupils the initial scientific and technical culture they need to understand the world and the major challenges facing humanity. A significant proportion of these programs is devoted to the environment: pupils are encouraged to use their knowledge to explain the impact of human activity on health and the environment, and they are made aware of the issues of climate change, biodiversity, and sustainable development.

Although the soil is of central importance in these environmental issues, it is mentioned in cycle 3 guidelines only twice; once in terms of resources, i.e., "Reasonable exploitation and use of resources (water, oil, coal, minerals, biodiversity, soils, wood, rocks for construction purposes, etc.)"; and once in terms of support, i.e., "Observe and describe the soil stand; follow its evolution over the seasons". Similarly, the links between the various scientific themes covered (biodiversity, origin of food consumed, needs of chlorophyll organisms, decomposers, landscapes, etc.) and soil are numerous, but they are not specifically addressed as the subjects of dedicated teaching. Furthermore, soil science is potentially relevant—but absent from—the plastic arts curriculum (modelling; quality of materials; pigments) and geography (characterizing spaces and their functions; meeting energy, water and food needs), for example[1].

Clearly, the teaching of soil science should be integrated into elementary school curricula to increase pupils' awareness of the links between people and soil, and thus raise their awareness of major soil-related issues (Brevik et al., 2022a). Indeed, the link between soils and ecosystem services has been the subject of much research (Adhikari and Hartemink, 2016), but despite their essential place in the environment, soils are still poorly understood by the public (Field et al., 2020). It is therefore crucial to raise people's awareness of soil as a fragile part of our environment and the importance of taking care of it (Field et al., 2020). This is one of the goals of the EU Mission "A Soil Deal for Europe," leading to a transition towards healthy soils by 2030 and raising people's awareness of their vital importance. This is also part of Sustainable Development Goal 4 "Quality education," in which raising awareness of soil, its existence, uniqueness and multiple connections with other ecosystem components is crucial (Lal et al., 2021). To make tomorrow's citizens aware of the importance of soils, without turning them into specialists, it is necessary to teach about soils from school onwards (Brevik et al., 2022a).

To raise schoolchildren's awareness of soil, it is first necessary to train their teachers. In a study reviewing the integration of environmental issues in primary and secondary education worldwide, over a third of survey respondent indicated that teacher training programs did not include any environment-related content (Unesco, 2021). For those benefiting from such training, the topics covered did not explicitly mention soil, except in context of land protection. As a result, for students intending to become school teachers, the subject is virtually absent from their syllabus: most have no notion of soil and its importance, and they do not see this knowledge as useful for their future profession. It is therefore essential to help students who intend to teach (notably at primary level) to become aware of and familiar with soils, through training that will enable them to teach the basics of soil science with confidence (Brevik et al., 2022b). The use of active teaching methods can be a good way of training these students, who are initially unmotivated by this discipline. In addition, for this type of teaching limited to an introduction to soil science, methods integrating content learning with problem-solving skills proved effective in terms of student engagement (Amador and Görres, 2004). With the development of the Internet and access to a multitude of information, and with the rapid evolution of concepts in the environmental sciences, it is no longer sufficient to simply have students memorize lectures; it is more efficient to teach them how to search for relevant information (Dahms et al., 2020). Furthermore, this work of evaluating and synthesizing the information gathered, and then transmitting it to a public of pupils, is the basis for the future employment of students intending to become school teachers. Throughout history, from Socrates to Montessori, pedagogues have been interested in active teaching methods, but these methods only really became established in higher education with the massive rise in student numbers in the 1960s, necessitating alternative training methods (De Graaff and Kolmos, 2007).

Project-based learning is a student-centered approach that requires students to produce a result, and it takes place at the end of a course when students have acquired sufficient knowledge to undertake a project (Savin-Baden, 2007). Though the realization of an end product is the driving force in such collaborative project work, the success of this approach lies in the knowledge and skills developed throughout the process according to Donnelly and Fitzmaurice (2005). De Graaf and Kolmos (2003) identify three types of project work in order of increasing degree of freedom left to students: the task project with a very high degree of planning and direction by the teacher, the discipline project where disciplines and methods are chosen in advance, the problem project in which the plan of action is not planned in detail by the teacher. This technique of project-based work enables significant achievements, as students are able to find new and original solutions, then apply them to real-life practice, without outside help (Alacapınar, 2008). To succeed with a project-based approach, Kokotsaki et al. (2016) recommend the adoption of the following six points: student support, teacher support, effective group work, balance between didactic instruction with independent inquiry method, assessment emphasis on reflection, self and peer evaluation and student choice and autonomy. Almulla (2020) and Guo et al. (2020) propose encouraging teachers in higher education to implement project-based pedagogy as it engages students in learning and promotes their capacity for innovation through a process of active construction of their knowledge. To achieve this, teachers need to change their role from presenting information as lectures to acting as facilitators, learning guides and coaches (Donnelly and Fitzmaurice, 2005; Özel, 2013). Although this type of pedagogy is attractive to teachers, they are often helpless when faced with this change of role and organization, and are often content to implement active learning methods intuitively. To support teachers in following project-based learning principles

[1]https://www.education.gouv.fr/bo/20/Hebdo31/MENE2018714A.htm

and acquiring their new role, García Martín and Pérez Martínez (2017) have developed a guide for designing activities detailing the phases of definition (objectives, context, resources etc.), support (weaknesses and strengths of students, supporting etc.) and organization (activities, scheduling).

The aim of the present study was to introduce future school teachers to the subject of soil, to fill the gap left by the absence of this discipline in teacher training programs, and despite soil being of crucial interest in environmental issues. For this purpose, an active teaching method was implemented with students intending to teach in primary schools. The aim of creating a concrete project around the theme of soil was firstly to help them acquire knowledge in this area, but also to interest them in this relatively unknown discipline so that they could integrate it into their future teaching. This project-based learning approach in addition aims to develop cross-disciplinary and professional skills that will be useful for their future teaching careers. Lastly, presenting their project in front of a real class (with its current teacher) helps to "bring soil" into the school and may help raise people's awareness of soil issues.

PROFILE OF STUDENTS INVOLVED IN THE PROJECT

Students intending to teach in primary schools (kindergarten and elementary) are required to pass a competitive examination to become a school teacher. The best way to take this exam is to enroll in a Master's degree in Teaching, Education and Training (TET), offered by the French national institutes of higher education. This Master's degree is available in a variety of specializations, and can be accessed after obtaining a bachelor's degree. To enter the "first degree" stream of the TET Master's program and prepare for teaching in primary school, it is necessary to have completed a Bachelor's degree in any subject, although it is advisable to choose a subject taught in primary schools (French, mathematics, science, history, etc.). As there are no soil science courses in Master's programs, future teachers need to be introduced to this discipline during their preparatory studies at Bachelor's level.

Many universities offer a preparatory course for the teaching profession within the framework of various Bachelor's degrees. This is the case at the University of Lorraine, which offers a multidisciplinary teacher training program linked to several science-related Bachelor's degrees: mathematics, physics, chemistry, life sciences, and Earth sciences. The program takes place in the 3rd year of a Bachelor's degree, and it is open to students from 2nd year scientific courses. Since it opened in September 2018 on the Metz site (University of Lorraine), this course has welcomed over fifty students from a variety of 2nd year backgrounds (**Figure 1**), all of whom participated in the project presented in this study. This course therefore has a fairly heterogeneous student body in terms of areas of scientific knowledge, with around two thirds of students not having studied life and Earth sciences since high school, and who therefore have no knowledge of soil science when they enter the multidisciplinary Bachelor's degree in teaching. This heterogeneity can also be used to develop students' interest in soil science through its sub-disciplines (soil chemistry, soil physics, etc., Churchman (2010)) with which they can identify.

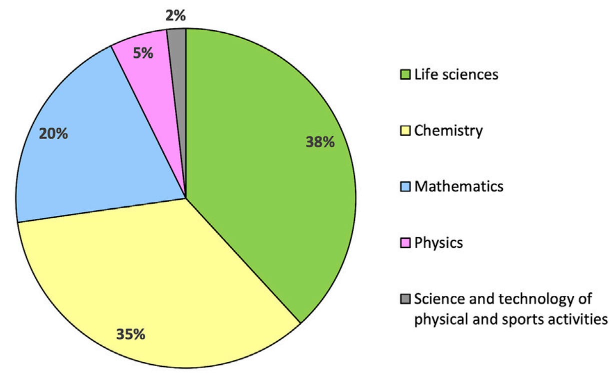

FIGURE 1 | Origin (Bachelor's degree, 2nd year) of students (n = 55) in the multidisciplinary Bachelor's degree in school teaching.

The program of this training includes courses preparing for entry into the TET Master's degree with a strong scientific focus, including a 55-hour life and Earth science course each semester (details of the program are provided in the **Supplementary Material**). In the first semester, the basics of geology and biology necessary for future science teaching are covered. These lessons are also an opportunity to make a link with soil sciences (types of rocks, plant needs, notions of ecosystems, etc.). In the second semester, additional lessons in Earth sciences are devoted to soil sciences (25 h). Given that the number of hours allocated to this teaching is relatively limited, it is difficult to provide students a solid grounding in soil science over such a short period. In addition, it should be remembered that these students are not destined to pursue studies in this field, and that soil science is not, for the moment, on the TET Master's program. It therefore seemed appropriate to provide a basic knowledge of soils by means of project-based learning in order to use the available time volume efficiently and to mobilize students on a subject that many have never approached and that they will probably never study again. For this type of introductory soil science course, project-based learning is a viable alternative to more classical methods (Amador and Görres, 2004).

USING PROJECT-BASED LEARNING

Project Framework

Students are tasked with creating an activity session for primary school pupils, with the aim of introducing them to the major issues related to soil. The choice of the type of activity (video, exercises, classic course) is entirely free in order to develop the creativity of the student and reinforce their motivation. The classes concerned have always been double classes, in 4th and 5th grade (corresponding to children aged 9–10), with an average of around twenty pupils per class. Certain constraints are imposed, such as the duration of the activity (45 min) and the date of the session. These constraints are established upstream between the higher education teacher who supervises the project (referent teacher) and the schoolteacher hosting the activity in their class. The theme of the activity must deal with soil, but the students are free to choose the angle from which they approach the subject (while respecting the expectations of the official program of the classes concerned). This mixture of autonomy and constraints places the students in their future professional situation from the start of the project in terms of analysis and respect of school programs; choice among different approaches for the development of a pedagogical sequence; and adaptation to the level of the pupils.

Project Organization

Soil science courses (25 h) take place in the second semester of the academic year (January–June) and start at the beginning of the semester with a presentation of the project-based approach, specifying objectives, constraints, assessment methods and general organization (1 h).

To ensure that students quickly gain a knowledge base that enables them to get involved in their project, classic classroom courses in soil science are given at the beginning of the semester. Over 12 h, these lessons present the basics of the discipline: soil definition; horizon concepts; soil constituents and properties; and an overview of the ecosystem services provided by soils and the threats affecting them. As this teaching is very dense in relation to the time devoted to it, students have access to an online course (on Moodle) created by the referent teacher, which enables them to review some concepts, access photographs or illustrations different from those in the course, and take part in short self-assessment quizzes. A two-hour field trip enables them to observe a local soil type (color, texture, structure, horizons, humus, etc.) and make connections between geological context, plant cover, and land use. At the end of these preparatory courses, an initial assessment of the knowledge acquired is carried out, and this counts for 40% of the final grade (of the soil science course).

Once the traditional lessons have been completed, the remaining 10 h are devoted to developing the project under the referent teacher's supervision. Sessions are staggered throughout the semester, so as to meet regularly with students before the activity date (end of April or end of May, depending on the year). Given the low number of hours, students are required to work on their projects outside of the sessions, which can entail a significant amount of personal work. During the sessions, monitoring by the referent teacher is fundamental, and this is one of Kokotsaki et al. (2016) recommendations for a successful project-based approach. The teacher must do more than simply answer students' questions; they must guide them to find answers themselves and warn them of certain pitfalls that could jeopardize their project (purchase of materials, time management, etc.). The role of the referent teacher here is to guide students, not direct them. It is a difficult balance between student motivation (answering all their questions will not encourage them think on their own) and frustration (ignoring their legitimate questions risks demobilizing them) (Morgan and Slough, 2013).

Project Implementation

Students are first divided into groups of four to seven people, either by the teacher (to mix profiles) or freely by the students. This division into small groups encourages collaborative work and facilitates teacher supervision. Due to the relatively small class sizes, two groups are formed each year. For the first year of the degree's existence (2018–19), only one group was formed due to the very low number of students. Nine students worked on the same theme (soil and water, **Table 1**), each taking charge of a different session (the water cycle, water storage in the soil, water pollution). This choice was also made because no school could be found to host the activity, so the students worked on a theoretical project. In the following years (2019–20 and 2020–21), two groups were formed and worked on separate topics, which were then carried out in different classes. Unfortunately, the COVID-19 pandemic triggered strict lockdown from March 2020, and the students were unable to carry out their activity in class. Although the rules were relaxed (classroom lessons could resume in April or June 2020, depending on the zone), outsiders were not allowed to intervene in classes. In 2021, the situation deteriorated further, and strict health protocols made it impossible to run the activity session face-to-face, so the students had to transform it into a distance-learning version. In 2021–22, the two groups worked on the same theme, one with a face-to-face version and one with a remote version in anticipation of a possible re-confinement, which did not occur but taught students how to prepare distance-learning sessions and master the skills needed (creating an e-book, for example). Finally, in 2022–23, the two groups were able to work on two different themes and carry out their activities in two classes. This somewhat complex series of events as disrupted by the pandemic enabled different types of group work (whole class or small groups) and different teaching methods (face-to-face, unscheduled distance learning, planned distance learning) to be evaluated. In all, over the 5 years of its existence, this project has involved just over fifty students (**Table 1**) and, counting only face-to-face actions, has reached around sixty elementary school pupils.

The topics chosen by the students (**Table 1**) relate to water (soil and water, soil water retention, soil water erosion) or soil biology (soil decomposers, soil fauna). Two themes (searching for treasure, the treble clef) are based on the discovery of treasure using soil-based clues, e.g., the type of soil on the boot-soles of the person that buried the treasure, or the type of soil in which the treasure chest key has been hidden. Another topic (soils of Lorraine), which will be detailed later, uses the same activities (study of color, texture, etc.) but for a different purpose. Students are totally free to choose their own theme, which is decided fairly quickly through group discussions (usually as early as the 2nd session). The referent teacher validates the chosen theme during a presentation where students explain the links between their theme and the school curriculum. It should be pointed out here that students are not asked to create an activity session from nothing; they are allowed to draw inspiration from anything they find in their research (mostly on the web), as this will later

TABLE 1 | Chosen themes and activities produced.

Year	Number of students	Themes	Activity type	Partner school
2018–19	9	- Soil and water	Theorical	none
2019–20	13	- Searching for treasure - Soil decomposers	Cancelled (COVID-19)	La Patrotte J. Moulins (57050 Metz)
2020–21	11	- The treble clef[a] - Soil water erosion	Distant (COVID-19)	La Ballastière (57300 Hagondange)
2021–22	11	- Soil water retention	Distant and presential	G. Hoffmann (57000 Metz)
2022–23	11	- Soil fauna - Soils of Lorraine	Presential	G. Hoffmann (57000 Metz)

[a]*French word game: the treble clef corresponds to the G clef in French, where the G note is called "sol", which also means soil.*

be part of their work as schoolteachers. Many examples of experiments on the theme of water or soil fauna can be found on the Internet. Students can use these examples, provided they make the effort to understand them correctly, examine them critically, and adapt them if necessary (to the audience, the material available, etc.).

Once the theme has been validated, the students work on designing the activity. They have to research the knowledge they need in relation to the theme and any existing resources on the subject. They then select the format of the activity (traditional course, in-class manipulations, games and riddles, etc.). They are required to have pupils practice the successive stages of the scientific approach, i.e., problem, questioning, hypotheses, experiments and/or observations, interpretations, and conclusions. The students also prepare documents (for the pupils and for the schoolteacher) and materials (video, soil and fauna samples, magnifying glasses, etc.) needed for their presentation. They also have to test their experiments and modify them if necessary, to make sure they work properly in the classroom. Throughout these sessions, the referent teacher assists students with theoretical aspects (acquisition of knowledge), practical aspects (help in choosing soils, loan of small equipment, etc.) and pedagogical aspects (advice on choosing vocabulary adapted to the audience, for example). The challenge for the referent teacher here is to avoid responding directly to students, rather encouraging them, wherever possible, to find their own solutions or answers to their questions or needs.

Finally, the concrete result of the project is the presentation of the activity to a class. The schoolteacher hosting the activity introduces the students to the pupils, then the students perform the various steps of their activity (information on the theme, questioning, presentation of equipment, division of pupils into small groups, management of experiments, summary on the blackboard). During the activity session, the students manage 'their' class on their own, with neither the schoolteacher nor the referent teacher intervening in the process. After the activity, the schoolteacher gives the students feedback on what went well and what could be improved. Lastly, a final exchange between the students and the referent teacher takes place to draw up an assessment of the project.

Student Evaluation

The assessment method varied from year to year depending on the number of students and the constraints imposed by the COVID-19 pandemic. The project grade counts for 60% of the final mark, and the assessment method has stabilized as follows: A mark is assigned by the referent teacher to the project as a whole in terms of structuring, quality of documents produced, scientific approach, in-class implementation, etc. All students in the group working on the same project have the same mark at this point. This score is then personalized for each student by applying bonus or penalty points. These points are awarded according to three aspects: First, the teacher evaluates each student's behavior throughout the project. These points are rather difficult to award, because while the teacher has a fairly clear view of what takes place during the classroom sessions, it is more difficult to assess a student's contribution outside these sessions. This is corrected by the application of points based on a second aspect: student peer-assessment within a group. Each student fills in a grid evaluating the behavior of other students on the basis of criteria such as their contributions (and their relevance), the responsiveness of each, responses to the solicitations of others, the organization of meetings, their coordination, influence in the group, conflict management). The teacher then compiles all these grids and has a clearer picture of everyone's involvement. However, care must be taken when awarding points to avoid any cronyism or unfair judgments on the part of students. Final points are awarded on the basis of the quality of the report produced by the students: on completion of the project, all students are required to write a report detailing their involvement, their feelings and their reflective analysis of the project, which is an important practice for future teachers (Loughran, 2002).

Example of Realization

It seems useful to detail here an example of an activity session to show what can be achieved by students with no prior knowledge of soil science (other than the 14-hour course at the start of the project). The example presented is "Soils of Lorraine" because of its originality and because it was one of the most accomplished projects.

The activity begins with questions asked by students to pupils: "Where do the vegetables we eat grow?", "What are our clothes

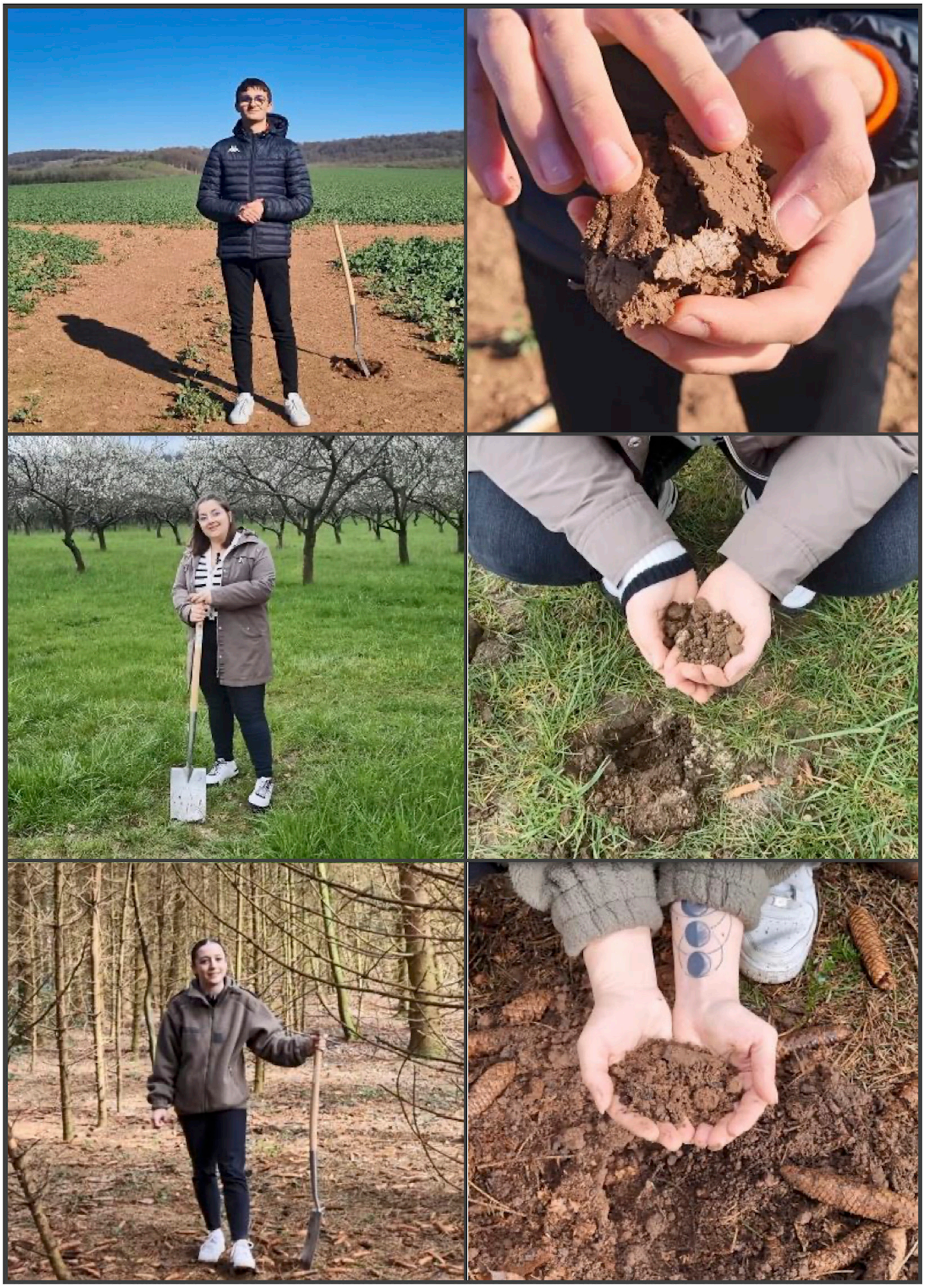

FIGURE 2 | Screenshots of the video showing three types of occupation (left) and their corresponding soils (right).

made of?", "Where do we get our cotton?", "Where does the wood we put in the stove, or the wood that makes up part of our houses, come from?" The aim of this question-and-answer game is to have pupils make the link between ecosystem services (food production, etc.) and the soil. Pupils are then invited to consider this diversity of services in relation to different soils using a short video (7 min). The video was created by the students on the model of a famous French TV program, "C'est pas sorcier"

FIGURE 3 | In-class activities. **(A)** Correction of the grid. **(B)** Observations and manipulations. **(C)** Synthesis on the board. **(D)** Distribution of the diploma. Photo credits: A and D: Delphine Aran, B and C: Christophe Deloison.

(that can be translated as "It's not rocket science"), which deals with science popularization for children. The video shows three types of land use in Lorraine (field, orchard, and forest) and describes the three related soils in terms of color, texture, etc. (**Figure 2**). As the video is shown, pupils fill in a questionnaire to help them identify important information (the soil under forest cover is sandy, for example). At the end of the viewing, students proceed with a correction to check that the correct information has been recorded (**Figure 3A**).

The class is then divided into three groups, each with one of the three soil samples. The game here is to have the pupils believe that the students in the video forgot to note the soil type on the bags and only put a number, so they'll have to work out which soil corresponds to which occupation type. Each group is supervised by a student who guides them in observing the soil and filling in the description grid. Pupils note color, presence of stones, texture (by touch), pH (using a pH measurement kit), and presence of limestone (HCl test) (**Figure 3B**). When the soil description is complete, a pupil from each group comes to the blackboard to record the observation results (**Figure 3C**), and it is then possible to link each soil sample to an occupancy mode (crop, orchard, forest).

The activity ends with an overview by the students of the diversity of soil properties and functions, and the variety of uses that can be made of it. They emphasize the importance of soil protection and make the link with the school curriculum (sustainable exploitation and use of resources, origin of food consumed, landscapes, etc.). At the end of the session, the students award each pupil a diploma as an "apprentice soil scientist" (**Figure 3D**).

ANALYSIS OF THIS APPROACH

The main aim of this project-based approach was to train students in soil science, enabling them to apply this knowledge to their future teaching careers.

In terms of the students' feelings, their perception evolves over time and goes through different stages. At the beginning of the project, students feel unable to carry out the project due to a lack of knowledge: "I was a bit puzzled [. . .] I did not think I had enough knowledge to be able to run an educational activity on the theme of soils," "This project seemed difficult to me because it involved teaching a scientific field I knew nothing about," "I was anxious because I do not have a good grasp of pedology and [. . .] I did not have any ideas for topics," "this project scared me to death [. . .] I was afraid of being a drag for my group." But as the project progressed, this anxiety phase gave way to a phase of unblocking: "A rewarding discussion about the project with one of my classmates reassured me," "As the sessions progressed, our activity idea became clearer to me, and I was able to project myself fully," "I then had a lot of ideas on how to organize the activity in class, which really relieved me," "It was only a few days before our first hour [of project-based learning] that I realized it was not impossible, and that together with our group and everyone's ideas, we were going to be able to carry out an activity." At the end of the project, most students were quite satisfied with the experience: "This presentation project [. . .] to an elementary school was an enriching and captivating experience," "I felt involved throughout the preparation [. . .] I was also proud of what we achieved together," "I really enjoyed doing this educational activity with a class. It's a project out of the ordinary that we probably would not have done without this course," "The whole project was very rewarding and fun to do. The realization of the project was wonderful."

The students particularly appreciated the training aspect of this project with regard to their future profession: "I realized how difficult it could be to create a work for pupils [. . .] I found this approach interesting for us as future school teachers," "This event gave us the opportunity to come face-to-face with the teaching profession, while receiving constructive feedback from a schoolteacher," "It allows us to better project ourselves into the situations that will face us in the future [. . .] this project has been [. . .] a very useful exercise which has enabled us to think like the teachers we would like to become."

For some of them, the project strengthened their choice of career direction: "In addition to the internship, it reinforced the fact that this was really the job I wanted to do," "I also loved presenting the experiments in front of the pupils [. . .] the interaction with the pupils and their enthusiasm were motivating factors, reinforcing the desire to become a school teacher," "Doing this educational activity in front of the children gave me another opportunity to experience what it's like to be a teacher. I felt at ease in front of the pupils and enjoyed watching them manipulate."

It is above all in terms of student motivation that the project-based learning delivers good results. Creating the activity and performing it in front of an audience of schoolchildren anchors their work in the real world and induces a strong sense of authenticity (Condliffe, 2017). Building an end product puts theoretical learning into practice and gives them a sense of pride. During this project, students developed professional skills (program analysis, classroom management), pedagogical skills (creation of documents for pupils), and cross-disciplinary skills (group work). The freedom given them in making choices develops their autonomy, which helps them take ownership of their learning (Kokotsaki et al., 2016). Through the project, they also become more critical of their web searches and learn to adapt (when classroom experimentation does not yield the expected results, for example).

In terms of soil science knowledge, the results are a little less convincing. The classic courses in soil science given at the start of the project were particularly useful for students who had never had access to this subject before (the majority of them, **Figure 1**), and it was here that the contribution of knowledge was most significant. This "preparatory" teaching is fundamental to ensuring that students have the basic knowledge and skills to tackle the project work aspect more easily (Kokotsaki et al., 2016). As part of their project, the students had to deepen their knowledge of some parts of the chosen theme: biodiversity and the trophic chain in the soil, the water storage capacity of the soil, the different types of soil in Lorraine, etc. They gain knowledge during the course of the project, but this is necessarily limited to the project's theme. On the other hand, it is through this deepening of knowledge that students become aware of the complexity of this environment. This awareness should encourage them to go deeper into other aspects of soil when teaching their pupils later on.

Teaching soil science to non-specialists requires more effort from the teacher to have students interested and involved, and project-based learning is a good way of achieving this, combining various teaching methods (Hartemink et al., 2014). Fieldwork is also a fundamental aspect of this discipline and is appreciated by students (Hartemink et al., 2014). Although the field trip is very limited (lasting just 2 hours, which means that only one type of soil and environment can be observed), it is nonetheless crucial, as this is where students will gain an understanding of soil as an ecosystem component and the links with other disciplines (Field et al., 2011). This field trip allows hands-on activities to be carried out (sampling of different horizons, texture, HCl test, pH measurement, etc.), which are known to be a powerful learning tool, particularly as this is not in the students' initial area of interest (Abit et al., 2018). It is also probably the only real contact most students will have with the soil, and it can also be a source of inspiration for the activity session.

As student evaluation had to adapt to the constraints of COVID-19 pandemic, it's not possible to compare the different student cohorts or draw any general trend. Nevertheless, one constant has been students working in teams (except in the first year 2018–19, when students worked on the project more individually due to their low numbers). This teamwork is precisely what makes student assessment complex in a project-based learning. It is therefore important for the grade to accurately reflect everyone's involvement in the group and the quality of each person's work (Field et al., 2011; Kokotsaki et al., 2016). The referent teacher has to set up tools to assess each individual's contribution (regular meetings, intra-assessment, individual reports, etc.) and be vigilant in awarding marks. But apart from the grade, students are attracted by the fact that project-based learning is a good way to demonstrate their learning, in a different way to traditional tests (Grant, 2011). Here, presenting the activity to a schoolchildren audience can be seen as a concrete representation of the students' learning (Condliffe, 2017). The schoolteacher's evaluation of the activity is also perceived positively by the students. Immediately after the activity, the schoolteacher analyzes how it was run and gives advice to the students, particularly in terms of adapting it to the target audience. The various teachers from the partner schools always played along, even during the pandemic when they had to judge on documents alone, and always gave constructive feedback to the students. Students are very sensitive to the opinions of people who are practicing their chosen profession, and this feedback gives them a sense of pride more important than a simple grade.

A subsidiary purpose of the project was to "bring soil" into the school and to reach pupils and their teachers (current and future). As this type of classroom activity is not very common, pupils should remember it fondly. Students always make the choice to provide pupils with an opportunity for hands-on activity, which is particularly beneficial for learning (Field et al., 2011), and soil science is particularly well suited to this. The themes chosen by the students are appropriate for this audience, in line with the official school curriculum, and follow Mori et al. (2020) recommendations on fundamental themes to be addressed in elementary school.

At the end of the activity, the pupils were made aware of the soil and its functions. For the students, this work can be valued in their future profession, when they are in charge of a class. They will be able to repeat the activity in their classrooms, with the improvements suggested by the schoolteachers. The latter can also carry out this activity in the class they will have the next year. Finally, emphasis was given to the implementation of a scientific approach so that pupils could practice it. It also enables students, future teaching staff, to prepare themselves. This is one of the recommendations of the Cavailles and Julien 2023 report,[2] which highlights the inadequate preparation for the scientific approach in the training of school teachers in France.

CONCLUSION

The aim of the soil science project presented here was to train future primary schoolteachers in this discipline, which has received very little attention in their curriculum. Is project-based learning a better approach for preparing students for this purpose compared with traditional methods? Given the heterogeneous nature of the student population and the relatively limited time available, placing students into a real-life professional situation by creating an activity session about soil seems to be an effective method, particularly in terms of motivating them. In carrying out this project, the students acquired knowledge and skills both in the field of soil science and for their future teaching profession. By practicing this project-based learning, they will also be able to apply this type of active pedagogy in their future teaching.

A secondary effect of this project was to raise public awareness of soil-related issues. The project reached out to three different audiences: elementary school pupils, their current teachers, and future teachers. The project also showed that students, most of whom had no initial knowledge of soil science, could be mobilized to organize an effective activity that raises awareness of soil protection among schoolchildren. Thanks to this action, current and future schoolteachers can consider soil as an interesting teaching tool for tackling different themes in the school curriculum (from environmental protection to artistic activities).

This project has only been running for 5 years, and restrictions linked to the COVID-19 pandemic (change of school, switch to distance learning) meant that the impact of this awareness-raising initiative on pupils and their teachers could not be fully monitored. Similarly, it was not possible to accurately assess the benefits of this project for students intending to become teachers, other than in terms of motivation and interest in the subject. With this situation now apparently stabilized, this project could be expanded. Schoolteachers could work with their pupils before the event to prepare the issues addressed and/or return later to assess what has been retained and understood. The students would then need to prepare the documents required for these various actions. Another possibility would be for an event prepared by one group of students to be taken up the following year by the new group of students, keeping the same class of schoolchildren. This would enable the theme to be explored in greater depth with the pupils in that class, and to be followed up. In addition, the progress made by pupils could be observed by means of tests carried out before and after the activity, in order to quantify their learning. A more effective tool should also be used to assess what the students have actually retained and understood thanks to this project. Ideally, it would be useful to interview them once they are in place, to see to what extent they have integrated soils into their teaching.

Finally, considering that the de-artificialization of schoolyards is a topical issue, students could take advantage of the project to raise awareness of this issue in schools. Students could also organize activities outside the school, to observe the soil in a more natural environment. This nature-based teaching, which redeveloped during the COVID-19 pandemic, promotes learning and is an effective way of training environmentally friendly people (Kuo et al., 2019).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The manuscript presents research on animals that do not require ethical approval for their study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

DA: conception, realization, student supervision, manuscript writing.

CONFLICT OF INTEREST

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

[2]J.A. Cavaillès & S. Julien (2023). Rapport N° 21-22 099A, IGÉSR, https://www.enseignementsup-recherche.gouv.fr/sites/default/files/2023-05/rapport-igesr-21-22-099a-27785.pdf

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/sjss.2024.12280/full#supplementary-material

REFERENCES

Abit, S. M., Jr, Curl, P., Lasquites, J. J., and MacNelly, B. (2018). Delivery and Student Perceptions of Drive-Through Laboratory Sessions in an Introductory-Level Soil Science Course. *Nat. Sci. Educ.* 47 (1), 1–8. doi:10.4195/nse2017.07.0015

Adhikari, K., and Hartemink, A. E. (2016). Linking Soils to Ecosystem Services—A Global Review. *Geoderma* 262, 101–111. doi:10.1016/j.geoderma.2015.08.009

Alacapınar, F. (2008). Effectiveness of Project-Based Learning. *Eurasian J. Educ. Res.* 32 (1), 17–34.

Almulla, M. A. (2020). The Effectiveness of the Project-Based Learning (PBL) Approach as a Way to Engage Students in Learning. *Sage Open* 10 (3), 215824402093870. doi:10.1177/2158244020938702

Amador, J. A., and Görres, J. H. (2004). A Problem-Based Learning Approach to Teaching Introductory Soil Science. *J. Nat. Resour. Life Sci. Educ.* 33 (1), 21–27. doi:10.2134/jnrlse.2004.0021

Brevik, E. C., Hannam, J., Krzic, M., Muggler, C., and Uchida, Y. (2022a). The Importance of Soil Education to Connectivity as a Dimension of Soil Security. *Soil Secur.* 7, 100066. doi:10.1016/j.soisec.2022.100066

Brevik, E. C., Krzic, M., Muggler, C., Field, D., Hannam, J., and Uchida, Y. (2022b). Soil Science Education: A Multinational Look at Current Perspectives. *Nat. Sci. Educ.* 51 (1), e20077. doi:10.1002/nse2.20077

Churchman, G. J. (2010). The Philosophical Status of Soil Science. *Geoderma* 157 (3-4), 214–221. doi:10.1016/j.geoderma.2010.04.018

Condliffe, B. (2017). *Project-Based Learning: A Literature Review. Working Paper*. New York: MDRC.

Dahms, H. U., Peterson, T. R., and Baveye, P. C. (2020). Editorial: Innovative Approaches to Learning in Environmental Science. *Front. Environ. Sci.* 8, 121. doi:10.3389/fenvs.2020.00121

De Graaf, E., and Kolmos, A. N. (2003). Characteristics of Problem-Based Learning. *Int. J. Eng. Educ.* 19 (5), 657–662.

De Graaff, E., and Kolmos, A. N. (2007). “History of Problem-Based and Project-Based Learning,” in *Management of Change* (Rotterdam: Sense Publishers), 1–8. doi:10.1163/9789087900922_002

Donnelly, R., and Fitzmaurice, M. (2005). “Collaborative Project-Based Learning and Problem-Based Learning in Higher Education: A Consideration of Tutor and Student Role in Learner-Focused Strategies,” in *Emerging Issues in the Practice of University Learning and Teaching*. Editors G. O’Neill, S. Moore, and B. McMullin (Dublin: AISHE/HEA), 87–98.

Field, D. J., Brevik, E., Hirai, H., and Muggler, C. (2020). “Guiding the Future of Soil (Science) Education: Informed by Global Experiences,” in *Soil Sciences Education: Global Concepts and Teaching*. Editors T. Kosaki, R. Lal, and L. B. Reyes Sánchez (Stuttgart: Catena-Schweizerbart), 191–198.

Field, D. J., Koppi, A. J., Jarrett, L. E., Abbott, L. K., Cattle, S. R., Grant, C. D., et al. (2011). Soil Science Teaching Principles. *Geoderma* 167, 9–14. doi:10.1016/j.geoderma.2011.09.017

García Martín, J., and Pérez Martínez, J. E. (2017). Method to Guide the Design of Project Based Learning Activities Based on Educational Theories. *Int. J. Eng. Educ.* 33 (3), 984–999.

Grant, M. M. (2011). Learning, Beliefs, and Products: Students’ Perspectives With Project-Based Learning. *Interdiscip. J. Problem-Based Learn.* 5 (2), 6. doi:10.7771/1541-5015.1254

Guo, P., Saab, N., Post, L. S., and Admiraal, W. (2020). A Review of Project-Based Learning in Higher Education: Student Outcomes and Measures. *Int. J. Educ. Res.* 102, 101586. doi:10.1016/j.ijer.2020.101586

Hartemink, A. E., Balks, M. R., Chen, Z. S., Drohan, P., Field, D. J., Krasilnikov, P., et al. (2014). The Joy of Teaching Soil Science. *Geoderma* 217, 1–9. doi:10.1016/j.geoderma.2013.10.016

Kokotsaki, D., Menzies, V., and Wiggins, A. (2016). Project-Based Learning: A Review of the Literature. *Improv. Sch.* 19 (3), 267–277. doi:10.1177/1365480216659733

Kuo, M., Barnes, M., and Jordan, C. (2019). Do Experiences With Nature Promote Learning? Converging Evidence of a Cause-And-Effect Relationship. *Front. Psychol.* 10, 305. doi:10.3389/fpsyg.2019.00305

Lal, R., Bouma, J., Brevik, E., Dawson, L., Field, D. J., Glaser, B., et al. (2021). Soils and Sustainable Development Goals of the United Nations: An International Union of Soil Sciences Perspective. *Geoderma Reg.* 25, e00398. doi:10.1016/j.geodrs.2021.e00398

Loughran, J. J. (2002). Effective Reflective Practice: In Search of Meaning in Learning About Teaching. *J. Teach. Educ.* 53 (1), 33–43. doi:10.1177/0022487102053001004

Morgan, J. R., and Slough, S. W. (2013). “Classroom Management Considerations: Implementing STEM Project-Based Learning,” in *STEM Project-Based Learning* (Rotterdam: Brill), 99–107.

Mori, K., Hirai, H., and Kosaki, T. (2020). “Guidelines for Introducing Essence of Soil Science in Pre and Primary School Children,” in *Soil Sciences Education: Global Concepts and Teaching*. Editors T. Kosaki, R. Lal, and L. B. Reyes Sánchez (Stuttgart: Catena-Schweizerbart), 21–30.

Özel, S. (2013). “W^3 of STEM Project-Based Learning: Who, Where, and When: Revisited,” in *STEM Project-Based Learning* (Rotterdam: Brill), 41–49.

Savin-Baden, M. (2007). “Challenging Models and Perspectives of Problem-Based Learning,” in *Management of Change* (Rotterdam: Sense Publishers), 9–29. doi:10.1163/9789087900922_003

Unesco (2021). *Learn for Our Planet: A Global Review of How Environmental Issues Are Integrated in Education*.

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An Educational Gaze From the International Union of Soil Sciences

Laura B. Reyes-Sánchez[1,2]*

[1]Agricultural Engineering Department, National Autonomous University of Mexico, México City, Mexico, [2]International Union of Soil Sciences, Rome, Italy

A lack of fertile soil is already a serious problem due to its role in access to sufficient food and water, but more serious are the social situations that its deficit engenders: loss of food safety and public health, poverty, displacement, inequality, violence, and injustice as a result of famine. The loss and degradation of the soil resource means the loss of all terrestrial flora, and with it, that of the fauna that it feeds. It also means a terrible loss of biodiversity at the planetary level, a serious destruction of the food chain of which we are a part, as well as the reduction of its capacities of available water reserve and C capture to lessen climate change in the long term and with immediate effects. In this context, the protection of the soil resource and an interdisciplinary and innovative education and practice of sciences to raise citizens' awareness of the importance of its preservation—with all the sciences collaborating as a team in a mediatized world—are keys to achieving the Sustainable Development Goals, and therefore, are the long-term goals and prioritized objectives of the International Decade of Soils of the IUSS, and they form the basis of its educational project.

Keywords: soil science, education, awareness, creative literacy, interdisciplinary teaching

INTRODUCTION

As we know, the International Union of Soil Sciences (IUSS) constitutes 60,000 scientists around the world; however, the number of inhabitants on this planet according to the UN is 8.0 billion (UN, 2024), and the vast majority of them do not know why soil is essential for the provision of food to eat, water to drink, and clean air to breathe, fundamental for the realization of all biogeochemical cycles and therefore an indispensable resource for the existence of life on Earth. This means that less than 1% of the world's inhabitants do not know how important the soil resource is for their daily lives. For this reason, the IUSS's "International Decade of Soils 2015–2024" (Horn, 2015; IUSS International Decade of Soils Programme, 2016) has defined two large priorities: "Stop land degradation as the most insidious and underestimated challenge of the 21st century to be defeated," and to achieve this, the "main the focus of our activities should be on school age children (who will be teenagers and young adults in 10 years' time)." Both tasks entail and demand that IUSS, as a scientific society committed to the sustainability of the resource that is the object of its study, aspires to define and lead both the processes of integral formation of its future scientists, as well as the citizen's awareness for the sustainability of the soil, creating a profound impact on the educational and governance environments (Reyes-Sánchez, 2019).

To achieve both tasks, diverse but concurrent actions that are required are proposed in this document to achieve and enhance the educational objectives declared by the IUSS. Reference is also

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Héctor Moreno Ramón, Universitat Politècnica de València, Spain

***Correspondence:**
Laura B. Reyes-Sánchez
lbrs@unam.mx

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made to all those educational actions that have already been undertaken and are currently being carried out.

Similarly to the IUSS, both the "Agenda 2030: an opportunity for people and planet" from (UNICEF, 2017) and the "Reflection Paper Towards a Sustainable Europe in 2030" (EU, 2019), issued by the European Community, recognize that permanent education and learning are indispensable to build a sustainability culture, and that education, science, technology, research, and innovation are a prerequisite to achieve a sustainable economy in the European Union and around the world for compliance with SDGs (UN, 2015).

All these actions are vital to achieve sustainability not only for a continent but at a global level, because there will be no real sustainability for any continent or country if we are not able to build global sustainability. The current challenges to overcome are global challenges.

One of those transcendental challenges is the preservation of fertile soil on the planet and to achieve that, today we need to work to educate and raise awareness about it among the future citizens of the world.

MATERIALS AND METHODS

Why Soil?

Because "the soil is a limited resource under increasing pressure" (FAO, 2012), it is "the fundamental basis for food security and the provision of important environmental services" (FAO, 2012), and is also a natural resource in serious danger of loss as a key element for the preservation of all life on the planet, for which it constitutes a common good of humanity (Mar del Plata declaration, 2012).

The soil is a limiting resource because without fertile soil there are no plants or animals to eat, no water to drink, no oxygen to breathe, that is, no life or development to reach or sustain. The soil is therefore the natural resource essential to preserve in order to achieve sustainable development (Reyes-Sánchez, 2018).

And What Does the Soil Have to do With Achieving the SDGs?

Much, because a lack of fertile soil is already a serious problem due to its role in access to sufficient food and water, but more serious are the social situations that their deficit engenders: poverty, displacement, inequality, and violence and injustice as a result of famine, and our planet is badly hit by these scourges, which is largely due to the degradation of the fertile soils that once produced enough food, and also the consequent lack of fair and honest labor in agriculture. Due to that, this problem is relevant to each one of us because it involves and affects us all (Reyes-Sánchez, 2018).

Sustainable development was defined by the UN (1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their needs." The 2030 Agenda and its 17 Sustainable Development Goals (SDGs) is a global effort that responds to this definition and expresses the aspiration of the present generation to achieve the proposed goals to improve the lives of all and preserve life on the planet.

The role of the soil resource is, directly or indirectly, an indispensable element to achieving the 17 Sustainable Development Goals. Therefore, preserving the properties and functions of fertile soil through its sustainable management and the preservation of its biodiversity, is essential to making them a reality. However, despite its importance for the existence of life on Earth, in the 17 Sustainable Development Goals, soil is only explicitly mentioned in goal 15.3 of objective 15, which refers to the preservation of life on Earth and terrestrial ecosystems, and in goal 12.4, which corresponds to objective 12 about responsible production and consumption.

It is clear, nevertheless, that without fertile soil, in which clean water is stored and which allows us to produce our food, it is not possible to achieve goal 2 of zero hunger, and therefore, it will not be possible to eradicate poverty to meet objective 1; which, in turn, makes it impossible to guarantee objective 3 of health and wellbeing for all, as well as the provision of drinking water and sanitation according to objective 6, affordable and non-polluting energy as indicated in objective 7, or the mitigation of climate change and preservation of the life of terrestrial ecosystems; as would correspond to the achievement of objectives 13 and 15.

However, none of the 17 SDGs can be achieved if we do not seriously and forcefully implement the SDG that supports and links the other 16: (SDG 4) Quality education and awareness.

Because without quality education and awareness, it is not possible to change knowledge, values, and principles that modify the behavior of a society, nor to build a culture of preservation in it if we do not change the methodology, the contents, and the pedagogical intention of our teaching—scaling it from unidisciplinary practice towards systemic and interdisciplinary teaching (Morín, 1981), and practicing at the same time a teaching committed to social, human, and environmental values (Echeverría, 1995) that build the necessary environmental awareness based on knowledge. Education is, therefore, the link and principle that can allow us to build a new way of living on and with the planet: one that includes respect for humans themselves.

For all these reasons, fertile soil is a common good of humanity that we need to preserve, and whether we do it or not, all our lives depend on it (Declaración de Mar del Plata, 2012).

The protection of the Soil resource and education for its preservation is key to the achievement of Sustainable Development Goals, and for that reason, constitute the long-term goals of the IUSS International Decade of the Soils as its main objectives. That is why, for the International Union of Soil Sciences, addressing soil science education, awareness, and outreach in an interdisciplinary way is fundamental, both to face the environmental challenges of today and to be able to confront those we already perceive for the future.

Replicating Comenius (1657), in Comenius: 2000, 20–21

> "*Man is born as a natural being, but Man is not born. He has to become a Man; in other words, he has to be formed as a Man and will only be a true Man until he has*

> *learned to be a Man, but how to transform into a Man?..…. To become a Man, he needs to shape through the knowledge of things that come from the experience. If we want to know something, then he has to be learned*".

For Comenius (2000), the first years of life are compared to soft wax, easy to model, or with small trees that can be transplanted, that is, taken to a new environment so that they can fully develop. According to his pedagogical approach, starting with the energy and interest of children is essential to the educational task that should be carried out in a processual, continuous, and systemic way to build knowledge.

However, in many cases, today's children are not provided with the richness of teaching environment that allows them to fully develop and acquire the necessary capabilities to respond to the challenges inherent to an environment in crisis. That is why, reflecting on how to educate for sustainability, part of the solution may come from the recognition that, like teaching, learning is not the accumulation of knowledge, and to learn to be a Man, the teacher as well as the student will only be able to be a true Man once they have learned to form themselves as a Man through the knowledge of the things that come from experience.

Therefore, reflecting on why something should be learned is a core issue to deliberate on, not to respond to pedagogical fashions, but because the teacher must define their meta-disciplinary position to reflect, from the adopted worldview, on why teaching is essential and what is the best way to teach children knowledge, so that they can respond to the challenges that life poses to us. But also, to act congruently and carry out an educational practice that allows children to learn to become Man through the knowledge of the things that come from experience, not memorization.

And How to Become Man?

Educating is not the same as teaching. Educating entails the explicit and implicit formation of values that emotionally and cognitively root the information transmitted, thus making possible the progressive formation of a conscience that in the medium and long term, builds, little by little, a culture (Reyes-Sánchez, 2012).

Educating humans for sustainable development involves training programs in order to improve and deepen knowledge in science, to offer sustainable solutions and defend their own points of view while being able to recognize those of others. However, the idea of the spontaneous regeneration of the soil resource, as well as of all our natural resources and the environment is still deeply rooted in the subconscious of citizens in general and constitutes a serious obstacle to sustainable decision-making; therefore, only an environmental education for the preservation of natural resources from childhood can achieve the changes required for the very existence of resistant and well-managed soils (Gómez and Reyes-Sánchez, 2004).

Educating involves the appropriation of knowledge accompanied by the construction of values that form principles and constitute the awareness necessary to achieve sustainability (Reyes-Sánchez, 2018; Reyes-Sánchez, 2020). This is the kind of education we need worldwide to achieve sustainability, because as was stated before, there will be no real sustainability for the benefit of some if that sustainability is not global.

This means that science needs to be taught by thinking and working in its teaching as a scientist: teaching science in the classroom, in the field, and in the laboratory; in the same way for children, young people, and postgraduate students, which is congruent with the concepts and methods of the sciences. Choosing questions or problems to define progressive hypotheses or research questions for the problem that we intend to solve, and proposing how to methodologically solve such research questions, helps to delimit the steps that need to be followed in order to respond to it. Therefore, to answer the questions through the progressive hypotheses, science teaching as a scientific activity must have a goal, a method, and an application field appropriate to the school context that allows the answer to the research questions that arise from the observation and definition of problems to study (Reyes-Sánchez, 2009).

In this regard, if the problem is the accelerated loss of the soil resource that makes life on the planet possible, the goal is to achieve their preservation, the method is the environmentalization[1] of knowledge: permeating the school curriculum not as a teaching resource, but as an agglutinating principle for all subjects treated within the everyday classroom; interconnecting the soil knowledge from any disciplinary perspective present in the classroom through a continuous methodological process that allows both the escalation of the cognizance of children and young people from the simple to the complex, and pedagogical organization of all actions in an equally processual way: establishing stages of knowledge construction, with increasing levels of complexity in terms of relationships and interrelations, and thus, closer to a perception of reality (Reyes-Sánchez, 2009), consistently with the goal, method, and the constructivist pedagogical model (Freinet, 1984).

Committing ourselves to the interdisciplinary practice and teaching of soil science in the framework of SDG 4 (Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all) to contribute to building education that advocates the search of alternatives that are ethically acceptable, economically feasible, energetically desirable, and environmentally respectful of the balance of ecosystems as a foundation and building the path of a socially responsible science (Reyes-Sánchez, 2018).

Achieving this requires:

* Equal access to inclusive quality education and training in all phases of life and for everyone.

[1]A methodological process that approaches the environmental problems in a cognitive and interdisciplinary way through education and the practice of science with the objective of building a preservation culture and conscience by providing models for the management and exploitation of natural resources towards the development for all (Reyes-Sánchez, 2009).

* Work so that educational institutions are places where sustainability skills are not only taught, but also actively practiced, because teaching is not the same as educating.
* Overcoming the technological gap: improving ICT[2] skills, basic digital skills, connectivity, the Internet, and cybersecurity against possible negative externalities.
* Willingness of governments to assume the United Nations 2030 Agenda and the SDGs.
* Respect for the rule of law, democracy, and fundamental rights by countries.
* Policy coherence at all levels since the SDGs are conceived as indivisible entities, and most cover several policy areas.
* Participation of civil society, the private sector and academia in the dialogue for the construction of sustainability to define specific goals for the application of the SDGs.

All of these are indispensable tasks to be performed in order to educate in science for sustainability, build citizen awareness of the care of natural resources, and achieve the participation of civil society, the private sector, and academia in a respectful and democratic dialogue to define the specific phases of application of the SDGs.

The IUSS GOES TO SCHOOL

> "*Study science first and then follow the practice born of science.*"
>
> Leonardo Da Vinci

According to the main goals of the IUSS "International Decade of Soils: 2015–2024" (Horn, 2015; Horn, 2017), the International Union of Soil Science aspires to define and be a leader in the process of integral formation of our future scientists, as well as in generating the citizen's awareness for the sustainability of soil; creating a profound impact on the educational and governance environments.

Educating children and young people is a priority for the IUSS, since in 10 years they will be the new citizens of the world and in their hands will be the future of the soil and therefore of life on the planet. However, the responsibility to ensure that children and young people understand what the value of the soil resource is, and commit to its preservation, it is ours and it is now.

Stopping soil degradation will not be possible if only us, the scientists of soil science, know its value for the existence of life on Earth. We need to teach children and young people, as our future citizens, why the soil is important for human wellbeing, how its loss impacts the lives of all living beings, and that for all this, the soil is an indispensable resource for the existence of life.

Citizens do not know or understand what the existence of the soil means, because despite the great importance of the soil resource for the conservation of life on The Earth, and the great amount of accumulated knowledge, there is a general absence of knowledge of the citizens, both in relation to the natural resources that Earth possesses, and about their value for the existence of life on the planet (Reyes-Sánchez, 2009).

This general unknown, of both the soil system and the functional value and impact that this natural resource has in our daily life, naturally entails the absence of citizen awareness regarding the primary need to preserve it, because although we have the knowledge share it between peers, we not only do it only among ourselves, but we use specialized language to communicate. Language that is excluding for citizenship. Language that does not allow the common citizen to understand the reason and meaning of the initiatives that are generated from the UN, GSP-FAO, and IUSS to preserve the soil, nor participate effectively in them because they do not have the information to understand them or the awareness to join us in this fight.

For all those reasons and in response to the main goals of the IUSS International Decade of Soils: 2015–2024, we committed to creating an educational project that brings together and leads the educative work of the National Soil Science Societies: the IUSS General Educative Project (Reyes-Sánchez, 2019). Consequently, on 5 December 5 2019, the educational project "THE IUSS GOES TO SCHOOL®" was launched (IUSS, 2019).

What is the Educative Proposal From the IUSS GOES TO SCHOOL and What Are Its Actions and Activities?

> "*IUSS propose to educate in soil science on a planet that is a natural system, and work all together as a team to put the gaze, heart, and concern of the world on the Soil*"
>
> Reyes-Sánchez Laura Bertha

With the purpose of educating and raising awareness among children and young people; aiming at the same time to allow scientists to find joy in doing so, and in order to achieve their collaboration to open the curriculum of soil science in the medium and long term to the interdisciplinarity and the professionalization of their teaching, as part of the IUSS General Educative Project and the "THE IUSS GOES TO SCHOOL®" (Reyes-Sánchez, 2019; IUSS, 2022a), the following lines of work are proposed:

* Education and awareness for children and young people
* Opening the professional curriculum of soil science to interdisciplinarity
* Interdisciplinarize the teaching of soil science
* Professionalize the teaching of soil science.

Education and Awareness for Children and Young People

> "*Education is the most powerful weapon which you can use to change the world.*"
>
> Nelson Mandela

[2]ICT: Information and Communication Technologies (ICT).

The proposal is to work as soil scientists and teachers, educating and raising awareness among children and young people. Meanwhile, scientists learn to communicate to the citizen the science we practice and develop, to fight for the preservation of the edaphic resource, strengthening soil science worldwide. The goal is to encourage children and young people to fall in love with soil science as participants and protagonists of activities and cognitive experiences that allow them to understand both the importance of preserving the soil resource for the sustainability of the Earth system, and to understand its value and involve them in a committed way in its preservation.

Achieving that objective and achieving the proposed goal implies recognizing that today's scientists belong to a generation that can decide what to impart, how, and for whom. Therefore, in the collective context and as scientists committed to the teaching of Soil Science, today it is up to us to decide if we continue to limit teaching to professional and specialization levels, or if we are willing to assume a personal commitment, generating and teaching knowledge in an accessible way to those school levels where children and young people are practically blank pages: provoking in them interest, enthusiasm, and love of scientific work. Working together to achieve this, researchers and university professors, along with teachers at all pre-university levels, should integrate school projects that lead to the construction of a new paradigm in the teaching of soil science: a teaching in which the interpretation of human facts converges with the explanation of scientific facts while they are confronted dialectically in the construction of children's learning (Reyes-Sánchez, 2012).

Opening the Professional Curriculum of Soil Science to Interdisciplinarity

> "*It is not so much a matter of opening the frontiers between disciplines, but of transforming what creates those boundaries, the organizing principles of knowledge*"
>
> Morín (2000)

The goal is to understand that the disciplinary divisions of science have a useful methodological value, but we cannot fail to observe and recognize that in reality, there are no simple or isolated problems, and therefore, it is not possible to address them from a partial view, nor only from within the isolated vision of the disciplinary divisions. The approach is to work towards building, through interdisciplinary integration from various fields of knowledge, specialized knowledge in soil science that allows solutions to complex problems to be addressed and proposed, from multicausal and interdependent perspectives (Morín, 1981); contributing to the recognition of natural and cultural values to revalue the small and decentralized, while consequently assuming the prominence of building the development process itself.

When soil science is taught at both professional and postgrad levels, basic and specialized information of various levels is transmitted, with students learning to use that knowledge in a theoretical and practical way; the information obtained is also analyzed, deciphered, and used to make calculations, interpretations, corrections, and projections, but that does not mean that persons have formed an environmental awareness, nor built a culture of preservation (Reyes-Sánchez, 2018). If there is no construction of a culture of preservation, there is no real development. Therefore, if what is wanted is to disseminate knowledge that entails the construction of a citizen consciousness and is reflected in a culture of preservation of the edaphic resource, we need to instruct future scientists and teachers to not only generate knowledge about the soil resource, but educate their students to preserve it as an indispensable element for life.

The really important thing is to train scientists and teachers to explain clearly to every citizen, and at every educational level, why the soil is essential to them and how its loss affects us all regardless of the social class to which we belong. It is important that the contents are taught with a sense of preservation and for the wellbeing of all to create a culture of sustainability. Understanding this is of immense importance when we are talking about forming scientists, not only because those who train them must understand and practice it, but also because they must be able to transmit it at both professional and postgraduate levels in an interdisciplinary way.

The indispensable thing is that every student of soil science understands it, lives it, and transmits it. This is the same in the classroom, in the laboratory, on the field, and as an example throughout their life. Achieving it is our challenge, and it should be our commitment to the next generations.

Interdisciplinarize the Teaching of Soil Science

> "*Most of the fundamental ideas of science are essentially simple and, as a rule, can be expressed in language understandable to everyone.*"
>
> Albert Einstein

As was stated before, to contribute to building education that advocates the search for alternatives that are ethically acceptable, economically feasible, energetically desirable, and environmentally respectful of the balance of ecosystems as a foundation and building the path of socially responsible science is a goal for the IUSS. This includes environmentalizing[3] all knowledge through a continuous methodological process that both escalates the

[3]A methodological process that approaches the environmental problems in a cognitive and interdisciplinary way through education and the practice of science with the objective of building a preservation culture and conscience by providing models for the management and exploitation of natural resources towards the development for all (Reyes-Sánchez, 2009).

knowledge of children and young people from the simple to the complex, and pedagogically organizes all actions in an equally processual way, as well as establishing stages of knowledge construction with increasing levels of complexity in terms of relationships and interrelations, and thus coming closer to achieving a perception of reality.

Understanding the complexity of the living world, that is, the medium in which education is meant to construct development, involves grasping that this is in itself a system (Morín, 1981). When we talk about Development Goals, we talk about the development and sustainability of natural and social systems, made up of living beings that exchange matter, energy, and information with the outside; systems that tend to a balance that is dynamic and establish intersystemic, intrasystemic, and system relationships with and towards the totality of its components (Gell-Mann, 1995). These systems are therefore open and dissipative, in constant change, and where change is paid with an increase of the entropy of the system (Reyes-Sánchez, 2018). It is a goal to be addressed and achieved, established in accordance with SDG 17, the Partnership Alliances that may be necessary among the various scientific societies of soil science with every expression, institution, or citizen organization and at all levels; working under the leadership of the UN, with the initiatives, programs and frameworks defined by GSP-FAO, for the achievement of the IUSS "International Decade of the Soils 2015–2024" (Horn, 2015 y 2017) and according to the IUSS General Educative Project (Reyes-Sánchez, 2019).

Professionalize the Teaching of Soil Science

> "*Teaching should be such that what is offered is perceived as a valuable gift and not as a hard duty.*"
>
> Albert Einstein

Moving towards development is not possible without teaching and learning science, which allows us to build today, in children and young people, the citizens of tomorrow. Both the knowledge and the values are necessary for this because as natural resources degrade and are lost, food and water will be insufficient for a population that continues growing in a planet with finite resources (Reyes-Sánchez, 2012).

That is why the UN and UNESCO (1987), UN (1992), UN (2012), UN (2002) summits, have emphasized the importance of training teachers whose activities and decisions significantly influence the education of Future citizens: "preparing them to meet the challenge of responding to present and future environmental problems."

Achieving it means educating for a sustainable Earth in time and space, implies empowering and sensitizing people so that they recognize that there are no pre-established rules that are always valid, so that they know how to make decisions according to the environment preservation, with friendly life models and with the diversity of cultures and people. It implies ensuring that people can change behaviors according to the circumstances, publicly defend their own opinion and recognize that of others, dialogue, and negotiate (Gómez and Reyes-Sánchez, 2004).

For that reason, among the primary characteristics to develop in teachers—to transfer them to the student through a process of building them—and as important as knowledge, are the development of values and attitudes as the only way to, in the future, have citizens capable of making and participating in all kinds of decisions; with solid arguments based on knowledge and manifesting firmly through reflective attitudes, but above all, built based on the analysis carried out in the light of the values formed.

Therefore, education for sustainability requires being participatory, affective, multicultural, dialogic, democratic, investigative, interdisciplinary, and activist, capable of turning children and young people into competent workers, reflective citizens, social critics, and agents of change. For that, it is necessary to have teachers capable of transmitting these approaches in order to have, in the future, citizens with both arguments and a thoughtful and determined attitude to promote and carry out the actions leading to the solution of the great environmental problems that we will face (Reyes-Sánchez, 2020).

Citizens aware of the need to preserve natural resources must begin to be formed today in each and every one of the educational levels, but for this, we require at the same time training for teachers and the integration of scientists to teaching with these same conceptions and interests.

RESULTS

What Have Been the Main Actions and Activities of the IUSS Educational Project?

From the IUSS, we are discussing how education of sustainability is vital for soil science in order to understand how to finally influence the construction of a citizen consciousness, generate a culture of preservation that allows us to impact long-term public policies, and move on towards the governance of this natural resource (Reyes-Sánchez, 2019). In this regard, with the aim of contributing to informing children and young people about the importance of the soil resource in our lives and the urgency to protect it (IUSS, 2022b), on 5 December 2019, in the frame of the celebration for World Soil Day, the IUSS launched the educative Project "THE IUSS GOES TO SCHOOL®" (IUSS, 2019) and created an online space for all children around the world, inviting them to take care of the soils of their Nation and teach their parents and teachers to do so.[4]

To involve soil scientists and soil science societies, research institutions, and universities from around the world in efforts to educate and raise awareness about soil value, the IUSS educative project called Scientists to respond to the theme "Soils, where food begins," to write "Stories and Crop Cards" for children to teach them to grow their food and raise awareness about the fact that food that arrives on our table is grown in the soil. This material is available in English, Spanish, German, and some are also available in French.[5]

[4]http://www.iuss-goes-to-school.org.mx/

[5]https://www.iuss-goes-to-school.org.mx/crop-cards/

"THE IUSS GOES TO SCHOOL®" website also has, at this moment, nine children's books online.[6]

The number of current challenges related to soil protection and sustainable land use, especially those linked to ongoing climate change and its effects on agriculture, food security, human health, social stability, and the global economy, require formal spaces within worldwide Soil Science Societies for the exchange of ideas, actions, and solutions among scientists' generations.

That is why, for the IUSS, it is not only a priority to educate children and young people but to support the development of early career scientists. In this regard, the International Union of Soil Sciences has declared the empowerment of young soil scientists a high priority to engage young scientists from different disciplines of soil sciences working in interdisciplinary ideas, since they are the upcoming generation in all the Soil Science Societies in charge of reaching their missions (Reyes-Sánchez, 2019; IUSS, 2022a).

Therefore, because the new generation of soil scientists plays a crucial role in soil sustainability achievement, the strength of future Soil Sciences, and the development of the International Union of Soil Sciences itself, in October 2022 the "Young and Early Career Scientists Working Group of the International Union of Soil Sciences" was approved.[7]

"THE IUSS GOES TO SCHOOL®" supports and promotes all educational activities carried out by the Soil Science Societies that have joined the project. Participating face-to-face, giving conferences, organizing didactical experiences, promoting teaching materials, supporting them through its Stimulus Fund Program, and giving some didactical materials to children and young people who participate in these events.

In this educational effort, the IUSS has joined forces with the Global Soil Partnership of FAO, launching in 2020, within the framework of World Soil Day, a Booklet contest for children through an annual call for soil scientists to collaborate in the literacy process of children and young people. As a result, the IUSS and FAO have co-published three books: "The magical world of Soil Biodiversity," "Salty soil adventures" and "Soils, where food begins" each containing the annual collection of 10 children's stories from around the world (FAO-IUSS, 2021; FAO-IUSS, 2022; FAO-IUSS, 2023).

About our perspectives: The project also seeks to involve soil scientists through their direct participation in soil science education and awareness-raising of future generations to bring soils into our hearts, arriving at the Centenary of the International Union of Soil Sciences with a real commitment of their scientists and teachers to educate children and young people as future citizens of the world, to preserve the resource that is the object of its study. In this regard, the IUSS scientific community has been called to present their educational actions and activities, innovative ideas, and research during the IUSS Centennial in the Session "Children and Young People Say Present at the IUSS Centenary Celebration".[8]

On 19 May 2024, celebrating the IUSS Centennial (IUSS, 2023), during the Session "Children and Young People Say Present at the IUSS Centenary Celebration," the IUSS educative project will launch the book "Soil is a Source of Life, Water, and Food" containing all children's material in English, Spanish, German, French, and Portuguese.

DISCUSSION

Looking to Go From Words to Deeds

Committing to the preservation of life on the planet means committing to the sustainability of the soil resource and requires a firm will, through teaching and research, to initiate an educational process of teaching and learning of soil sciences in an interdisciplinary way with an emphasis on school-age children and youth. In this regard, the educative proposal by the International Union of Soil Sciences corresponds to a vision in which the search for the sustainability of the soil resource is our goal and commitment (Reyes-Sánchez, 2019; IUSS, 2022b).

Therefore, working to make reality the education and awareness of children and young people through an educational project in a network between the National Soil Science Societies in all countries and regions, beyond being a desire, is an invitation to work as a team and participate with the educational project THE IUSS GOES TO SCHOOL® to train future citizens of the world with the knowledge and environmental awareness that allows us to teach and learn that the loss of the planet's natural resources affects us all and that our lives depend on it.

It is a call to scientists and teachers to move from words to facts in order to build, in an organized way, the education and awareness necessary in today's children and youth to ensure the preservation of the soil resource.

CONCLUDING STATEMENTS

Educating for sustainability is an objective that goes beyond another subject in the curriculum, and that does not consist of mechanically reproducing or memorizing knowledge and techniques, but in educating for debate and reflection on knowledge, type of technology, and social organization, which allow people to live in harmony with each other and the environment.

The change of beliefs, principles, and values is harder to achieve than any change of statements or legislation, and only

[6]https://www.iuss-goes-to-school.org.mx/booklets/

[7]https://www.iuss.org/organisation-people/organisation/working-groups/, https://forms.gle/kQRNAitqdijbAP8V9

[8]https://centennialiuss2024.org/

an education for sustainability throughout the planet and at an early age can fulfill the changes required for the accomplishment of soil preservation and the SDG's.

Because children and young people cannot love what they do not know, or understand what they ignore, our scientific tasks are also to teach, educate, and raise awareness.

The school can and should be our ally to achieve soil preservation and Sustainable Development Goals, so we must start by realizing that we need to revalue education against science because education is also a science. Therefore, we must teach science congruently with the concepts and methods of science.

For Einstein, "Most of the fundamental ideas of science are essentially simple and, as a rule, can be expressed in language understandable to everyone." For those of us who today witness soil degradation and the consequent shortages of clean water, loss of biodiversity, and the impacts of climate change, learning to communicate with citizens in that understandable language is an essential task if we want children and young people to understand why the soil is fundamental for the existence of their life and how its loss affects them, their family, and their country.

The IUSS summons scientists and teachers of soil science to move from words to actions and commit to the education and awareness of children and young people that guarantees the sustainability of the soil resource as an indispensable element to preserve life on Earth.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

LBR-S wrote the document, reviewed it and is the responsible author.

CONFLICT OF INTEREST

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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REFERENCES

Comenius, J. A. (2000). *Didáctica Magna*. Porrúa, México: Editorial Porrúa.

Declaración de Mar del Plata (2012). Latin-American Soil Science Society. Available at: http://slcs.org.mx/index.php/es/informacion-general/declaraciones/8-mar-del-plata (Accessed March 2004).

Echeverría, J. (1995). "El pluralismo axiológico de la ciencia," en: *Isegoría*. España: CSIC 12, 44–79.

EU (2019). Reflection Paper Towards a Sustainable Europe in 2030. Available at: https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/reflection-paper-towards-sustainable-euro (Accessed March 2019).

FAO (2012). Global Soil Partnership Mandate. Available at: http://www.fao.org/globalsoilpartnership/es/ (Accessed January 2023).

FAO-IUSS (2021). *The Magical World of Soil Biodiversity - A Collection of 10 Children's Stories From Around the World*. ISBN 978-92-5-134249-7. Rome: © FAO and IUSS. doi:10.4060/cb4185en

FAO-IUSS (2022). *Salty Soil Adventures: A Collection of 10 Children's Stories From Around the World*. ISBN 978-92-5-136403-1. Rome: © FAO and IUSS. doi:10.4060/cc0530en

FAO-IUSS (2023). Soils Where Food Begins: *A Collection of 10 Children's Stories From Around the World*. ISBN 978-92-5-138028-4. Rome: © FAO and IUSS. doi:10.4060/cc7127en

Freinet, C. (1984). *La enseñanza de las Ciencias*. Barcelona, España: Editorial LAIA.

Gell-Mann, M. (1995). El Quark y el jaguar. *Aventuras en lo simple y lo complejo*. España: Editorial Tusquets. Barcelona.

Gómez, M. R., and Reyes-Sánchez, L. B. (2004). Educación Ambiental, Imprescindible en la Formación de Nuevas Generaciones. (Environmental Education, Essential in the Development of New Generations). *TERRA Latinoam.* 22 (4), 515–522.

Horn, R. (2015). "International Decade of Soils 2015–2024" (IUSS–IDS). Vienna Declaration. Available at: https://www.iuss.org/international-decade-of-soils/ (Accessed April 2019).

Horn, R. (2017). *WSD FAO General Assembly*. Rome, Italy.

IUSS (2019). Iuss Educational Project "The Iuss Goes to School®". Available at: http://www.iuss-goes-to-school.org.mx/ (Accessed July 2023).

IUSS (2022). IUSS International Union of Soil Sciences Strategic Plan 2021-2030. Available at: https://www.iuss.org/about-the-iuss/iuss-strategic-plan-2021-2030/ (Accessed August 2023).

IUSS (2022). Young and Early Career Scientists Working Group of the International Union of Soil Sciences. Available at: https://www.iuss.org/organisation-people/organisation/working-groups/ (Accessed January 2023).

IUSS (2023). IUSS Centenary Celebration. Available at: https://centennialiuss2024.org/ (Accessed July 2023).

IUSS International Decade of Soils Programme (2016). *IUSS Inter-Congress Meeting Document*. Brasil: Río de Janeiro, 121–123.

Morín, E. (1981). *El método. La Naturaleza de la naturaleza*. Madrid, España: Editorial Cátedra.

Morín, E. (2000). *La mente bien ordenada: repensar la reforma, reformar el pensamiento*. Barcelona, España: Editorial Seix Barral.

Reyes-Sánchez, L. B. (2009). *Propuesta interdisciplinaria de enseñanza y aprendizaje de las ciencias de orden ambiental, para la educación básica; utilizando el recurso suelo como eje*. México: ITCR - UNAM.

Reyes-Sánchez, L. B. (2012). Enseñanza de la Ciencia del Suelo: Estrategia y Garantía De Futuro. (Teaching Soil Science: A Strategy and Warranty Towards the Future). *Span. J. Soil Sci.* 2 (1), 87–99. doi:10.3232/SJSS.2012.V2.N1.07

Reyes-Sánchez, L. B. (2018). "Edaphological Approaches to Advancing Sustainable Development Goals: An Educational Perspective to Build a Citizen Preservation Culture," in *Soil and Sustainable Development Goals of the U.N.* Editors R. Lal, R. Horn, and T. Kosaki (Stuttgart, Germany: Schweizerbart Science Publishers).

Reyes-Sánchez, L. B. (2019). The Iuss Goes to the School®. in *the Iuss General Educative Project*. Iuss Document. Available at: https://www.iuss.org (Accessed July 2023).

Reyes-Sánchez, L. B. (2020). "Educating to Build a Citizen Preservation Culture," in *Soil Science Sciences Education: Global Concepts and Teaching*. Editors T. Kosaki, R. Lal, and L. B. Reyes-Sanchez (Stuttgart, Germany: IUSS Catena soil sciences series book).

UN (1987). Our Common Future: Brundtland Report. Available at: http://www.un-documents.net/wced-ocf.htm (Accessed March 2020).

UN (1992). Rio Declaration on Environment and Development. Available at: http://www.un.org (Accessed June 2023).

UN (2002). *Resolution 57/254*. Johannesburgo, África. Available at: https://digitallibrary.un.org/record/482207?ln=es (Accessed June 2023).

UN (2015). Objectives and Goals of Sustainable Development. Available at: http://www.un.org/sustainabledevelopment/es/objetivos-de-desarrollo-sostenible/ (Accessed January 2016).

UN (2024). There Are Already 8 Billion People in the World. Available at: https://onuhabitat.org.mx/index.php/ya-somos-8-mil-millones-de-personas (Accessed June 2023).

UN (2012). Conferencia de las Naciones Unidas sobre el Desarrollo Sostenible, Río de Janeiro, Brasil. Available at: https://www.un.org/es/conferences/environment/rio2012 (Accessed December 2023).

UNESCO (1987). La Educación ambiental: las grandes orientaciones de la Conferencia de Tbilisi. Available at: https://unesdoc.unesco.org/ark:/48223/pf0000038550_spa (Accessed December 2023).

UNICEF (2017). Agenda 2030: Una Oportunidad Para las Personas y el Planeta. Available at: https://www.unicef.es/publicacion/agenda-2030-una-oportunidad-para-las-personas-y-el-planeta (Accessed June 2023).

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The "Soil Skills" Pedagogical Approach Conjugated With Soil Judging Contests

Said Al-Ismaily[1], Anvar Kacimov[1], Ahmed Al-Mayhai[1,2], Hamed Al-Busaidi[1], Daniel Blackburn[1], Afrah Al-Shukaili[1] and Ali Al-Maktoumi[1,3]*

[1]Department of Soils, Water and Agricultural Engineering, Sultan Qaboos University, Muscat, Oman, [2]Department of Earth Sciences, Utrecht University, Utrecht, Netherlands, [3]Water Research Center, Sultan Qaboos University, Muscat, Oman

The inherent complexity of soil and its interactions with Earth's diverse spheres, including the atmosphere, biosphere, hydrosphere, lithosphere within the ecosphere, and anthroposphere, requires that soil science specialists and students develop not only a profound understanding of soil science, but also the ability to collaborate across various disciplines to address these complex challenges. Equipping students with the necessary knowledge, skills, and attitudes to tackle the intricate and dynamic issues of the 21st century, spanning soil science, water sciences, hydropedology, geology, agronomy, geotechnical engineering, sedimentation, waste management, recycling, and environmental management, is of paramount importance. In response, innovative pedagogical approaches that integrate classroom learning from diverse soil science courses with practical skills and field-based competencies are needed. This paper suggests merging our own "Soil Skills" (SSK) pedagogical method with the "Soil Judging Contest" (SJC), a teaching approach supported by the American Society of Agronomy and the Soil Science Society of America since 1961. This integration aims to enhance the holistic, harmonized, interdisciplinary, and enthusiastic nature of soil science education. Both the SSK and SJC approaches received positive feedback from students and demonstrated significant improvements in academic performance. Our study begins with an in-depth exploration of the SSK contest, followed by an overview of the pertinent aspects of the SJC. Subsequently, we offer a comparative analysis of the complementarity of these two approaches. Finally, in the concluding remarks, we summarize the strengths of the implemented SSK and outline prospective applications. Our findings underscore the unique advantages of combining SSK and SJC approaches in delivering comprehensive, problem-based, and practical field-learning experiences. This combination approach closely aligns with applied scenarios that demand multidisciplinarity and interdisciplinarity perspectives, preparing students for their future professional careers, and enabling the practical application of their soil science knowledge in real-world contexts.

Keywords: soil science, inquiry-based learning, scaffolding in course levels, teaching and learning, pedagogical practices

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***Correspondence:**
Said Al-Ismaily
esmaily@squ.edu.om

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INTRODUCTION

Soil science education plays a crucial role in understanding and managing one of our planet's most critical resources—the soil. Soil is a complex and dynamic ecosystem that supports agriculture, forestry, environmental sustainability, and overall ecosystem health. Soil is also identified as being integral and central to many of the challenges facing ecological and societal systems, including the challenges of food, water, and energy security, environmental impact and remediation, loss of biodiversity, effective land use planning and management, and climate change abatement, all of which contribute to human health and wellbeing (Hartemink and McBratney, 2008; Flannery, 2011; Janzen et al., 2011; Koch et al., 2013).

For students and industry stakeholders who require in-service training and practical experience, the focus on a multi-disciplinary approach is essential (Field et al., 2017). As articulated by Hartemink. (2006), soil science cannot operate in isolation; it must actively engage with multidisciplinary or interdisciplinary teams and establish connections with other fields of study. Díaz-Fierros Viqueira. (2015) stated that "Soil in all its complexity cannot be understood without some basic knowledge of geology, biology, physics, chemistry, and mathematics." The sub-disciplines into which soil science is divided may represent fields of knowledge that should be investigated further through the application of certain techniques and specific concepts. However, they should never represent hermetic spaces delimited by insurmountable barriers, as is often the case. Students and lifelong learning soil science professionals should understand the concept of soil security in connection with food, water, and energy security edifices (Brevik et al., 2022). As envisioned by McBratney et al. (2014), such security brings a social aspect to the soil security concept, the idea that the public, government officials, and others need to bond to the soil not only through traditional aspects of soil's conditions, capabilities, and capital but also via soil connectivity, describing links with stakeholders, society at large and the policy arena, including soil codification describing links with environmental rules and regulations. These aspects of connectivity have strong links to soil knowledge, which means they would be supported by well-considered educational strategies. Soil scientists emphasize the need for a holistic approach to understanding the multifaceted nature of soils, especially in developing countries. Bridges and Catizzone. (1996) underscored viewing soils systemically while recognizing their labyrinthine interconnectedness, which poses challenges to human comprehension. Adopting a systems perspective leads to a more profound grasp of soil-related matters and enhances decision-making in their management (Vogel et al., 2018). To revamp the soil science curriculum, one potential direction is the adoption of the "know," "know of," and "aware of" soil framework proposed by Field. (2019). This student-centric concept fosters learning environments either concentrated on in-depth soil science expertise ("know soil") or on the application of this knowledge in contexts where soil science is just a component ("know of soil"). This approach facilitates the crafting of a curriculum that merges specialized knowledge with a holistic learning setting, driven by ominous problems (Brevik et al., 2022).

Consequently, it is essential and in congruence with the Sustainable Development Goal (SDG) 4 "Quality Education" to teach individuals the science of soils to ensure responsible land use, climate change mitigation, and resource conservation, in particular, clean water and sanitation, among others. In addition to a better scientific understanding, major developments have been made in the perception of both the ecological and non-ecological functions of soils in providing fundamental ecosystem goods and services (Lal and Stewart, 2013; Urbańska and Charzyński, 2021). This means that those who self-identify as soil scientists or have soil science expertise will need to engage with a variety of stakeholders to pinpoint what the problems are, and in doing so, work towards providing solutions to these ever-increasing complex environmental problems. This, in part, has resulted in the teaching of soil science no longer being confined to its traditional founding in agriculture and agronomy. As a discipline, soil science has expanded its scope to other specializations in environmental sciences, botany, forestry, ecology, geography, geology, soil mechanics, and hydrology (Hartemink et al., 2014). Graduates not only need to acquire knowledge, skills, and capabilities in traditional soil sciences, but they must also work between and across other disciplines. As pointed out by Bouma. (2010), solving complex contemporary problems will not solely rely on the objective (science) answers of "right or wrong," but also the relativistic (societal and political) answers that consider decisions as "better" or "worse." Subdisciplines of soil sciences, such as pedology, soil physics, soil chemistry, and soil microbiology, still operate somewhat independently. For example, a combined expertise of soil physicists and pedologists in hydropedology offers a basic package, to be completed by soil chemists and biologists, to interdisciplinary teams studying ecosystem services in line with the UN SDGs (Bouma, 2023). This should change when focusing on providing effective contributions of soil scientists to SDGs and communities of scientific practices to form a suitable vehicle for their integration (Bouma, 2019a). We recall that historically, despite soils' inherent uniqueness and tortuous integration within the natural world, the "soil system" endured a period of diminished recognition, during the "environmental wave" spanning from the 1970s to the late 1980s (Díaz-Fierros Viqueira, 2015). This era witnessed the agricultural revolution's surge, accompanied by the intensive use of synthetic fertilizers and other agrochemicals and the relentless pursuit of maximized agricultural yields, giving rise to substantial environmental concerns. Consequently, the study of soils and other traditional aspects of agrarian production underwent a gradual decline in significance, while environmental research topics garnered the favor of both funding agencies and the general public.

Soil science students, as future experts, have to learn how to make, coordinate, and manage "*ad hoc*" social learning groups on, e.g., "the problem of secondary salinization caused by seawater intrusion in a plant-cultivated area." The students should be trained to simulate situations when the brainstormed recipes "what can be done," "what is worth doing," and "what should not be done" are transmitted within the groups involving "experts" of various calibers and laymen (Krzywoszynska, 2019). Furthermore, future graduates need to be able to engage with scientists from many disciplines, policy experts, practitioners (e.g., farmers), and users of relevant soil information (Wessolek, 2006).

Therefore, there is a need for innovative pedagogical approaches that integrate knowledge learned in classrooms from various courses of the soil science curriculum along with developing practical skills and field-based competencies in soil education. Unfortunately, in contemporary soil science research, the heavy reliance on controlled laboratory experiments, mathematical models, and remote sensing techniques has overshadowed genuine fist-person direct field observations and measurements (Díaz-Fierros Viqueira, 2015).

Soil Skills (SSK) and the Soil Judging Contest (SJC) exemplify innovative pedagogical techniques designed to enhance students' engagement and enthusiasm within dynamic and stimulating learning environments (Rees and Johnson, 2020; Al-Ismaily et al., 2021). These educational methodologies transcend traditional lecture-based instruction by embracing problem-based learning and active teaching strategies, with the primary objective of providing students with hands-on experiences. Furthermore, the extracurricular nature of these approaches, coupled with the element of competition among participating teams, serves as a motivational catalyst, inspiring students to immerse themselves in their knowledge fields with genuine enthusiasm.

SJC is a competitive soil science educational program organized at various universities across the United States. and the world (Galbraith and Thompson, 2014; Rees and Johnson, 2020). The competing teams evaluate crucial soil properties and morphogenic diagnostic features (e.g., soil texture, structure, moisture content, soil color, epi-endo-pedons, etc.), and make informed judgments based on their observations and knowledge of soil science principles. The winning teams at the national level will then compete at the international level [See Official Handbook Inaugural International Soil Judging Contest (World Congress of Soil Science, 2014)].

While SJC has a long history of successful organization at local, regional, and national levels, SSK is a recent initiative, having been launched in 2018 by the Department of Soils, Water, and Agricultural Engineering (SWAE) at Sultan Qaboos University (SQU) in Oman. In contrast to SJC, which primarily emphasizes soil profile description and landscape interpretation, SSK challenges participating students to apply an interdisciplinary approach, synthesizing knowledge acquired from various aspects of the soil science curriculum to address real-world case studies that illustrate the interconnectedness of soil, water, landscape, and community (Al-Ismaily et al., 2021).

It is noteworthy that recently, the concept of "citizens' science" emerged, in particular, in engaging local communities in soil sciences endeavors (Pino et al., 2022).

In this study, we propose the conjugation and integration of the SJC and SSK approaches to maximize the learning experience of soil science education in a holistic, harmonized, interdisciplinary, and enthusiastic manner. The conjugation of these two approaches provides students and future soil science professionals with the ability to gain novel multidisciplinary knowledge and dexterity for making connections between the variety of ecosystem services that soil provides.

The paper's structure unfolds as follows: Firstly, we delve into an in-depth exploration of the SSK contest. Following that, we shift our focus to the SJC. Subsequently, we provide a comparative analysis of these two approaches. Lastly, we offer our concluding remarks and outline future perspectives.

THE SOIL SKILLS (SSK) CONTEST

Description of the SSK Approach

Global platforms like "World Skills"[1] and the Dutch initiative of "Wetskills"[2] focus on professional training and water technologies, correspondingly. The SQU through the Department of SWAE collaborates with the Netherlands Embassy in Oman to organize "Wetskills" events, conducted annually in 2017–2020 and—after a COVID gap—in 2022–2023. These engagements provided SWAE soil scientists with insights into Dutch procedures, such as pitching, coaching, team evaluations, and awarding. Drawing from this experience, SQU unveiled the SSK program in January 2018. Unlike "Wetskills," which is centered on water-related topics, and is prevalently based on "in-auditorium" interactions, SSK adopts a cross-disciplinary lens. Predominantly field-based, SSK strengthens participants' proficiency in soil-related practical tasks, but at the same time, requires background and mental acuity acquired in other BSc-level courses taught at SQU in the "Soil Sciences" program. Unlike the varied international composition of qualifications, ages, languages, and nationalities of "Wetskills" participants, SSK participants are more homogenous.

Competitions pertaining to soil profile descriptions or SJC have been previously documented (Field, 2019; Rees and Johnson, 2020). However, our competition encompasses a wider range of cross-disciplinary standards. SSK module, now a part of the Soil and Water Winter Tour (SWWT) course (Al-Maktoumi et al., 2016; Al-Ismaily et al., 2019), which is required and elective in Soil Science and Water Technology, respectively, BSc programs at SQU-SWAE.[3]

The SWWT course structure comprises 5 days of intensive training, instrument familiarity, field explorations, and mini-competitions. The first 4 days involve guidance from the primary educator, skill acquisition, hands-on field experiences, and short challenges, such as quick assessments of soil properties, rapid soil surveys, or evaluating water flow rates in a wadi channel (fluvial valley that only flows during a rainy season). The final, fifth day, is dedicated to the SSK contest. This day is the

[1] https://worldskills.org/
[2] https://wetskills.com/
[3] https://www.squ.edu.om/agriculture/Academic-Department/Soils-Water-and-Agricultural-Engineering/Description

culmination of SWWT, with a continuous competition between the student groups.

This course parallels foundational soil science courses, like SOIL 1113 (Abit Jr et al., 2018), in its complexity. Yet, the SSK distinguishes itself by placing students, for example, in authentic scenarios of arid land, salinized soils, falaj, and modern irrigation in Oman. The SSK inculcates and evaluates holistic understandings of integrated soil sciences (Bouma, 2019b; de Sousa et al., 2019).

In essence, the SSK challenge pushes undergraduates to confront diverse soil and water dilemmas in Oman in an exhilarating setting. For instance, the 2018 batch tackled a project focusing on enhancing home gardening in specific Omani regions to address waterlogging and secondary salinity issues. We adopted the problem-based learning methodology, inspiring students to address and resolve challenges emblematic of Earth's dynamics.

The SSK competition integrates specific outcome-oriented objectives, aligning them with the broader goals of the SQU Soil Science curriculum. One key objective is to bolster students' ability to think critically, equipping them with the potential to deal with current soil challenges. These challenges can often be wicked, open to multiple interpretations, and have various potential resolutions, as noted by Cantor et al. (2015). Another objective is to merge classroom theory with field research, covering topics that intersect with various geosciences, such as geoengineering, hydropedology, agroecology, and more, as referenced by Field et al. (2017). Another goal is to encourage students to explore the relationship between soil, water, and societal factors and to extract vital information to address their assigned tasks. Lastly, providing students with practical training using cutting-edge field equipment and methodologies in soil and water research rounds out these objectives.

The SSK Learning Strategy

The SSK is an advanced active learning strategy for senior Soil Sciences undergraduates at SQU), Oman. This pedagogical model amalgamates several strategies:

(i) Embracing active problem-based learning as highlighted by Lukes et al. (2020) and Schmidt (1983), underscoring inquiry-driven learning facets essential for soil science graduates. This encompasses 1) teamwork spirit, 2) synergistic cooperation, 3) analytical problem-solving, 4) a full understanding of soil concepts, and 5) adept utilization of appropriate tools and methodologies (Lin, 2005; Wilding and Lin, 2006; Field et al., 2011; Hartemink et al., 2014).
(ii) Induction of scaffolding (Calder, 2015; Quintana et al., 2018), where students gradually transition towards autonomous learning while delving into hard assignments.
(iii) Introducing inter-team competition, an approach shown to be impactful across numerous science, technology, engineering, and mathematics (STEM) disciplines, inclusive of Soil Sciences (see, e.g., Sulzman, 2004; Barbarick, 2010; Hupy, 2011).
(iv) Adhering to the Data-Information-Knowledge-Wisdom (DIKW) progression model (Ackoff, 1989). This DIKW paradigm illustrates the evolution from raw data acquisition to its insightful application, particularly in specific research contexts (Frické, 2019).

Our tailored teaching techniques bolster students' competence in applying their multifaceted abilities to untangle the mechanisms of insidious events and "in the field" conundrums. The SSK approach invigorates students with meta-cognitive, inquiry-driven learning traits.

SSK Contest Description

Over the initial 4 days of the SSK challenge, students undergo intensive training, which encompasses small-scale tasks, that refresh their understanding of soil concepts, and fosters teamwork, while using modern field equipment and tools. **Figure 1** illustrates a step-by-step procedure of the SSK.

On the fifth day, two groups, each consisting of 5–10 students, compete for the SSK award. From the outset, students nominate their team leaders, who are then granted the authority to handpick their team members. This procedure and team structure ensured the groups grew familiar with one another as the challenge advanced from day one through day five. The selection of team members consists of a discreet session where the leaders alternate in choosing members, beginning with those perceived as the most skilled down to the least. This selection order remains undisclosed to the other team members. Moreover, the instructors provide the leaders with confidential guidance, which includes fostering unity and participation from all members, prioritizing task completion, celebrating even minor achievements, continuously assessing and refining team performance, and embodying exemplary leadership.

Prior to the beginning of the SSK challenge, a field site with convoluted soil-related problems is pre-selected by several SWAE faculty members and technicians. These members, experts in the domains of soil and water science, also compose the Jury. They are tasked with gauging team performance against a predetermined set of criteria related to the specific problem present in the chosen field.

Participants are equipped with challenge protocols, directives, and evaluation criteria. Additionally, each team is provided a blank field notebook, intended for the duration of the challenge. Upon the contest's conclusion, this notebook, filled with illustrations, computations, and notes, alongside student identifications, is to be presented to the Jury for scrutiny.

The challenge avails a range of soil and water field instruments, kits, and the General Soil Map of Oman, all distributed to the teams (**Figures 2A–G**). Genuine case studies and tasks, depicting soil-water-landscape-community interconnections, are presented on the competition day. Examples of such tasks including: i) Describing soil profiles and estimating physicochemical parameters, ii) Investigating challenges and proposing agroengineering solutions in sabkha ecosystems, iii) Addressing urban flood management by analyzing, planning, and proposing solutions, iv)

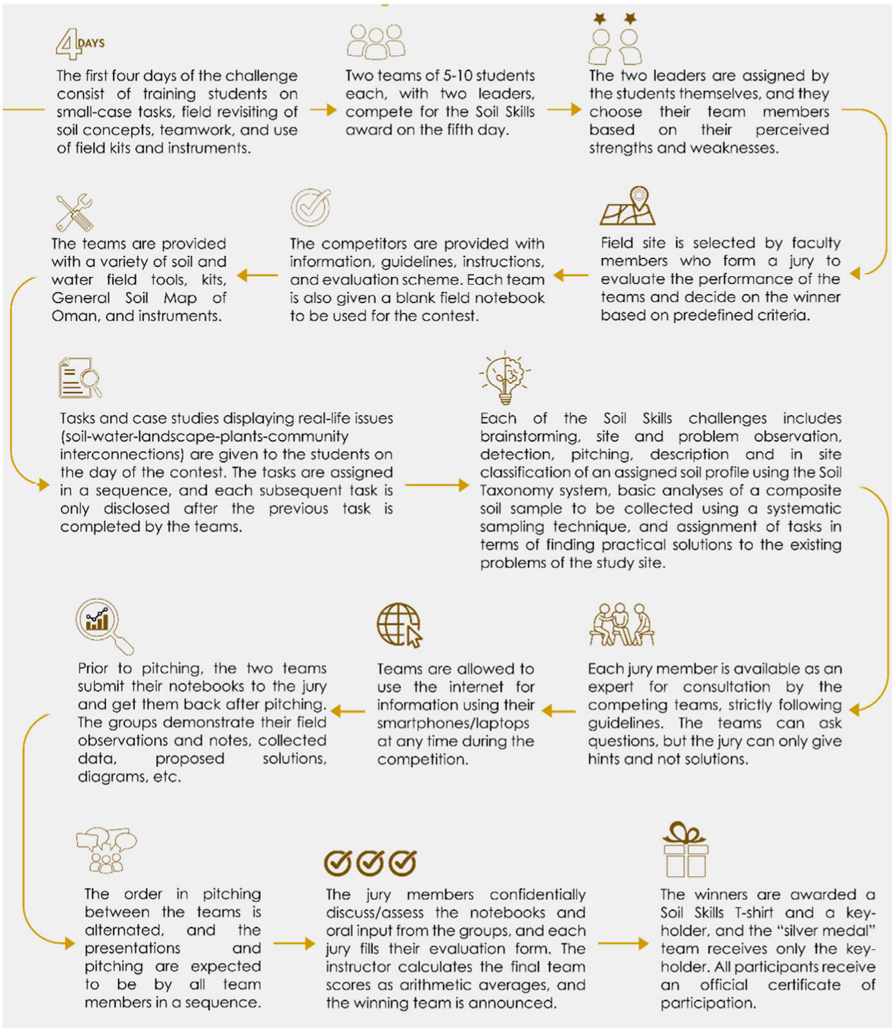

FIGURE 1 | Diagram, which illustrates the procedures and rules adopted in SSK during the four consecutive days of the yearly contest carried out during the January Winter Tour course, offered in 2017–2023.

Conducting a hypothetical crime scene investigation through soil forensics, and v) Installing and programming sensor-based irrigation systems.

These tasks are sequenced, with the revelation of each subsequent task contingent upon the completion of the preceding one. The timing for executing each task is meticulously managed and rigorously kept, with rubrics applied to assess the students' skills in each task (see Al-Ismaily et al., 2021; Al-Maktoumi et al., 2016 for detailed examples of tasks and the rubrics used).

Generally, the SSK challenges encapsulate brainstorming, onsite observations, issue and challenges identification, and in-depth analysis (Al-Maktoumi et al., 2016; Al-Ismaily et al., 2019). Sometimes the problems, which the teams confront, are puzzling, i.e., complex, argumentative, and have multiple solutions (Cantor et al., 2015). The aim is to discern practical remedies to the study site's existing predicaments.

Each Jury member serves as a consultant, adhering to strict guidelines. The Juries can offer hints and respond to yes-or-no questions, but must refrain from providing outright solutions. All interactions between teams and experts are kept "isolated", ensuring no exchange of information between the rival teams. Consultation limits are set at 3 min per task, and each team can engage an expert only once for every task.

Teams can consult the Internet using their own electronic mobile devices. However, the imposed time constraints compelled the judicious use of this resource. Post-task completion, teams have to submit and later retrieve their notebooks. Written-drawn sketches depict teams' observations, data, proposed solutions, etc. Importantly, teams cannot access each other's submitted field book, safeguarding originality during oral sessions in front of the Jury. Consistency between written and spoken content is imperative. **Figures 2F, G** vividly depict the essence of teamwork in addressing two pivotal challenges within

FIGURE 2 | Illustration of the SSK activities. **(A)** Soil profile description, sampling and field analysis of collected soil samples. **(B)** Measurement of moisture content across soil profile using ThetaProbe. **(C)** Surface soil sampling. **(D)** Use of hydraulic auger for soil sampling. **(E)** Field method for fast, easy, and cheap measurement of soil infiltration rate. **(F)** Measurement of falaj water flow. **(G)** Installation and programming of irrigation system controller challenge. **(H)** Award ceremony for winning team members. **(I)** Example awards to honor the winning and participated students. **(J)** Group photograph of participating students, Jury, and organizing faculty at the SSK- 2023.

SSK: measuring the water flow of a Falaj and racing against the clock to install and program irrigation system controllers, respectively.

The order of presentations alternates between the teams, with the Jury emphasizing collaborative participation from all team members.

Post-presentation, the Jury confidentially appraises the contents of the field books and verbal contributions. Each Jury member uses an evaluation form to document their assessment. Subsequently, these are consolidated by the lead instructor to derive the final scores, a process spanning approximately 15 min. During this interlude, students could unwind.

At the end of the challenge, the winning team is announced and honored with T-shirts or notebooks with handmade SSK insignia/symbols (**Figures 2H, I**). The runners-up receive key holders or mugs engraved with SSK (**Figure 2H**). All participants are awarded official SSK certificates recognizing their participation. **Figure 2J** depicts a group photograph featuring the participating students, jurors, and the organizing team of the SSK 2023 contest.

It's noteworthy that, akin to the structure in Mikhailova et al. (2015), the SSK tasks were meticulously organized. Unlike Mikhailova et al. (2015), where students had an entire semester to learn and execute their tasks, in our case SSK evaluations are conducted instantaneously in the field.

Evaluation of the SSK Initiative

Adhering to Biggs (1996) constructive alignment theory, our assessment strategy was designed to mirror the pedagogical approach implemented. Evaluations of the SSK initiative's outcome-based learning objectives were conducted through in-field assessments of learning traits, encompassing critical reasoning, proficiency in techniques and equipment, predictive abilities, cause-identification, structured argumentation, proposal of solutions with their justifications, and innovative thinking, among others.

The teams' success in fulfilling their set tasks was similarly assessed [refer to Al-Ismaily et al. (2021) for a detailed rubric elucidating the criteria the juries employed to gauge student performance]. Post-field activities, participants were prompted to engage in a confidential online survey (Al-Ismaily et al., 2021). This feedback was collated and interpreted by the course facilitator. The principal instructor was also furnished with data from the official SQU Course and Teaching Evaluation (Al-Maktoumi et al., 2016). Additionally, a peer assessment exercise was facilitated through email. This assessment, rooted in reciprocity and confidentiality, involved team members assessing their leaders, while the leaders reviewed and provided feedback on the performance of individual team members.

In spring 2018, the introduction of the SSK program to the SWWT course marked a significant improvement in its teaching evaluation scores. The course received a high rating of 3.93 out of 4.0, notably higher than the College's average score of 3.16. This was a substantial increase compared to the course's previous rating pre-SSK of 3.06 out of 4.0 in spring 2017, where the College average was 3.30 at the time. These statistics highlight the positive impact of the SSK program on the course's quality and effectiveness in teaching (Al-Ismaily et al., 2021).

Our questionnaire-based survey, involving 22 students who register the course, highlighted the positive impact of SSK on their transferable skills, encompassing teamwork, communication, problem-solving, creative thinking, observation, and leadership (Al-Ismaily et al., 2021). More than 87% noted an enhanced understanding of soil-water interaction and a greater willingness to express opinions. Every participant in the questionnaire study agreed that "Soil Skills" stimulated new ideas and integrated knowledge across Soil Science courses. The majority (86.4%) expressed satisfaction with SSK activities, such as brainstorming and engaging in scientific debates, finding them both interesting and challenging. Over 95% of students affirmed that the assigned case studies were clear, well-organized, relevant to the Soil Science program, and had adequately allocated time.

Benefits and Strengths of the SSK

The SSK approach offers several benefits and strengths. In practical relevance SSK emphasizes daunting actions involving field-based experiences, the approach enhances students' ability to apply soil science concepts to practical scenarios. This prepares the participants for thriving careers in the fields of soil science, environmental management, agriculture, and related fields. The SSK facilitates deep learning and critical thinking. The SSK encourages students to engage critically with soil science concepts, analyze holistic-complex problems, and develop innovative solutions. It cultivates critical thinking skills necessary for tackling soil-related challenges.

The SSK develops students' collaboration and communication skills. Through group work and teamwork, the SSK approach enhances students' collaboration and communication skills. They learn to effectively communicate ideas, share responsibilities, and work together to achieve common goals.

The SSK enhances students' field skills. Field-based activities incorporate handling field tools and the use of modern instruments, observation and inspection, soil sampling, mapping, and data collection. These skills are valuable for conducting accurate assessments, research, and environmental monitoring.

Limitations and Challenges of Implementing the SSK

Despite its strengths, the SSK approach also has limitations and challenges.

Resource-intensive nature of SSK requires field equipment/kits, laboratory facilities, and transportation for field trips. This may pose challenges in terms of resource availability, funding, and logistics.

The SSK requires careful planning and coordination to integrate field trips, practical exercises, and collaborative activities into the curriculum. This may necessitate fine adjustments to schedules and additional time commitments.

Weather conditions and safety concerns in SSK may levee certain impediments. That may restrict or complicate field trips, affecting the implementation of the approach.

The SSK may need adaptation to suit different educational settings, disciplines, and cultural contexts. It requires consideration of local soil characteristics, regional challenges, and available resources.

Student motivation and engagement in SSK by some students may require additional support from the faculty to adapt to the hectic and deeply interpersonal experience, which depends on specific personality traits.

THE SOIL JUDGING CONTEST (SJC)

Description of the SJC

The state Future Farmers of America, the North American Colleges and Teachers of Agriculture through the Soil Science Society of America and the American Society of Agronomy since 1961 organized soil judging contests for high-school and bachelor-level students (Cooper and Dolan, 2003; Cavinder et al., 2011). The undergraduate contests are carried out, scaffolding from a state in the United States to seven country's regions and, eventually, to a national level (Rees and Johnson, 2020).

Each school develops its own contest but follows the national guidelines. The duration of the contests varies from 1 day to a week. In some cases, soil samples (to be evaluated by students' teams) are mailed to each participating school. From each regional contest, a specified number of top-performing teams advance to the National Collegiate Soils Contest (NCSC). Students progressing to the national contest already have a diversity of experiences in soil profile-cores judging, gained in the contests of the lower level. The NCSC is held during the spring of each year. Host universities are rotated. Some specific elements of the competition are changed each year, to be in congruity with local soils and landscapes at the host university.

The judging tournament, which involves thousands of students being trained in soil morphology and pedology, has been a success (Hill et al., 1984; Cooper and Dolan, 2003). The objectives of an SJC, as defined by Post et al. (1974), are to:

(i) acquire knowledge about soil in a specific landscape with "in-field" training;
(ii) exchange ideas between the students and faculty;
(iii) to advocate soil science as a subject and future profession;
(iv) put on a student's resume the fact of participation in such an academic competition; and
(v) have fun. Post et al. (1974) suggested that the winning aspect should be de-emphasized.

The SJC accents on soil morphology as the best tool to assess soil limitations for various land uses (Vepraskas et al., 1988). of the participating students are typically majoring in soil science, agronomy, forestry, horticulture, education, economics, animal science, geology, geography, natural resources, geotechnical engineering, and environmental studies. Soil judging has been extensively used by many countries since 2012 including Australia and New Zealand (Levin and Morgan, 2013), Brazil (Pedron et al., 2023), Libya (Zurqani et al., 2023), and Taiwan (Chen et al., 2022), among others.

Participation in SJC and the Process Involved

The SJC process typically involves the following steps [see details in Galbraith and Thompson. (2014)].

Contest registration: Students form teams and register for soil judging contests at regional or national levels. These contests are often organized by educational institutions, soil science societies, or agricultural agencies.

Site selection: Contest organizers identify suitable soil pits where participants can observe and evaluate soil profiles. These pits are carefully prepared to represent different soil types and horizons.

Soil profile examination: Teams visit the designated soil pits and examine the exposed soil profiles. Students observe soil properties such as color, texture, structure, consistency, and the presence of horizons.

Data collection and analysis: Teams collect data by measuring soil properties, conducting field tests, and making detailed observations. Students record their detailed findings, paying close attention to distinctive features, soil layering, and any variations within the pit.

Soil classification and interpretation: Based on students' observations and knowledge of soil science principles, teams classify the soil profile according to established soil classification systems. The teams interpret the soil's suitability for various land uses, considering factors such as drainage, fertility, and erosion potential.

Judging and feedback: Teams present their findings and interpretations to a panel of judges. The students explain their reasoning, provide supporting evidence, and respond to questions from the judges. The judges evaluate the teams' performance based on their accuracy, depth of analysis, communication skills, and teamwork.

Emphasis on Critical Thinking, Problem-Solving, and Teamwork Skills

The SJC places a strong emphasis on developing critical thinking, problem-solving, and teamwork skills. Through the process of SJC, students engage in the following activities:

Analysis and interpretation: Students analyze complex soil profiles and apply their knowledge of soil science principles and soil morphology and taxonomy concepts to describe soil layers, identify diagnostic horizons, taxonomically classify soils, and interpret their characteristics and land use implications. One of the primary goals of SJC is to empower students to apply their understanding of soil genesis and classification. This facilitates a deeper comprehension of the interconnected influences of climate, parent material, relief, and organisms on soil formation over time, as well as the ensuing processes. Students are required to make informed decisions and judgments based on their observations and interpretation of soil horizons. The participants critically evaluate the information at hand, consider different possibilities, and justify their decisions with logical reasoning.

The SJC fosters collaboration and teamwork. Students work together in teams, sharing their observations, discussing different perspectives, and arriving at a consensus regarding horizons pedogenic features and diagnostic epi-endo-pedons and ultimately soil classification and interpretation. This collaborative process enhances their ability to work effectively in a team setting.

Students develop their communication skills by presenting their findings and interpretations to judges. The students should articulate their thoughts clearly, provide supporting evidence for their conclusions, respond to questions from the judges, and give coherent feedback. Effective communication is crucial for conveying scientific concepts accurately and convincingly.

Benefits and Strengths of the SJC

SJC offers several benefits and strengths, including:

1. Practical application of soil science: SJC provides "hands-on" practical experience linked specifically to the understanding of how soil morphology and classification together can provide knowledge for land use interpretation. Soil morphology exploration and description of excavated soil pedons is the best tool to assess soil limitations and land use suitability and capabilities (Vepraskas et al., 1988).
2. Development of critical thinking skills: SJC fosters critical thinking by challenging students to analyze complex soil profiles, consider multiple soil formation factors, and make informed judgments based on soil pedogenic processes (Galbraith, 2012). It promotes the ability to think critically, evaluate evidence, and apply scientific principles to solve problems.
3. Teamwork and collaboration: Participating in soil judging contests cultivates teamwork and collaboration skills. Students learn to work effectively in teams, share responsibilities, and collaborate to arrive at a consensus. These skills are transferable to various professional settings that require collaborative problem-solving.
4. Effective communication: The approach emphasizes effective communication as students present their findings, interpretations, and reasoning to judges. This enhances their ability to convey scientific concepts clearly and concisely, strengthening their communication skills.

A survey conducted by Cavinder et al. (2011) found that participation on a judging team increased interpersonal skills including communication, critical thinking, and information management, and that these skills provided an advantage in job placement and success in the chosen profession. However, motivation or activity alone is not as effective for producing student engagement as is the product (not summation) of the two (Barkley and Major, 2020). Through pre- and post-contest surveys completed by 83 and 62 participants respectively, Rees and Johnson. (2020) reported that a significant improvement was observed in five out of seven soil-judging skills. Most students held positive views on soil science after the contest. Feedback highlighted the value of location-based learning, though some criticized environmental factors and long days. Overall, the event was deemed highly educational and beneficial.

Limitations and Challenges of Implementing SJC

While SJC offers numerous benefits, there are some limitations and challenges to consider, including:

Accessibility and resources: Participation in the SJC may require access to suitable soil pits, transportation to contest sites, and availability of necessary equipment and facilities. These factors can pose challenges, particularly for institutions with limited resources or in geographically remote areas.

Time commitment: Preparing for SJC requires a significant amount of time from both students and instructors. It involves organizing practice sessions, field trips, and coordinating team activities. Balancing these demands with other academic responsibilities can be stressful.

Subjectivity of judging: Evaluating SJC participant's performance involves subjective judgments by a panel of judges. While efforts are made to standardize the evaluation process, there may still be some variation in assessments, which can affect the fairness of the competition.

Limited transferability: SJC is specific to soil science education and may not be applicable to other disciplines. Its focus on soil classification and interpretation may not align with the learning objectives of educational contexts, which are only coterminous to classical soil sciences (pedology), for example, soil mechanics.

Student engagement: Not all students may be equally motivated or interested in participating in the SJC. Some students may thrive in competitive environments, while others prefer alternative learning methods. Engaging all students and maintaining their enthusiasm can be a challenge.

CROSS COMPARISON BETWEEN THE SSK AND SJC

In this Section, we address the commonality and difference between two pedagogical methods, SSK and SJC. The aim is to cross-fertilize the two for their mutual advances.

Similarities in Providing Practical, Hands-on Experience in Soil Science

Both SSK and SJC contests overlap in the following characteristics:

- emphasize practical, hands-on experiences in soil science education. They recognize the importance of engaging BSc students in activities that involve soil classification, interpretation, and problem-solving.
- involve field-based learning experiences where students have the opportunity to observe and interact with soil profiles, collect soil samples, and apply soil science principles in a practical context. Field lessons are one of the most effective techniques for teaching soil science (Kasimov et al., 2013; Hartemink et al., 2014; Al-Maktoumi et al., 2016; Smith et al., 2020). 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).

- aim to bridge the gap between theoretical knowledge and practical application by providing students with direct experiences in soil-related activities, such as soil mapping, sampling, data collection, and analysis.
- focus on developing specific skills and competencies related to soil science, such as soil characterization, analysis, and interpretation; foster deep learning, critical thinking, collaboration, and field skills development. Critical thinking, problem-solving, teamwork, and effective communication skills are common attributes.
- blend egalitarian collaboration (within students' groups) and hierarchical judgment by "elite experts" of the Jury/contest panel are logistically and financially supported by higher education institutions and professional societies.
- students participating in SSK and SJC are surveyed by the organizers.

Differences Between SSK and SJC

The SSK and SJC contests are different in some methodological aspects, learning outcomes, and technicalities.

1. Methodology: The SSK, as a child of "Wetskills" utilizes problem-based learning, active learning, and engagement of students in activities through classroom instructions, laboratory exercises, field trips, and inquiry-based learning to facilitate the acquisition of strong skills and knowledge in disciplines broader than "soil science" *per se*. SJC is more specific in targeting soil pedons, profiles, cores, and taxa.
2. Learning Outcomes: the SSK aims to inculcate a broader understanding of soil science concepts in companion with other disciplines including the ability to solve subtle soil-water-land-geoengineering-related problems. However, the understanding in the SJC is deeper but narrower: Students work collaboratively in teams to assess soil profiles and classify soils, less trespassing to the "sister disciplines" in sciences and engineering. At SQU students learn once by participating in SS, while in the United States some students participate in SJC for several academic years.
3. The SSK contest is managed and budgeted by one academic department at a higher education institution in one country (Oman), benefiting from an international (Dutch) program of "Wetskills." The pool of organizers-experts in SJC is geographically broader and resources of participating universities and national agencies (USDA-NRCS) are ubiquitous. SJC surveys sample participating students from different locales in the United States.
4. Historically, SJC has a much longer horizon of post-auditing and planning, as compared with the SSK. This is both a strength and a weakness. Specifically, it is easier to tailor an educational contest of a specific academic program to meet its changing needs or adapt it quickly on demand, as opposed to managing a much larger contest such as the SJC. Coordination and innovations within SWAE in the SSK are overall easier to implement than in the SJC with multilevel governance.
5. The SJC is already implemented in the online (e-contest) mode (Owen et al., 2021), while to date, the SSK is not.

Suitability for Different Educational Settings and Student Preferences

SSK is suitable for educational settings that emphasize overarching and holistic knowledge and skills development in soil science. It is well-suited for students interested in pursuing careers in soil science and related fields. Both SJC and SSK are suitable for educational settings that value competitive environments, teamwork, and the development of critical thinking and problem-solving skills. It appeals to students who thrive in settings analogous to team sports (e.g., baseball, basketball, football), and enjoy collaborating with a "gold medal" climax, enjoying the challenge of contests *per se*, and prefer a more structured and competitive learning experience.

Considerations for Educators in Choosing the Right Approach

When choosing between the SSK and the SJC or their combinations, educators may consider the following factors:

1. Learning Objectives. The SSK approach may be more suitable if the emphasis is on multi-intra-disciplinary knowledge acquisition, practical skills development, and a deep understanding of soil science concepts. The SJC may be preferable if the focus is on developing critical thinking, problem-solving, teamwork, and communication skills within a competitive context.
2. Educational Context: Educators should consider the resources, facilities, and logistical constraints of their institutions. The SSK requires field equipment, laboratory facilities, and transportation for field trips. The SJC may require access to suitable soil pits/core samples, coordination of judging contests, and collaboration with other educational/professional institutions. Educators should assess the feasibility and availability of resources before choosing the most suitable approach, or their combinations.
3. Student Preferences and Engagement: Educators should consider student preferences and engagement when selecting the approach. Some students may prefer hands-on activities and field experiences offered by the SSK. Others may thrive in competitive environments and enjoy the teamwork and challenges of soil judging contests provided by the SJC. Educators should assess the interests, learning styles, and differences of their students, e.g., cultural, gender, and physical strengths to ensure maximum engagement and motivation.
4. Learning Outcomes: Educators should align the chosen approach with desired learning outcomes. If the goal is to develop specific field skills, a deep understanding of soil science concepts, and practical application, the SJC approach may be more appropriate. If the focus is on developing critical thinking, problem-solving, teamwork,

and communication skills within a competitive context, the SSK may be a better fit.

CONCLUDING REMARKS AND PERSPECTIVES

Educators should provide students with the opportunity and time to develop their own thinking, creativity, and action; only the combination of such attributes with appropriate soil science content in textbooks, supported by field lessons, can shape a "new" citizen who is ready to tackle the future challenges facing our planet. From this perspective, the concept of "from idea to action" (Xylander and Zumkowski-Xylander, 2018) should be propelled worldwide. Some educational solutions will help to achieve this goal. For instance, theoretical issues in the field of knowledge of facts (e.g., soil profile, soil genesis, country, and world soils, etc.) should be discussed in connection with the reality.

University teachers should carefully consider their specific context, learning goals, available resources, and student preferences when choosing the most suitable approach. By aligning the chosen approach with the desired outcomes, educators can foster knowledge acquisition, critical thinking, problem-solving, teamwork, and effective communication skills among students.

The following peculiarities distinguish the mode of the SSK-SJC soil contests:

a) The SSK, as compared with other BSc students' tournaments, is not narrowly focused on soil profile description (either American taxonomy or any other national classification of soils based on their genesis). The SSK gives a broader, more multidisciplinary pedagogical perspective and prospective.
b) In the SSK, students have to analyze and propose technical (e.g., engineering, environmental, social-cultural, and regulatory) solutions to daunting problems, that students are confronting in the field, e.g., the consequences of secondary salinization of agricultural land, waterlogging of foundations of buildings constructed on soils with subjacent perched aquifers, illegal disposal of municipal waste in wadi (arroyo) channels, and their banks, siltation of reservoirs of local dams, peculiarities of urban soils, the impact of devastating flashfloods on deluded urban districts and villages with the necessity to propose agroforestry and geotechnical methods to mitigate such floods, etc.
c) Different techniques and instruments have to be used by students. They have to quickly learn these tools and means in the field conditions, e.g., assembling (in 30 min) an irrigation unit with a controller, soil moisture sensors, data logger, or soil fertility evaluation using soil kits and pH-EC meters, measuring the flow rates by a current meter in farmers' falaj.[4]
d) SSK students are challenged to come up with an express method of assessing the parameters of soil and water systems when advanced instruments are instructed not to be used. The students had to improvise. For example, in one of the contests, the students are given a shovel, ruler, stopwatch, and container with a limited quantity of water. The task is to contrive an *ad hoc* protocol to evaluate the infiltration rate, without a double-ring or tension infiltrometer. The teams of students, upon intensive but short discussions, arrive at several ideas, e.g., the construction of a mini-basin with a shoveled bed and confining bunds, which allows for measuring the infiltration rate (see **Figure 2E**).
e) Each new academic year, several tasks in SSK are updated. For example, in the most recent contest of 2022, the students acted as forensic detectives (the Konan Doyle-type "soil Sherlock Holmes"). They had to decipher the soil-buried footprints of a hypothetical crime, committed at a remote site in Muscat. The new cohorts of students enjoy these overhauled tasks.
f) During the SSK, the soil science majoring students, who have a stronger background, as compared with other participating students with other majors, are *au fait* in the foundations of soil sciences, i.e., they teach their water technology classmates several fields/instrumentation techniques, e.g., soil profile description, basic of soil genesis and classification, and soil fertility assessments. Vice versa, the water technology students, who are more versed in hydraulics, fluid mechanics, and calculus, help to upgrade the level of soil science students in these disciplines.

We anticipate that the intertwining of the SSK with the SJC may have the following implications-extension:

1) Establishment of an in-depth, problem-based, practical enjoyable, and competitive learning experience, which closely aligns with professional scenarios requiring multi-, intra-disciplinary mindsets. It will facilitate students' application of soil science knowledge to emerging quandaries. Students' abilities and self-efficacy in bridging their acquired academic baggage (obtained in classrooms' lectures, textbooks, and laboratories) will be combined and upgraded with the soft and dexterity skills;
2) Students' mindset with metacognitive inquiry-based learning attributes such as a better capacity to gather information and knowledge, and the ability to collaboratively use this to formulate logical solutions will be enhanced;
3) The vital significance of soil sciences in relation to other academic disciplines and the broader public will be fostered. The SJC and the SSK, combined with their propelling at local, national, and international levels, if bolstered by robust media coverage, will hold the potential to thrust soil science back into the limelight, rekindling its visibility and relevance across scientific disciplines and the public at large;
4) The SSK and the SJC-exposed students will recognize the contextual nature of problems, and the need to work and

[4]https://en.wikipedia.org/wiki/Aflaj_Irrigation_Systems_of_Oman

communicate with the broader multi-cross-disciplinary community of experts and "citizen scientists";

and

5) The "back-to-field-work" principle is reinstated. Both the SJC and the SSK prioritize hands-on fieldwork in their pedagogical approaches. This will undoubtedly serve as a catalyst, motivating researchers and students to recognize and embrace the immense value of field studies.

Ahead are some areas that warrant further investigation:

1. Comparative Studies: Conducting comparative studies to assess the effectiveness of the SSK and the SJC in different educational settings and student populations would provide valuable insights.
2. Assessment Methods: Developing robust assessment methods that align with the learning outcomes of the SSK and SJC is essential. These assessments should go beyond traditional exams and consider authentic tasks and scenarios.
3. Integration with Technology: Researchers can investigate the use of digital tools, virtual field trips, online simulations, and data analysis software to augment student learning experiences in the field. Technology can provide the SSK and the SJC with opportunities for remote teaching and learning, data visualization, and interactive platforms, expanding access to soil science data and information beyond the limitations of physical resources at a specific geographical locale.
4. Teacher Training and Professional Development: Providing adequate training and professional development opportunities for educators is crucial for the effective implementation of the SSK and the SJC. The design of the SSK-SJC training programs will equip educators with the knowledge, skills, and instructional strategies necessary to implement these approaches effectively.
5. Inclusivity and Diversity: the SSK and the SJC approaches should be accessible and engaging for students from diverse backgrounds, including underrepresented groups and students with different learning styles. Investigating strategies to address potential barriers and biases in soil science education can contribute to creating an inclusive and equitable learning environment for all students.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

All photographs in the manuscript were taken by the lead author, SA-I. The majority of the identifiable images feature BSc students from SQU who were enrolled in the SWWT course. Prior to taking these photographs, all students were informed of their intended use and gave their consent on exposing these photos. Any remaining identifiable individuals in the photographs are co-authors of this manuscript and have also given their consent for publication.

AUTHOR CONTRIBUTIONS

SA-I and AK: A substantial contribution to the concept or design of the manuscript; AhA-M: Revised the manuscript critically for important intellectual content; HA-B, DB, AA-S, and AlA-M: Revised the manuscript for critical feedback. All authors contributed to the article and approved the submitted version.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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REFERENCES

Abit, S. M., Jr, Curl, P., Lasquites, J. J., and Macnelly, B. (2018). Delivery and Student Perceptions of Drive-Through Laboratory Sessions in an Introductory-Level Soil Science Course. *Nat. Sci. Educ.* 47, 1–8. doi:10.4195/nse2017.07.0015

Ackoff, R. L. (1989). From Data to Wisdom. *J. Appl. Syst. analysis* 16, 3–9.

Al-Ismaily, S., Al-Mayhai, A., Al-Busaidi, H., Kacimov, A., Blackburn, D., Al-Maktoumi, A., et al. (2021). Soil Skills Challenge: A Problem-Based Field Competition Towards Active Learning for BSc. Geoscience Students. *Geoderma* 385, 114903. doi:10.1016/j.geoderma.2020.114903

Al-Ismaily, S. S., Kacimov, A. R., Al-Maktoumi, A. K., and Al-Busaidi, H. A. (2019). Progressing From Direct Instruction to Structured and Open Inquiry-Based Teaching in a Bachelor of Soil Sciences Program: Experience at the National University in Oman. *J. Geoscience Educ.* 67, 3–19. doi:10.1080/10899995.2018.1509571

Al-Maktoumi, A., Al-Ismaily, S., and Kacimov, A. (2016). Research Based Learning for Undergraduate Students in Soil and Water Sciences: A Case Study of Hydropedology in an Arid-Zone Environment. *J. Geogr. High. Educ.* 40, 321–339. doi:10.1080/03098265.2016.1140130

Barbarick, K. (2010). Crossword Puzzles as Learning Tools in Introductory Soil Science. *J. Nat. Resour. Life Sci. Educ.* 39, 145–149. doi:10.4195/jnrlse.2010.0002

Barkley, E. F., and Major, C. H. (2020). *Student Engagement Techniques: A Handbook for College Faculty*. United States: John Wiley & Sons.

Biggs, J. (1996). Enhancing Teaching Through Constructive Alignment. *High. Educ.* 32, 347–364. doi:10.1007/bf00138871

Bouma, J. (2010). Implications of the Knowledge Paradox for Soil Science. *Adv. Agron.* 106, 143–171. doi:10.1016/s0065-2113(10)06004-9

Bouma, J. (2019a). How to Communicate Soil Expertise More Effectively in the Information Age When Aiming at the UN Sustainable Development Goals. *Soil Use Manag.* 35, 32–38. doi:10.1111/sum.12415

Bouma, J. (2019b). Soil Security in Sustainable Development. *Soil Syst.* 3, 5. doi:10.3390/soilsystems3010005

Bouma, J. (2023). The Role of Hydropedology When Aiming for the United Nations Sustainable Development Goals. *Vadose Zone J.*, e20269. doi:10.1002/vzj2.20269

Brevik, E. C., Hannam, J., Krzic, M., Muggler, C., and Uchida, Y. (2022). The Importance of Soil Education to Connectivity as a Dimension of Soil Security. *Soil Secur.* 7, 100066. doi:10.1016/j.soisec.2022.100066

Bridges, E. M., and Catizzone, M. (1996). Soil Science in a Holistic Framework: Discussion of an Improved Integrated Approach. *Geoderma* 71, 275–287. doi:10.1016/0016-7061(96)00015-8

Calder, N. (2015). Student Wonderings: Scaffolding Student Understanding Within Student-Centred Inquiry Learning. *ZDM* 47, 1121–1131. doi:10.1007/s11858-015-0734-z

Cantor, A., Delauer, V., Martin, D., and Rogan, J. (2015). Training Interdisciplinary "Wicked Problem" Solvers: Applying Lessons From HERO in Community-Based Research Experiences for Undergraduates. *J. Geogr. High. Educ.* 39, 407–419. doi:10.1080/03098265.2015.1048508

Cavinder, C. A., Byrd, B., Franke, J., and Holub, G. (2011). Texas A&M University Student Life Skill Development and Professional Achievement From Participation on a Collegiate Judging Team. *NACTA J.* 55, 60–62.

Chen, Z. S., Wu, C. Y., Tsai, C. C., Lai, H. Y., Juang, K. W., Jien, S. H., et al. (2022). Soil Connectivity Makes University Social Responsibility Practice in Taiwan. *Soil Secur.* 6, 100046. doi:10.1016/j.soisec.2022.100046

Cooper, T. H. (1991). TEAM Soil Judging—An Experiment. *J. Agronomic Educ.* 20, 123–125. doi:10.2134/jae1991.0123

Cooper, T. H., and Dolan, M. (2003). TEAM and Individual Scores at the 2002 National Soil Judging Contest. *J. Nat. Resour. Life Sci. Educ.* 32, 20–22. doi:10.2134/jnrlse.2003.0020

De Sousa, L. O., Hay, E. A., and Liebenberg, D. (2019). Teachers' Understanding of the Interconnectedness of Soil and Climate Change When Developing a Systems Thinking Concept Map for Teaching and Learning. *Int. Res. Geogr. Environ. Educ.* 28, 324–342. doi:10.1080/10382046.2019.1657684

Díaz-Fierros Viqueira, F. (2015). What Does the Future Hold for Soil Science? *Span. J. Soil Sci.* 5 (1), 54–59. doi:10.3232/sjss.2015.v5.n1.05

Field, D. (2019). "Soil Security and Connectivity: The What, So What and Now What," in *Global Source Security: Towards More Science-Society Interfaces*. Editors A. C. Richer-de Forges, F. Carre, A. B. McBratney, J. Bouma, and D. Arrouays (Boca Raton: CRC Press).

Field, D. J., Koppi, A. J., Jarrett, L. E., Abbott, L. K., Cattle, S. R., Grant, C. D., et al. (2011). Soil Science Teaching Principles. *Geoderma* 167, 9–14. doi:10.1016/j.geoderma.2011.09.017

Field, D. J., Yates, D., Koppi, A. J., Mcbratney, A. B., and Jarrett, L. (2017). Framing a Modern Context of Soil Science Learning and Teaching. *Geoderma* 289, 117–123. doi:10.1016/j.geoderma.2016.11.034

Flannery, T. F. (2011). *Here on Earth: An Argument for Hope*. Melbourne, Australia: Text Publishing.

Frické, M. (2019). The Knowledge Pyramid: The DIKW Hierarchy. *Ko. Knowl. Organ.* 46, 33–46. doi:10.5771/0943-7444-2019-1-33

Galbraith, J. M. (2012). Using Student Competition Field Trips to Increase Teaching and Learning Effectiveness. *J. Nat. Resour. Life Sci. Educ.* 41, 54–58. doi:10.4195/jnrlse.2011.0023u

Galbraith, J. M., and Thompson, J. A. (2014). *Handbook for American Society of Agronomy Collegiate Soils Contest, Southeast Association of Soil Judging Coaches*. USDA, USA: Southeastern Region.

Hartemink, A. E. (2006). "The Future of Soil Science," in *International Union of Soil Sciences. IUSS* (The Netherlands: Wageningen).

Hartemink, A. E., Balks, M. R., Chen, Z. S., Drohan, P., Field, D. J., Krasilnikov, P., et al. (2014). The Joy of Teaching Soil Science. *Geoderma* 217, 1–9. doi:10.1016/j.geoderma.2013.10.016

Hartemink, A. E., and Mcbratney, A. (2008). A Soil Science Renaissance. *Geoderma* 148, 123–129. doi:10.1016/j.geoderma.2008.10.006

Hill, W., Simpson, T., Collins, M., Counce, E., Frye, W., and Hillsman, K. (1984). Soil Judging Coaches Workshop. *J. Agronomic Educ.* 13, 7–10. doi:10.2134/jae.1984.0007

Hupy, J. P. (2011). Teaching Geographic Concepts Through Fieldwork and Competition. *J. Geogr.* 110, 131–135. doi:10.1080/00221341.2011.532229

Janzen, H., Fixen, P., Franzluebbers, A., Hattey, J., Izaurralde, R. C., Ketterings, Q., et al. (2011). Global Prospects Rooted in Soil Science. *Soil Sci. Soc. Am. J.* 75, 1–8. doi:10.2136/sssaj2009.0216

Kasimov, N. S., Chalov, S. R., and Panin, A. V. (2013). Multidisciplinary Field Training in Undergraduate Physical Geography: Russian Experience. *J. Geogr. High. Educ.* 37, 416–431. doi:10.1080/03098265.2013.794331

Koch, A., Mcbratney, A., Adams, M., Field, D., Hill, R., Crawford, J., et al. (2013). Soil Security: Solving the Global Soil Crisis. *Glob. Policy* 4, 434–441. doi:10.1111/1758-5899.12096

Krzywoszynska, A. (2019). Making Knowledge and Meaning in Communities of Practice: What Role May Science Play? The Case of Sustainable Soil Management in England. *Soil Use Manag.* 35, 160–168. doi:10.1111/sum.12487

Lal, R., and Stewart, R. (2013). "Soil Management for Sustaining Ecosystem Services," in *Principles of Sustainable Soil Management in Agroecosytems* (Boca Raton: CRC Press), 521–536.

Levin, M., and Morgan, C. (2013). Taking Collegiate Soils Contests to the International Stage. *Soil Horizons* 54, 0–1. doi:10.2136/sh2013-54-3-tp

Lin, H. (2005). Letter to the Editor on "From the Earth's Critical Zone to Mars Exploration: Can Soil Science Enter Its Golden Age?". *Soil Sci. Soc. Am. J.* 69, 1351–1353. doi:10.2136/sssaj2005.0063

Lukes, L. A., Jones, J. P., and Mcconnell, D. A. (2020). Self-Regulated Learning: Overview and Potential Future Directions in Geoscience. *J. Geoscience Educ.* 69, 14–26. doi:10.1080/10899995.2020.1820828

Mcbratney, A., Field, D. J., and Koch, A. (2014). The Dimensions of Soil Security. *Geoderma* 213, 203–213. doi:10.1016/j.geoderma.2013.08.013

Mikhailova, E., Post, C., Sharp, J., and Speziale, B. (2015). Creative Inquiry in Soil Science: Soil Inventory of Private Lands. *Nat. Sci. Educ.* 44, 122–129. doi:10.4195/nse2015.05.0006

Owen, R. K., Anderson, A., Bhandari, A., Clark, K., Davis, M., Dere, A., et al. (2021). Evaluating Student Attitudes and Learning at Remote Collegiate Soil Judging Events. *Nat. Sci. Educ.* 50, e20065. doi:10.1002/nse2.20065

Pedron, F. D. A., Galbraith, J. M., Scharenbroch, B. C., Pereira, M. G., and Fontana, A. (2023). Soil Judging e-Contest: The Virtual Experience Expanding the Soil Learning Process. *Nat. Sci. Educ.* 52, e20125. doi:10.1002/nse2.20125

Pino, V., Mcbratney, A., O'brien, E., Singh, K., and Pozza, L. (2022). Citizen Science and Soil Connectivity: Where Are We? *Soil Secur.* 9, 100073. doi:10.1016/j.soisec.2022.100073

Post, D. F., Miller, F. P., and Allen, B. (1974). The Collegiate Soils Contest—A Report and Analysis. *J. Agronomic Educ.* 3, 82–86. doi:10.2134/jae.1974.0082

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., et al. (2018). A Scaffolding Design Framework for Software to Support Science Inquiry. *J. Learn. Sci.* 13, 337–386. doi:10.1207/s15327809jls1303_4

Rees, G. L., and Johnson, D. K. (2020). Impact of a National Collegiate Soil Judging Competition on Student Learning and Attitudes. *Nat. Sci. Educ.* 49, e20007. doi:10.1002/nse2.20007

Schmidt, H. G. (1983). Problem-Based Learning: Rationale and Description. *Med. Educ.* 17, 11–16. doi:10.1111/j.1365-2923.1983.tb01086.x

Smith, C., Chau, H., Carrick, S. T., Van Dijk, J., Balks, M., and O'neill, T. (2020). "Learning by Doing Is More Memorable: The Practice of Pedagogically Aligned Learning in Soil Science in New Zealand," in *Catena Soil Sciences* (Stuttgart, Germany: Imprint of Schweizerbart Science Publishers).

Sulzman, E. W. (2004). Games in an Introductory Soil Science Course: A Novel Approach for Increasing Student Involvement With Course Material. *J. Nat. Resour. Life Sci. Educ.* 33, 98–101. doi:10.2134/jnrlse.2004.0098

Urbańska, M., and Charzyński, P. (2021). SUITMAs as an Archive of the Human Past: Educational Implications. *J. Soils Sediments* 21, 1928–1937. doi:10.1007/s11368-021-02886-2

Vepraskas, M., Mcdaniel, P., and Camberato, J. (1988). Teaching Soil Morphology to Introductory Soil Science Students. *J. Agronomic Educ.* 17, 93–96. doi:10.2134/jae1988.0093

Vogel, H. J., Bartke, S., Daedlow, K., Helming, K., Kögel-Knabner, I., Lang, B., et al. (2018). A Systemic Approach for Modeling Soil Functions. *Soil* 4, 83–92. doi:10.5194/soil-4-83-2018

Wessolek, G. (2006). Some Reflections on the Future of Soil Science. *future soil Sci.*, 150–152.

Wilding, L. P., and Lin, H. (2006). Advancing the Frontiers of Soil Science Towards a Geoscience. *Geoderma* 131, 257–274. doi:10.1016/j.geoderma.2005.03.028

World Congress of Soil Science (2014). Inaugural International Soil Judging Contest. Available at: https://www.20wcss.org/sub03_5.php (Accessed September 7, 2023).

Xylander, W. E., and Zumkowski-Xylander, H. (2018). Increasing Awareness for Soil Biodiversity and Protection: The International Touring Exhibition 'The Thin Skin of the Earth. *Soil Org.* 90, 79–94. doi:10.25674/KKY5-A011

Zurqani, H. A., Mikhailova, E. A., Post, C. J., Schlautman, M. A., Sharp, J. L., Sherif, A. S., et al. (2023). Soil Science Education: Adaptation of Soil Judging (Evaluation) to Libya. *Al-Mukhtar J. Sci.* 38, 78–92. doi:10.54172/mjsc.v38i1.1203

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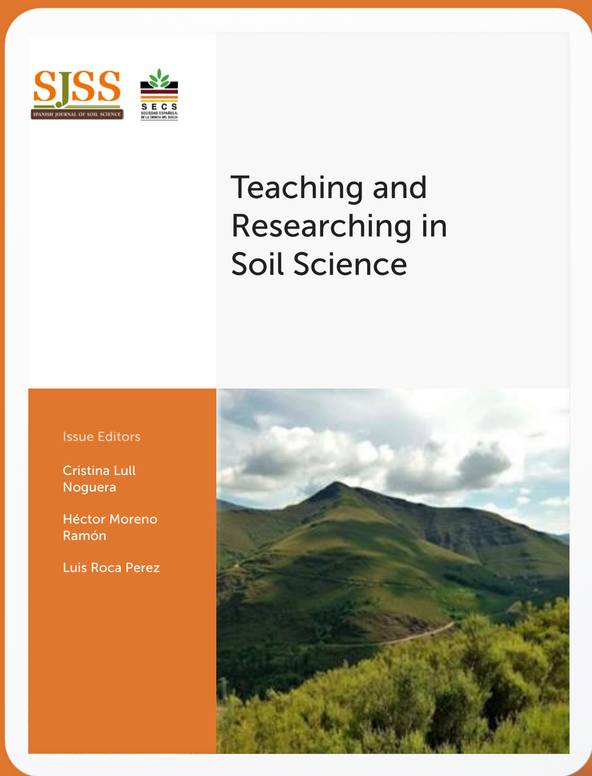

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Contact

sjss.office@frontierspartnerships.org