INNER
INNOVATIVE EDUCATIONAL RESEARCH ©INNER
www.innovativedu.org Volume 7, Issue 2, 2025

Operationalising GreenComp in Soil Geography Through Experiential Outdoor Learning: A Qualitative Case Study in Slovenia

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Abstract

This study examines how sustainability competence dimensions in soil geography are enacted in an outdoor, experiential learning setting and which learning mechanisms most effectively support that enactment. A qualitative single-case study was conducted at the Educational Polygon for Self-Sufficiency Dole (Slovenia) across six facilitated learning sessions (18 hours) with vocational education and training (VET) teachers (N = 30 enrolled; session attendance varied). Data comprised learning materials, structured observation notes, participant reflection artefacts, and pedagogical documentation, and were analyzed through directed thematic analysis using sustainability competence categories (e.g., systems, strategic, normative, and interpersonal competences) and the European Sustainability Competence Framework (GreenComp) as sensitizing concepts. The analysis converged on five recurrent competence dimensions enacted during soil-geography activities: systems thinking about soil–water–biota–land-use feedback, spatial–analytical reasoning grounded in landscape position and soil-profile evidence; normative judgement concerning stewardship and long-term soil protection; strategic, indicator-informed action planning; and interdisciplinary, collaborative competence in group sense-making. These dimensions were most strongly supported when hands-on observation, structured reflection prompts, and collaborative planning tasks were intentionally sequenced. Overall, place-based soil learning can make sustainability competences observable and discussable when pedagogy explicitly connects field evidence to value-laden trade-offs and feasible management decisions. Accordingly, teacher education and curriculum designs should revisit the same sites over time, align reflection prompts and assessment rubrics with domain-specific competence indicators, and use collaborative scenario tasks as capstone assessment moments.

Keywords: Soil geography; Soil literacy; Sustainability competences; GreenComp; Experiential learning; Teacher professional development; Qualitative case study

To cite this article: Vovk, A. (2025). Operationalizing GreenComp in soil geography through experiential outdoor learning: a qualitative case study in Slovenia. *Innovative Educational Research (INNER), 7,* (2), 107-126.

Article Type	Received	Accepted	Published Online
Research Article	09.09.2025	05.11.2025	12.31.2025

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Soil geography, as an interdisciplinary field, integrates pedology, physical geography, ecology, and spatial planning. In the context of sustainable development, it plays a key role in understanding the spatial diversity of soils, their vulnerability, and their contribution to ecosystem services and food security. The development of sustainability competences in this field is essential for educating professionals capable of holistic, systemic, and responsible soil management (Brevik et al., 2020; Demir, 2025). Such a competence-based approach also requires appropriate learning environments where theoretical knowledge relates to practical experience in real-world settings.

In this context, the Educational Polygon for Self-Sufficiency Dole plays an important role as an applied learning environment for developing sustainability competences in soil geography. The site enables experiential learning about soils as spatially differentiated and living systems and promotes an understanding of the relationships between soil properties, land use, ecosystem services, and societal needs. In doing so, it contributes to reducing the gap between scientific knowledge and its application in practice.

In the European context, sustainable soil management is also reflected in the legislative and policy frameworks of the European Union. Until recently, the EU lacked a specific legally binding instrument that would comprehensively regulate soil protection at the level of the entire Union, although soils are addressed through several related policies (e.g., water, agriculture, waste, chemicals) that indirectly affect their condition (Heuser, 2022). This situation has often hindered the systematic treatment of soils as a strategic natural resource (Nature-based Solutions for Soil Management [NBSOIL], n.d.).

A major milestone in this area is the adoption of the Soil Monitoring and Resilience Directive (Soil Monitoring Law), which will enter into force on 16 December 2025. This is the first EU legal act dedicated exclusively to soils, aiming to establish a comprehensive European framework for monitoring soil health, managing contaminated sites, and mitigating key pressures such as erosion, compaction, loss of organic matter, soil sealing, and the degradation of soil biodiversity. The directive requires the establishment of national soil health monitoring systems and regular reporting to the European Commission and the European Environment Agency, contributing to harmonized and comparable data across the Union. The ultimate objective of the legislation is to ensure that all European soils are in good condition by 2050, in line with the ambitions of the European Green Deal and the EU Biodiversity Strategy for 2030.

The Soil Monitoring Directive also includes principles aimed at limiting soil sealing and protecting topsoil during construction activities, thereby introducing mechanisms to reduce the permanent loss of soil as a natural resource. Although Member States are granted a certain degree of flexibility in adapting measures to local conditions, they are required to ensure that national monitoring and management systems contribute effectively to the common European objectives of soil protection.

In addition to this directive, soil health and the sustainable use of soil in the EU are supported by other strategic documents, notably the EU Soil Strategy for 2030 (European Commission, 2021), as well as broader environmental policies within the framework of the European Green Deal. These policies highlight the importance of soil ecosystem services, such as carbon sequestration, water filtration, support for biodiversity, and resilience to climate change, and include measures for their conservation and restoration.

Integrating these legislative and strategic frameworks into education and the development of sustainability competences enables professionals to better understand the links between scientific concepts, environmental objectives, and legal requirements. In this regard, the Educational Polygon for Self-Sufficiency Dole represents a good practice example, where European soil protection strategies are translated into action at the local level through education, practical land management, and responsible soil stewardship. This approach is essential for effective soil management at local, national, and European levels.

The Concept of Sustainability Competences

Sustainability competences are defined as a combination of knowledge, skills, values, and attitudes that enable individuals to act effectively, responsibly, and reflectively towards sustainable development (Çimen, 2025; Wiek et al., 2011; Vovk Korže, 2014). The discussion on sustainability competences stems from the recognition that the mere transfer of knowledge about environmental problems is not sufficient to address the complex environmental and societal challenges of the modern world. What is needed are individuals capable of systems thinking, critical judgment, ethical decision-making, and long-term planning under conditions of uncertainty.

In this context, sustainability competences represent a response to the so-called knowledge–action gap, where, despite the availability of knowledge, sustainable practices often fail to materialize in space and society. Education oriented toward competence development therefore goes beyond a descriptive understanding of environmental processes and promotes the active role of individuals in shaping sustainable solutions (Wiek et al., 2011). Experiential and problem-based learning environments play a key role in this process, as they enable a direct connection between knowledge and action in real-world settings.

Such a learning environment is also represented by the Educational Polygon for Self-Sufficiency Dole, where sustainability competences are developed through practical work, observation, reflection, and collaborative learning. The polygon allows participants not only to acquire theoretical knowledge about environmental processes, but also to develop the capacity for responsible soil management under specific spatial and environmental conditions.

In the field of soil geography, sustainability competences primarily relate to understanding soils as a limited, spatially differentiated, and slowly renewable natural resource, which at the same time forms the basis of numerous ecosystem services, such as food production, water regime regulation, carbon sequestration, and biodiversity conservation (Blum, 2005). Due to their long regeneration time, soils are particularly vulnerable to unconsidered interventions, which require a high level of professional responsibility and a long-term perspective in spatial management. At the Educational Polygon for Self-Sufficiency Dole, this understanding is reinforced through direct experience of soil diversity, land-use impacts, and the consequences of different management practices.

FAO emphasizes that a lack of knowledge about soils is one of the key reasons for soil degradation at the global level. Soil degradation is not only the result of natural processes, but primarily of inappropriate human practices stemming from an insufficient understanding of soil functions and their spatial variability (Food and Agriculture Organization of the United Nations [FAO], 2015). The development of sustainability competences is therefore a crucial

prerequisite for sustainable soil resource management and for preventing long-term environmental and social consequences, such as loss of fertility, increased vulnerability to climate change, and threatened food security. In this sense, the Dole Self-Sufficiency Learning Polygon functions as a preventive educational space, where inappropriate practices are identified, analyzed, and replaced with sustainable solutions.

Of particular importance in the contemporary European context is GreenComp – the European Sustainability Competence Framework (European Commission, 2022), developed by the European Commission. GreenComp defines sustainability competences as a set of four interrelated domains: embodying sustainability values, embracing complexity in sustainability thinking, envisioning sustainable futures, and acting for sustainability.

This framework emphasizes that sustainability is not merely a technical or natural-science issue, but also a matter of values, culture, and socio-political considerations. In soil geography, GreenComp is reflected in the development of the ability to understand complex relationships between soils, land use, societal needs, and environmental constraints, as well as in translating this understanding into responsible decisions and concrete practices. At the Educational Polygon for Self-Sufficiency Dole, these GreenComp dimensions are directly realized through experiential learning, collaborative work, and reflection on one's own actions in space.

The integration of soil geography with the GreenComp framework and with applied learning environments such as the Educational Polygon for Self-Sufficiency Dole thus contributes to the formation of professionals who are not only analysts of soil properties, but also drivers of sustainable change in space. Such a competence-based approach strengthens the role of soil geography in education for sustainable development and positions it as a key discipline in the implementation of environmental policies, sustainable spatial planning, and the long-term protection of soils as a shared natural heritage. What follows is a comparative table of sustainability competences linking the framework of Wiek et al. (2011), GreenComp (European Sustainability Competence Framework), and specific competences in the field of soil geography (Table 1).

Table 1

Comparative Framework: Wiek Et Al. – GreenComp – Soil Geography

Wiek et al. (2011) framework	GreenComp (EU)	Soil geography – thematic and competence-based application
Systems competence		
Understanding complex systems and interconnections	Embracing complexity in sustainability thinking	Understanding soils as part of a complex pedospheric system connected to relief, climate, hydrology, land use, and social processes; spatial analysis of soil degradation processes (erosion, compaction, contamination)
Anticipatory competence		
Ability to anticipate future scenarios	Envisioning sustainable futures	Assessment of long-term impacts of land use (urbanization, intensive agriculture) on soil fertility, ecosystem services, and food security; development of sustainable land-use scenarios

Wiek et al. (2011) framework	GreenComp (EU)	Soil geography – thematic and competence-based application
Normative competence		
Evaluating sustainability goals and norms	Embodying sustainability values	Understanding soils as a common natural heritage and a limited resource; ethical decision-making in spatial planning, protection of agricultural land, and prevention of soil sealing
Strategic competence		
Designing and implementing sustainability interventions	Acting for sustainability	Application of soil knowledge in developing sustainable practices (agroecological farming, green infrastructure, ecoremediation); participation in spatial strategies and environmental assessments
Interpersonal (collaborative) competence		
Collaboration, communication, and stakeholder engagement	Acting for sustainability + Embodying sustainability values	Interdisciplinary collaboration among geographers, agronomists, urban planners, and decision-makers; communication of soil-related knowledge to the public and policymakers
Critical thinking		
(implicit in the framework)	Critical thinking and reflection (cross-cutting GreenComp dimension)	Critical evaluation of soil maps, spatial datasets, and land-use policies; identification of conflicts between short-term economic interests and long-term soil protection
Integrative competence		
Linking knowledge to decision-making	Holistic action for sustainability (cross-cutting dimension)	Synthesis of pedological, geographical, and social data to support sustainable spatial decision-making; use of GIS and field data in planning and policy processes

The comparative analysis shows that the frameworks of Wiek et al. and GreenComp are conceptually complementary. Wiek et al. provide an analytically structured academic model of competences, while GreenComp introduces a normative–operational framework specifically tailored to the European educational and policy context (Council of the European Union, 2025). Soil geography represents an applied domain in which both frameworks are concretized through an understanding of soils as a spatially differentiated, vulnerable, and

sustainability-critical natural resource (Özergun-Köse & Timur, 2025; European Commission, n.d.; 2022; 2025).

Such integration enables the development of professionals who not only understand the physical and biological properties of soil, but are also capable of ethical judgment, long-term planning, and active engagement in support of sustainable spatial management.

The analysis is anchored in sustainability competence scholarship (e.g., systems thinking, strategic competence, normative competence, and interpersonal competence) and the European Sustainability Competence Framework (GreenComp). In this study, these frameworks are treated as sensitizing concepts that inform the development of observable indicators and analytic categories for qualitative coding (Vovk Korže, 2018; Vovk Korže & Korže, 2020).

To increase domain specificity, competence dimensions are operationalized for soil geography by linking (i) soil-system concepts (e.g., soil formation factors, horizons, texture/structure, water regimes, biodiversity), (ii) spatial reasoning and mapping, (iii) value-laden trade-offs (e.g., soil sealing, topsoil protection), and (iv) management-oriented planning (e.g., site-adapted interventions).

The Aim and Research Questions

The aim of this study is to examine how sustainability competence dimensions in soil geography are enacted and potentially developed through experiential learning activities implemented at the Educational Polygon for Self-Sufficiency Dole (Slovenia). The study is guided by the following research questions:

- Which sustainability competence dimensions are most visibly enacted during soil-geography learning activities at the Dole Learning Polygon?
- Through which experiential learning mechanisms (e.g., hands-on tasks, observation, reflection, collaborative planning) are these competence dimensions supported?
- How do participants describe changes in their understanding and intended soil-related actions after engaging in the polygon activities?

Method

Research Design

This research adopts a qualitative approach to enable an in-depth, interpretive understanding of sustainability competence enactment within a real-world educational setting. Qualitative designs are particularly appropriate when the purpose is to examine processes, meanings, and contextual influences that cannot be reduced to isolated variables without losing explanatory power (Creswell & Poth, 2018; Merriam & Tisdell, 2016).

In addition, the case study is informed by an experiential learning perspective in which competence enactment is expected to emerge through cycles of concrete experience, reflective observation, and the translation of insights into situated judgements and action-oriented plans (Kolb, 2015). This lens guided both the design-sensitive observation protocol (what was looked for during activities) and the analytic focus on how observation, reflection, and collaborative planning were sequenced to make sustainability competences visible in situ.

A single-case study serves as the primary research strategy. Case study methodology is well-suited to investigating complex educational phenomena within their natural contexts, especially when the boundaries between the phenomenon (competence enactment) and the

context (the polygon as a place-based learning environment) are not clearly separable (Yin, 2018). The present case is defined as the Educational Polygon for Self-Sufficiency Dole and its soil-geography learning program, examined holistically to produce an analytically rich account of how competence dimensions are enacted through activity participation.

To enhance the credibility of the case account, the design incorporates multiple qualitative sources of evidence and relies on triangulation as a logic for converging interpretations across data types (Patton, 2015; Yin, 2018). This aligns with established guidance that case studies should build robust explanations by integrating complementary evidence (e.g., learning materials, observations, reflections, and pedagogical documentation) rather than relying on a single stream of data (Stake, 1995; Yin, 2018). Overall, the single-case design supports context-sensitive explanation, enabling the study to illuminate how and why competence-related learning processes emerge within this specific experiential learning ecology (Stake, 1995; Merriam & Tisdell, 2016).

Case Setting

The case is the Educational Polygon for Self-Sufficiency Dole in Slovenia, conceptualized as an applied outdoor learning environment where soil observation, land-use decision-making, and sustainability discussions are integrated into structured learning activities. The learning sessions analyzed here took place from March 2024 to March 2025 and included 6 sessions (total duration 18 hours).

Participants And Recruitment

Participants were vocational education and training (VET) teachers enrolled in the polygon program (N = 30; session attendance varied). For participant-level reflection analysis, inclusion required (i) attendance in at least one documented session and (ii) submission of at least one reflection artefact; all sessions were retained for session-level analysis using observation notes, learning materials, and pedagogical documentation. Table 2 summarizes the session-level data corpus and attendance.

Data Sources

Four complementary qualitative data sources were collected to enable triangulation and to document learning processes at different levels (planned curriculum, enacted activities, and participant sense-making):

- Learning activity materials (activity plans, worksheets, mapping tasks, prompts).
- Structured participant observation field notes focused on competence indicators during activities (e.g., systems reasoning, spatial explanations, ethical justifications, strategy proposals, collaboration episodes).
- Participant reflection products collected immediately after sessions (written reflections and/or recorded group debriefings).
- Pedagogical documentation (learning objectives, teacher/educator notes, photo documentation of artefacts where ethically permissible).

Data Collection Procedures

Observation Checklist and Reflection Prompts

The indicator checklist operationalized sustainability competence domains for soil-geography practice (e.g., soil–water–biota feedback explanations, profile- and landscape-position reasoning, explicit value/trade-off justifications, indicator-informed action proposals, and collaborative synthesis episodes). Reflection prompts asked participants to (a) justify interpretations with field evidence, (b) identify sustainability trade-offs and normative considerations, and (c) propose feasible actions or teaching transfers. Exemplars of the checklist and prompts can be provided as supplementary material upon request.

Researcher Role and Reflexivity

The researcher attended each session as a non-participant observer and did not lead instruction; facilitation was conducted by the program educators. To reduce observer expectancy effects, field notes were structured around pre-defined competence indicators, supplemented with reflexive memos documenting assumptions, emerging interpretations, and instances of uncertainty. Analytic decisions (e.g., code refinements, theme boundaries) were logged in an audit trail to support transparency.

Data collection followed a common protocol across sessions. For each session, the researcher (a) archived learning materials, (b) conducted structured observations using a pre-defined indicator checklist aligned with the competence framework, and (c) collected participant reflections using standard prompts. All data were labeled by date, activity type, and participant pseudonym (where applicable) and stored on a secure drive.

Data Analysis

Framework Integration and Comparative Mapping

Wiek et al.'s competence framework and GreenComp were treated as complementary sensitizing frameworks. During codebook development, overlapping constructs were aligned (e.g., systems thinking with embracing complexity; strategic competence with acting for sustainability; normative competence with embodying sustainability values), and soil-geography–specific indicators were specified to increase domain validity. This alignment supported the construction of a competence–activity mapping that links (a) planned tasks, (b) observed enactments, and (c) participant reflections, enabling transparent comparison across competence models while keeping the analysis grounded in field evidence.

Analytical Foci

Beyond coding for competence categories, the analysis paid particular attention to (i) evidence of movement from descriptive knowledge toward action-oriented reasoning (i.e., the knowledge–action gap), (ii) the role of guided reflection in eliciting normative and strategic judgements, and (iii) how spatial context (microrelief, slope position, land cover, hydrological conditions) shaped explanations and decisions. These foci were used to interpret why certain competence dimensions became salient activity sequences.

A directed thematic analysis was conducted using pre-defined competence categories informed by the conceptual framework. Analysis proceeded in six steps: (1) data familiarization; (2) development of a codebook with competence categories and operational indicators; (3) initial coding of all evidence sources; (4) inductive development of sub-codes to capture soil-domain specific patterns; (5) consolidation of themes and selection of

illustrative evidence excerpts; and (6) cross-source comparison to identify convergent and divergent patterns across observations, reflections, and documentation. The final output includes a competence–activity mapping matrix and an evidence table linking themes to data excerpts (Table 3).

Additional strategies were used to strengthen interpretive warrant: (a) triangulation was conducted not only across data types but also across analytic moments (initial coding, theme consolidation, and cross-session comparison); (b) negative-case searches were performed to identify episodes where expected competence indicators were absent or contradicted; and (c) periodic peer debriefing with a colleague familiar with qualitative analysis was used to challenge emerging themes and refine operational definitions. Together, these steps enhance credibility and confirmability.

Credibility was supported through methodological triangulation across the four data sources, iterative refinement of the codebook, and maintenance of an audit trail documenting analytic decisions (Lincoln & Guba, 1985). Transferability is addressed through thick description of the case setting and activities.

This qualitative single-case study supports analytic rather than statistical generalization. The context (one polygon site), variable attendance across sessions, and reliance on program-embedded reflections may shape which competence indicators were most observable. Furthermore, the design documents intentions and perceived learning rather than independently verified long-term behavior change. These limitations should be considered when transferring the competence–activity mapping to other teacher education, VET, or school contexts.

All participants were informed about the study purpose, data types collected and intended use of anonymized excerpts for research dissemination. Participation was voluntary, and participants could decline specific data uses (e.g., photography of artefacts) without consequences for program participation. Reflection artefacts were de-identified at the point of transcription/archiving; pseudonyms and session codes were used in reporting. Data were stored on an access-restricted drive and handled in line with institutional and national guidance for educational research. Where photographs of learning artefacts were used, identifying information was removed or the image was not retained.

Teachers in vocational education and training (VET) participated in the program to develop their personal professional competences and expressed an interest in public dissemination, as this allows them to promote care for healthy soils through their own professional learning.

Table 2

Data Corpus and Session Overview

Session / date	Activity focus	Duration	Participants (N)	Data collected	Notes (context / conditions)
S1 / 2024-15.3.	Soil formation: parent material, soil-forming factors (climate, organisms, relief, time, human impact)	3 h	N = 24	obs notes; reflections; worksheets; docs	Early spring; dry weather; introductory outdoor session; emphasis on

Session / date	Activity focus	Duration	Participants (N)	Data collected	Notes (context / conditions)
					landscape–soil relationships
S2 / 2024-21.4.	Pedogenetic processes: weathering, humification, eluviation/illuviation; soil profile observation	3 h	N = 26	obs notes; reflections; worksheets; docs	Late spring; warm conditions; soil pit excavation and horizon identification
S3 / 2024-20.9.	Soil properties: texture, structure, color, depth; basic field characterization	3 h	N = 23	field observation notes; soil description sheets; participant reflections; pedagogical documentation	Early autumn; moist soil conditions; hands-on field tests
S4 / 2024-18.11.	Physical, chemical, and biological soil analyses (pH, organic matter, bulk density, indicators)	3 h	N = 21	obs notes; analysis worksheets; measurement records; reflections; docs	Late autumn; combination of outdoor sampling and indoor analysis
S5 / 2025-14.2.	Water in soil: infiltration, retention, permeability; soil–water interactions	3 h	N = 22	obs notes; experiment worksheets; measurement records; reflections; docs	Winter conditions; frozen surface locally; demonstration-based activities
S6 / 2025-21.3.	Soil biodiversity and life in soil: organisms, soil food web, ecosystem services	3 h	N = 25	obs notes; organism observation sheets; reflections; docs	Early spring; favorable weather; focus on soil life, sustainability, and land-use implications

Findings

Findings are reported in alignment with the research questions. To meet qualitative transparency standards, each theme is linked to concrete evidence excerpts (reflection segments, observation notes, or documented artefacts).

Overview of Enacted Learning Activities

Across the case, learning activities combined site-based soil observation with spatial interpretation and group discussion. Typical task sequences involved (i) noticing and describing soil features in situ, (ii) interpreting relationships between microrelief, water regime, vegetation, and land use, (iii) considering value-laden trade-offs (e.g., top-soil protection vs. development), and (iv) proposing site-adapted management actions. Evidence for this activity structure is documented in session materials and observation notes (Table 3).

Table 3

Themes, Codes, And Evidence (Aligned with Table 2)

Theme (competence dimension)	Operational definition (soil-geography specific)	Codes / sub-codes	Evidence source	Illustrative excerpt	Interpretation (link to RQ)
Systems thinking	Understanding soils as dynamic systems shaped by soil-forming factors and pedogenetic processes, with interactions between soil, water, organisms, and land use.	soil-forming factors interaction; pedogenetic feedback; soil–water–biota links	reflection; observation	*"Climate and parent material determine the starting conditions, but land use can accelerate erosion and change soil development."* (S1-P6-R)	Evidence shows participants linking multiple soil-forming factors and human impact, demonstrating enactment of systems thinking competence (RQ1).
Spatial & analytical competence	Using spatial observations (soil profiles, depth variation, landscape position) and analytical descriptions to explain soil variability.	profile interpretation; scale reasoning; pattern recognition	artefact; reflection	*"The upper slope profile is shallower and less structured than the valley soil, which explains different land-use suitability."* (S2-P11-A)	Demonstrates how soil profile observations and landscape position are used analytically, addressing RQ1 and RQ2 on competence development through field activities.
Normative & ethical competence	Evaluating soil management choices using sustainability values, responsibility, and long-term soil protection.	stewardship reasoning; trade-offs; intergenerational responsibility	reflection	*"Improving short-term productivity does not justify practices that reduce organic matter and soil life."* (S6-P4-R)	Shows value-based judgment related to soil protection and ecosystem services, contributing to RQ1 on normative competence enactment.
Strategic & applied competence	Applying soil analysis results to propose realistic management strategies and evaluate	action planning; indicator-based decisions; feasibility checks	reflection; artefact	*"Based on pH and bulk density results, reduced tillage and cover crops*	Indicates translation of analytical soil data into applied decision-making, addressing RQ2

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Theme (competence dimension)	Operational definition (soil-geography specific)	Codes / sub-codes	Evidence source	Illustrative excerpt	Interpretation (link to RQ)
	alternatives under constraints.			*were identified as the most feasible improvement strategy."* (S4-P9-R)	on how activities support strategic competence.
Interdisciplinary & collaborative competence	Integrating physical, chemical, biological, and spatial perspectives through group work and shared interpretation.	disciplinary integration; role negotiation; collaborative synthesis	observation; reflection	*"One group focused on water infiltration, another on organisms, and together we connected both to soil structure."* (S5-P14-O)	Illustrates collaborative integration of hydrological and biological perspectives, supporting RQ3 on social and interdisciplinary learning dimensions.

Competence Themes Evidenced in the Case

Evidence indicated that participants frequently connected observable soil features (e.g., texture, moisture, vegetation) to broader functional relationships such as infiltration, erosion risk, and habitat conditions. For example, one reflection noted: *"Climate and parent material determine the starting conditions, but land use can accelerate erosion and change soil development"* (S1–P6–Reflection), demonstrating causal reasoning and recognition of feedback within the soil–water–land use system.

Participants enacted spatial reasoning when they used location-based evidence (microrelief, slope position, land-cover patterns) to justify interpretations and decisions. Observation notes recorded episodes such as: *"Participants compared soil depth and structure along the slope transect and linked shallower profiles upslope to higher erosion risk"* (S2–Observation), illustrating scale-sensitive explanation and pattern recognition.

Normative reasoning appeared when participants articulated responsibilities regarding soil protection and weighed competing land-use priorities. Reflections included statements like: *"Improving short-term productivity does not justify practices that reduce organic matter and soil life"* (S6–P4–Reflection), which framed soil as a common good and justified decisions using stewardship and intergenerational equity arguments.

Strategic competence was evident when participants translated observations and values into feasible action plans (e.g., measures to reduce compaction, protect topsoil, manage runoff). Group planning artefacts documented proposals such as: *"Based on pH and bulk density results, the group proposed reduced tillage combined with cover crops as a realistic soil improvement strategy"* (S4–Artefact), demonstrating scenario comparison and feasibility considerations.

Collaborative competence emerged through group deliberation, role negotiation, and integration of different viewpoints (scientific, practical, and ethical). Observation notes captured collaborative synthesis moments: *"One subgroup analyzed water infiltration results while another focused-on soil organisms, and the groups jointly agreed on management implications"* (S5–Observation), where participants coordinated perspectives to reach a shared recommendation.

Experiential Learning Mechanisms Supporting Competence Enactment

Three experiential learning mechanisms were particularly salient across the learning sessions and supported the enactment of sustainability competences in soil-geography learning. First, embodied observation—including handling soil material, examining structure and texture, observing moisture conditions, and identifying soil horizons in situ—anchored participants' reasoning in tangible, place-based evidence. This mechanism was evident in sessions focused on soil formation and pedogenetic processes (S1–S2), where direct interaction with soil profiles enabled participants to connect abstract concepts (e.g., soil-forming factors, eluviation) with observable features.

Second, guided reflection prompts played a central role in fostering analytical and normative reasoning. Across sessions S3–S6, participants were explicitly asked to justify their interpretations of soil properties, analysis results, and management implications using field evidence and sustainability considerations. Reflection products required participants to articulate causal explanations, evaluate trade-offs, and relate soil conditions to long-term land-use consequences, thereby supporting the development of systems thinking and ethical competence.

Third, collaborative planning tasks functioned as a key mechanism for strategic and interdisciplinary competence enactment. Group-based activities—such as comparing soil management scenarios based on physical and chemical indicators (S4) or jointly interpreting soil–water interactions and biodiversity observations (S5–S6)—required participants to negotiate perspectives, prioritize actions, and assess feasibility under real-world constraints. These tasks made trade-offs explicit and encouraged the integration of ecological, spatial, and practical knowledge.

Together, these mechanisms were observed consistently across the case and are supported by convergent evidence from observation notes, participant reflections, and learning artefacts (see Table 3). The findings indicate that experiential, place-based soil learning environments can effectively support the enactment of sustainability competences when observation, reflection, and collaborative action planning are systematically combined.

Perceived Learning and Intended Action

Participants' reflections indicated a noticeable shift from predominantly descriptive understanding of soil characteristics toward more action-oriented and responsibility-based reasoning. Across sessions, many participants articulated an increased awareness of soil vulnerability and explicitly connected newly acquired knowledge to intended changes in practice. For example, one reflection stated: *"I now understand how easily topsoil can be lost, so protecting it should be a priority in any land-use decision"* (S3–P10–Reflection), illustrating a transition from observation to normative and strategic consideration.

Intended actions were frequently framed in relation to soil protection and sustainable management practices. Reflections from later sessions included statements such as: *"When planning activities on the land, I will consider soil permeability and avoid practices that increase compaction"* (S5–P7–Reflection), indicating that participants were beginning to internalize soil–water relationships as decision-making criteria. Similarly, after engaging with soil biodiversity topics, participants emphasized the importance of maintaining soil life as a basis for ecosystem services: *"Healthy soil organisms are not optional; they are essential for long-term productivity and resilience"* (S6–P4–Reflection).

Evidence of perceived learning also appeared in participants expressed intentions to transfer knowledge beyond the learning setting, particularly in educational and advisory contexts. Several participants noted plans to integrate soil-related sustainability messages into their professional roles, for instance: *"I intend to highlight soil structure and organic matter more explicitly when teaching about sustainable land use"* (S4–P15–Reflection). Such statements suggest emerging agency and a willingness to act as multipliers of soil sustainability knowledge.

At the same time, variability across participants and sessions was observed. While many reflections articulated concrete intended actions, others remained at a more general level, expressing concern without specifying clear behavioral changes (e.g., *"Soil protection is important, but implementation depends on external conditions"*; S2–P3–Reflection). This counterevidence highlights differences in participants' readiness to act and suggests that contextual constraints and prior experience may influence the extent to which learning translates into intended action.

Overall, the findings indicate that the learning activities supported not only cognitive understanding but also emerging action orientation, addressing RQ3 by demonstrating how experiential soil-geography learning can foster perceived learning outcomes and intentions aligned with sustainability-oriented practice.

Results and Discussion

This case study demonstrates how experiential soil-geography learning can render sustainability competences observable, discussable, and documentable in situ. Across the case, competence enactment clustered around five interrelated dimensions: (i) systems reasoning, (ii) spatial–analytical explanation, (iii) normative justification, (iv) strategic and applied planning, and (v) interdisciplinary and collaborative competence. Evidence from observations, participant reflections, and learning artefacts consistently showed that these competences were not expressed in isolation, but rather co-occurred within concrete learning situations (Tables 1–2). Such co-occurrence is consistent with competence-based models of sustainability learning that conceptualize competencies as integrated configurations of knowledge, values, and action-oriented skills enacted in context (Barth et al., 2007; Brundiers et al., 2021; Sipos et al., 2008).

The results indicate that systems thinking emerged when participants linked observable soil characteristics (e.g., texture, moisture, profile depth) to functional processes such as infiltration, erosion risk, and habitat conditions (RQ1). Spatial and analytical competence was enacted using landscape position, microrelief, and soil profile comparisons to justify interpretations and land-use implications. Normative and ethical reasoning became visible when participants framed soil as a common good and articulated stewardship responsibilities and intergenerational considerations. Strategic competence was expressed in

action-oriented proposals grounded in soil analysis results, while collaborative competence was evident in group-based synthesis of physical, chemical, biological, and spatial perspectives. Each of these claims is substantiated by concrete evidence excerpts reported in Table 3, strengthening interpretive warrant and analytical transparency. The observed clustering of systems, normative, and strategic reasoning echoes sustainability competence scholarship, where systems thinking is treated as interdependent with anticipatory, normative, and strategic competencies rather than as a standalone cognitive skill (Brundiers et al., 2021; Rieckmann, 2012; Wiek et al., 2011).

A key contribution of this study lies in the operationalization of general sustainability competence frameworks within a soil-geography domain. By translating abstract competence dimensions into domain-specific indicators (e.g., soil–water feedback, profile-based spatial reasoning, indicator-informed management decisions), the study offers a concrete toolset for researchers and educators. The competence–activity mapping matrix (Tables 1–2) functions as a practical bridge between planned learning activities and observed learning processes, supporting systematic documentation of competence enactment in outdoor and experiential settings. Similar work in higher education emphasizes the methodological importance of translating broad competence frameworks into assessable domain indicators and performance descriptors—while making explicit the pedagogical mechanisms expected to foster them (Barth et al., 2007; Rieckmann, 2012).

The findings further suggest that soil-based topics are particularly well suited to competence-oriented sustainability education when learning designs intentionally (a) connect field observations to spatial patterns and land-use decisions, (b) incorporate structured reflection prompts that elicit ethical and strategic reasoning, and (c) culminate in collaborative planning outputs that make decision-making processes explicit. Such outputs can be meaningfully assessed using rubric-based indicators aligned with sustainability competence frameworks. Future iterations of this approach should pilot and validate such rubrics in teacher education, vocational education and training, and secondary school contexts. This aligns with arguments that transformative sustainability learning benefits from deliberately integrating cognitive insight, practical engagement, and affective–ethical commitment ("head–hands–heart") through tangible learning products and structured reflection (Sipos et al., 2008; Sundman et al., 2025).

These mechanisms are consistent with evidence syntheses showing that well-designed outdoor learning can support cognitive, affective, and social outcomes—provided that activities are clearly framed and followed by structured reflection and debriefing (Dillon et al., 2006; Rickinson et al., 2004). From a place-based education perspective, the polygon's local soil–landscape context may also strengthen meaning making and engagement by connecting scientific explanations to lived places and learners' senses of place (Gruenewald, 2003; Semken & Freeman, 2008).

In soil education specifically, recent work argues that building "connectivity" to soil is a prerequisite for stewardship and public support for soil security agendas (Brevik et al., 2022; Bouma, 2019). The prominence of normative justifications and stewardship language in this case also resonates with calls to cultivate soil literacy through pedagogies that foreground soil as a living system and a shared responsibility (Johnson et al., 2023).

At the same time, prior research cautions that field-based experiences do not automatically yield enduring conceptual change or action competence. Learning gains can be constrained by "novelty space" and logistical distractions if participants lack preparatory orientation and post-visit consolidation (Orion & Hofstein, 1994). Moreover, the well-documented knowledge–action gap suggests that even strong pro-environmental attitudes may not translate into sustained behavior without supportive social and institutional conditions (Kollmuss & Agyeman, 2002), and teachers may face practical constraints to routinizing outdoor learning in formal schooling settings (Bentsen et al., 2009).

As a qualitative single-case study, the findings support analytic rather than statistical generalization. Differences in participant backgrounds, session design, and environmental conditions may influence how and when competences are enacted. Future research should therefore include comparative cases, longer-term follow-up on intended and enacted actions, and mixed-method designs that combine qualitative process data with validated competence assessment instruments. These limitations are widely noted in outdoor and competence-oriented education research, which stresses the value of longitudinal designs, triangulation, and attention to contextual constraints when claiming competence development (Bentsen et al., 2009; Brundiers et al., 2021; Orion & Hofstein, 1994).

Overall, positioning soils as a competence-oriented educational domain strengthens sustainability education by explicitly linking scientific understanding with spatial reasoning, ethical judgment, and actionable planning. The Educational Polygon for Self-Sufficiency Dole provides a structured template for documenting such learning processes through triangulated qualitative evidence and competence-informed thematic analysis.

Suggestions

Based on the findings of this case study, several suggestions can be formulated for the design, implementation, and evaluation of competence-oriented soil-geography learning.

First, learning designs should prioritize sustained, place-based engagement with soil. The results indicate that repeated encounters with the same learning site across seasons (S1–S6) supported systems thinking and spatial–analytical reasoning. Educators are therefore encouraged to design learning sequences that revisit soil sites over time, enabling learners to observe changes, compare conditions, and relate soil properties to environmental processes and land-use decisions.

Second, embodied and sensory-rich observation should be systematically integrated into instruction. Handling soils, observing profiles, and conducting simple field experiments anchored abstract sustainability concepts in tangible evidence. Tasks that explicitly require learners to connect observations (e.g., texture, moisture, biological activity) to functional implications (e.g., infiltration, erosion risk, ecosystem services) appear particularly effective for making competence enactment visible.

Third, the findings suggest that structured reflection prompts are essential for eliciting normative and strategic reasoning. Reflections that asked participants to justify interpretations, evaluate trade-offs, or consider long-term consequences supported ethical judgment and action-oriented thinking. Future learning designs should therefore include reflection questions explicitly aligned with sustainability competence dimensions rather than relying on open-ended reflection alone.

Fourth, collaborative planning tasks should be used as capstone activities. Group-based scenario comparison and action planning made interdisciplinary integration and strategic competence observable. Such tasks are recommended as assessment-rich moments, as they require learners to synthesize physical, chemical, biological, spatial, and ethical perspectives into feasible proposals.

Fifth, the study highlights the value of domain-specific competence indicators. Translating general sustainability competence frameworks into soil-geography–specific indicators (e.g., soil–water feedback, indicator-based management decisions) supported both analysis and pedagogical design. Researchers and educators are encouraged to further refine and validate such indicators for use in curriculum planning, teacher education, and vocational education and training.

Finally, future implementations should integrate competence-aligned assessment tools, such as analytic rubrics linked to observable indicators. While this study focused on qualitative evidence of competence enactment, the findings suggest that combining qualitative documentation with transparent assessment criteria could strengthen both research rigor and instructional feedback.

Overall, these suggestions emphasize that sustainability competences in soil education are most effectively supported when experiential observation, structured reflection, and collaborative action planning are intentionally aligned and documented within a coherent pedagogical design. In this regard, the Educational Polygon for Self-Sufficiency Dole plays a crucial role as an applied outdoor learning environment, providing authentic soil–landscape contexts in which such competence-oriented learning can be systematically enacted, observed, and documented. The case demonstrates how place-based learning settings like the Dole Polygon can function as living laboratories that connect soil science, geography, and sustainability education in practice.

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Conflict of Interest: The researcher declares no personal conflicts of interest related to the research.

Funding, Support and thanks: There is no funding for this research.

Ethical Standards: Formal institutional ethical approval was not obtained. Nevertheless, the study was conducted in accordance with internationally recognized ethical principles for research involving human participants (including the Declaration of Helsinki). Participation was voluntary; participants were informed about the study aims and data use and provided informed consent. Identifying information was removed or pseudonyms were used, and data were securely stored with restricted access.