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Implementing citizen science programmes in the context of university gardens to promote pre-service teachers' scientific literacy: a study case on soil

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ABSTRACT
This work presents an assessment of pre-service teachers' argumentative practice, after implementing a novel teaching-learning sequence on soil health including a citizen science programme, which was applied outdoors at the university garden. The sequence was implemented at five Spanish universities with 351 undergraduates studying Early Childhood and Primary Teacher Education. It posed a final assessment task consisting in a real-world situation that involved making decisions on science-related issues: students needed to argue whether it was possible to use a piece of land as a school garden, based on soil data provided in a variety of formats. To assess participants' level of achievement, a rubric was specifically designed by adapting the *Evidence-Explanation Continuum* approach, which was applied to a subsample of 123 answers (35%). Results evidenced that the process of knowledge-building discourse from initial data to final explanations involved a series of transformations of increasing difficulty, since the percentage of students who were able to correctly accomplish them decreased a long the continuum. Including the citizen science programme promoted the development of basic aspects of scientific literacy related to interpreting data and evidence scientifically but, for students to be generally capable of drawing evidence-based conclusions, argumentation practices should be regularly included in science classes.

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Argumentation; context-based science education; Design-based Research (DBR)

Introduction

Gardens are valuable outdoor teaching and learning resources that facilitate addressing a range of curricular topics, particularly in science education (Williams & Dixon, 2013). They also help achieve various educational objectives, such as social and emotional

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learning (Block et al., 2012; Lohr et al., 2020). In recent years, gardens have proliferated in higher education institutions, where they contribute to campus sustainability and sustainability education (Cheang et al., 2017; Eugenio-Gozalbo et al., 2021). Concerning science education, gardens have traditionally been used in elementary education for complementary practical training on certain curriculum content, mainly related to plants (Klemmer et al., 2005; Wells et al., 2015). Nevertheless, they provide opportunities to address a wide range of scientific topics at different levels of complexity, thus being valuable for science education across all educational stages (Eugenio-Gozalbo et al., 2020).

From a scientific viewpoint, gardens should be considered *agro ecosystems*: ecological systems managed by humans for production purposes, whose elements and processes can be scientifically approached (Altieri, 1994; Lin et al., 2015). Importantly, they are real-world contexts that facilitate authentic learning, linking new knowledge to prior knowledge, and enabling students to see the relevance and possible application of their learning (Eugenio-Gozalbo et al., 2019). Both characteristics make educational gardens suitable contexts to implement citizen science programmes (CS hereafter) programmes, such as those dealing with biodiversity of pollinators (Eugenio-Gozalbo et al., in press1), or soil health (Zuazagoitia et al., 2021). Finally, instructional gardens are also important for pre-service teachers (PST hereafter) from a professional perspective, since they may use them as didactic resources in the future (Eugenio-Gozalbo et al., 2019).

Based on all such considerations, we propose the use of sustainably managed gardens (*organic learning gardens*, OLGs hereafter) to implement context-based curricular products that aim to promote PST's scientific literacy (Eugenio-Gozalbo et al., in press2), among other factors, through the inclusion of CS programmes. CS includes a large variety of forms of participation of non-professional 'scientists' in the production of scientific knowledge (Eitzel et al., 2017), which can be useful to promote teaching opportunities, both in formal and informal educational settings. This work used a previously designed teaching-learning sequence (TLS hereafter) built around the key question of '*Can vegetables be grown in the soil of this garden?*' (Zuazagoitia et al., 2021), which was implemented with PST at five Spanish universities during the academic years 2018/19 and 2019/20. A core activity of the TLS consisted in diagnosing the health of the soil in the OLGs after measuring a variety of biological, chemical, and physical indicators, following a standardised protocol and written material of a CS programme (CEA, 2021), that was adapted for educational purposes and contextualised in OLGs. Finally, a real-world assessment task was proposed, in which students were expected to use data in a variety of representations to provide explanations and make decisions.

Theoretical framework

Scientific literacy and its assessment

The *Programme for International Student Assessment* (PISA hereafter) was launched in 1998 to evaluate how well 15-year-old students are prepared in science, from the radically different approach of assessing their ability to actively use knowledge in real-world situations (Fensham, 2009). Following the latest PISA Science Framework, three closely linked competencies conform *scientific literacy*, and are treated separately for analytical purposes: (1) explaining phenomena scientifically, (2) evaluating and designing scientific enquiry, and (3) interpreting data and evidence scientifically (OECD, 2019). The first competency demands exclusively *content knowledge*: on the facts, concepts, ideas, and theories about the natural world that science has established. The second and third competencies demand also *procedural* and *epistemic knowledge*: on the practices and concepts on which empirical enquiry is based and understanding the role of specific constructs and features essential to building scientific knowledge, respectively (Duschl, 2008; Osborne, 2013, 2014). These three competencies are clearly linked to specific areas of science education, such as the nature of science, inquiry, modelling, and argumentation (Fensham, 2009). It is the third PISA competency that targets the same practices as argumentation, namely the use of evidence to evaluate scientific claims, be it to draw conclusions from evidence or to identify the evidence behind conclusions (Erduran et al., 2015; Jiménez Aleixandre, 2010).

In developing the PISA framework, a variety of models of scientific literacy and science teaching were considered, among which *Science-Technology-Society* (STS) or *context-based* approaches played a prominent role, given their emphasis on the application of knowledge in real-life situations (Eivers & Kennedy, 2006). Using context and applications of science to develop a scientific understanding – instead of covering scientific ideas before their applications – has been one of the most significant trends in science curriculum development over the last three decades (Bennett et al., 2007; Fensham, 2009). Arguments for adopting these approaches include making the scientific knowledge taught to students more relevant, thus motivating and improving their attitudes towards science and its study, as well as enhancing learning itself, considering the difficulty involved in students applying knowledge to situations other than that in which it was learned (Gilbert, 2006). Evidence has been provided to support the use of contexts as the starting point in science teaching, with no drawbacks in the development of understanding of science, and benefits in terms of attitudes to school science (Bennett et al., 2007).

Assessing scientific literacy is difficult for both teachers and students, since it involves evaluating the ability to use conceptual, procedural, and epistemic knowledge in new contexts and situations (Crujeiras Pérez & Jiménez Aleixandre, 2015). PISA approaches this issue by setting real-world situations or contexts and posing questions in a variety of formats, including (i) simple multiple-choice questions (in which students circle one of four options), (ii) closed constructed responses (in which students write a short, simple answer that is compared to a single correct answer), and (iii) open constructed response items (where students write a more detailed response that requires marking by trained markers) (OECD, 2019). The use of multiple-choice questions has largely been criticised because students are not required to justify their choices, which results in the loss of valuable information about their knowledge, for instance regarding the use of evidence (Crujeiras Pérez & Jiménez Aleixandre, 2015; Haja & Clarke, 2011). Furthermore, PISA assessments detail the overall performance of student's scientific competence on a scale of six levels (OECD, 2019), which has been used as the basis for more detailed analyses by means of purposely designed rubrics (Crujeiras Pérez & Jiménez Aleixandre, 2015). Rubrics are well-established assessment instruments in the educational literature for grading the level of achievement in particular areas of competence, such as argumentation (Cebrián-Robles et al., 2018; Deng & Wang, 2017; Özçinar, 2015). These rubrics should ideally be topic-specific; emphasis has been placed on assessment instruments not following a domain-general approach, given the knowledge-dependency of scientific reasoning (Krell et al., 2015; Osborne, 2013). Thus, in this study, a rubric was purposely designed to allow evaluating the argumentative capacity of PST in the context of solving a real-world situation about the possibility of cultivating a certain soil for which a range of data was provided.

Soil in science education

Soil supports all terrestrial vegetation and is estimated to host more than 25% of the planet's biodiversity (FAO, ITPS, GSBI, SCBD, and EC, 2020). It is a non-renewable resource with a key role in ecosystem services, such as water purification, carbon sequestration, and food production. Thus, its conservation is considered critical to achieve the Sustainable Development Goals (Bouma, 2014). The recent *EU strategy for healthy soil* has highlighted the need to promote soil literacy, conceived as a combination of broad awareness with specialist knowledge, suggesting that it could be integrated under the common reference framework of *sustainability competences* (EC, 2021). It appears an appropriate strategy, since efforts are being made in European higher education to include competencies and active learning methods (e.g. problem-based learning, case studies) that enhance the critical thinking and problem-solving skills required to address sustainability issues, including those in which soil plays a role (Solis et al., 2021).

Despite soil undoubtedly being a key topic in science education (Field et al., 2017), its treatment in curricula varies greatly across countries (Hayhoe, 2013). In Spain, soil is addressed throughout primary and secondary education, and students are expected to be capable of answering biological, geological, ecological, and socioeconomic questions about it before accessing university (Martínez Peña et al., 2016). However, some research works have shown that the topic of soil is not always taught effectively, including errors or simplifications that prevent effective learning (Alcalde, 2015; SECS, 2017; Vila Calzado et al., 2017). Noticeably, a range of innovative didactic proposals are being developed for primary and secondary education, which involve students in practical sessions of inquiry and modelling, both in outdoor contexts and in laboratories (Krzic et al., 2014; Margenot et al., 2016). Since it is also necessary to implement these types of didactic proposals in initial teacher training, we decided to consider CS programmes, which could offer enrichment and novel chances.

Citizen science

CS, namely the intentional involvement of citizens in scientific research, has become increasingly popular as a tool for expanding science knowledge but also for developing of scientific literacy (Bonney et al., 2014; Eitzel et al., 2017). Although CS initiatives focused on the engagement of adult volunteers have existed for decades, an increasing number of voices are advocating for the educational benefits of involving students in CS (Roche et al., 2020), derived from introducing them to genuine research practices (Kelemen-Finan et al., 2018; Lüsse et al., 2022). Indeed, CS has long been considered to hold vast potential in the field of science education (Bonney et al., 2009, 2014; Lüsse et al., 2022; Roche et al., 2020), and for environmental and sustainability education (Peter et al., 2021).

Significant differences exist between the CS projects developed for the public and those purposely designed for the educational community, classified as educational CS projects, or curriculum-based CS projects (Bonney et al., 2016; Nistor et al., 2019), since in the last case, teachers play a key role for successfully integrating CS projects into curricula (Roche et al., 2020). Additionally, the focus shifts from research results as the primary outcome to including also instructional outcomes, for which it is fundamental to purposely design TLSs with specific learning objectives (Roche et al., 2020). Through a CS approach, students are active partners in their learning (Freeman et al., 2014), and in participating in authentic scientific research. Thus, the potential exists for attending to learning and practicing science in ways more in tune with learners' motivations and local places (Haywood et al., 2016; Mannion et al., 2013).

Overall, although progress has been made to integrate citizen science into mainstream education systems, important challenges still arise (e.g. competing scientific goals and learning outcomes, differing underlying ontologies and epistemologies, diverging communication strategies, etc.) (Roche et al., 2020). An important drawback of the of majority educational CS projects is that they are mainly contributory (Nistor et al., 2019); participants are mostly involved in data collection and reporting, which provide less opportunities to improve their scientific skills, develop a proper behaviour towards science and the environment, or an adequate understanding of scientific processes (Bonney et al., 2009). Additionally, teachers' lack of confidence regarding the scientific and/or pedagogical content knowledge can be a major obstacle, even more when exploring outdoor environments is involved (Jenkins et al., 2015). Thus, teacher-training institutions may play a key role as a necessary intermediary between scientists and (prospective) educators in order to provide the necessary skills that ensure that specific research and educational outcomes are ultimately achieved. Finally, as motivation and engagement may be lacking even if students participate as part of their curriculum, educators have an additional important challenge to overcome (Roche et al., 2020).

With the rising popularity of educational CS projects, there has been also an increasing demand to assess their impacts (Schaefer et al., 2021). While gains in knowledge and skills – as defined by Phillips et al. (2018) – have been reported (Land-Zandstra et al., 2021; Phillips et al., 2018), comprehensive studies in the framework of soil education, organic learning gardens, and preservice teacher training are still scarce.

Objectives

The main objective of this research work was to assess PST' scientific literacy, and, in particular, their argumentative practice in a discursive context of decision-making on a science-related situation (Jiménez-Aleixandre et al., 2014). This, in turn, involved evaluating the academic impact of a novel TLS on soil, based on a CS programme aimed at diagnosing soil health which was adapted here for educational purposes and contextualised in OLGs. Research questions were:

- Can university gardens be effectively used to promote the scientific competence of PST through the implementation of contextualised didactic proposals?
- Could CS programmes be useful to the same purpose, when incorporated into novel curricular products (e.g. TLSs) on particular science topics?
- How could students' scientific literacy, and, in particular, argumentative practice, be assessed after such instruction? In particular:

  Would posing a real-world question be adequate?

  Would designing topic-specific assessment instruments be helpful?

- And finally: Are future teachers able to argue on soil based on evidence, after this type of instruction?

Material and methods

Instructional context

TLSs are a key tool for teachers to plan teaching and learning processes and consist of small- or medium-scale curricular products that cover the teaching and learning of a specific scientific topic for a given educational level (Guisasola & Oliva, 2020). The design, implementation, and assessment of TLSs contextualised in university OLGs and whose aim is to improve PST's scientific competence, is a main line of work in the Educational Innovation Group 'Organic Learning Gardens' (University of Valladolid, Spain). One of its products is the TLS '*Can vegetables be grown in the soil of this garden?*' (Zuazagoitia et al., 2021), which was designed following the constructivist proposals of

Table 1. General structure of the TLS '*Can vegetables be grown in the soil of this garden?*' (Zuazagoitia et al., 2021).

Phases	Time	Learning Goals	Activities
Opening: *What is soil for you?*	2h 15′	G1. Understand that initial knowledge and soil personal model are not sufficient to address the initial question	A1. Individual definitions and drawings of soil, group discussions, self-assessment of scientific competence
Development: '*What are the main characteristics of soil?*', '*What ecosystem services does it provide?*', and '*How can we know if it is possible to cultivate a certain soil?*'	3h 30′	G2. Understand and identify the main characteristics of soil, including its components and the functional relations among them G3. Know the ecosystem services that are provided by soils G4. Recognise which soil parameters are used as indicators of soil's health, and apply the suitable procedures to obtain data on them	A2. Group definitions and drawings of soil. A3. Lectures and peer-to-peer cooperative classes guided by TSEA. A4. Research at the OLG's guided by TSEA; manipulation and use of devices for obtaining soil data. A5. Evidence-based diagnosis of OLG's soil
Closing: '*What have I learned?*' '*How do I apply it?*"	3 h	G5. Recapitulate the acquired knowledge G6. Apply a scientific soil model to interpret phenomena G7. Argue basing on evidence in the context of real-world situations	A6. Group report on OLG's soil health, answering: '*Can we grow crops in our garden soil?*'. A7. Solving a situation in the same context (soil, learning garden). A8. Individual definition of soil. A9. Self-assessment of scientific competence.

Giné and Parcerisa (2003), and Zabala and Arnau (2007). It comprises three phases (Table 1) and has the overall aims of enhancing students' mental model of soil, and improving their scientific literacy. This TLS was implemented over some 9 hours with 351 undergraduate students of Early Childhood ($n = 73$, 20.8%) and Primary Education ($n = 278$, 78.2%) from five different Spanish universities: University of Valladolid, University of the Basque Country, University of Salamanca, University of València, and University Jaume I.

In the opening phase, students were asked '*What is soil for you?*', since considering learners' misconceptions or alternative frameworks is a well-established requirement that involves inquiring about students' views, conceptions, and affective variables of the topic, and considering them to make design decisions (Couso, 2012).

In the development phase, students were asked: '*What are the main characteristics of soil?*', '*What ecosystem services does it provide?*', and '*How can we know if it is possible to cultivate a certain soil?*'. The core activity was to diagnose soil health in each university OLG, following a CS protocol to measure biological, chemical, and physical soil indicators (Table 2).

Initially, time was devoted to learning related to each indicator, based on the material (videos and written materials) provided by the CS programme (*Agricultural Ecosystems Health Cards Manual*, CEA Vitoria-Gasteiz, 2021). Subsequently, the measurements were conducted by students with recommended instruments (including weight scale, flat shovel, dipstick, cylinder and hammer, beaker, pH strips, and hydrogen peroxide) (Figure 1(a and b)), and recorded in a data table, where the numerical values or observations obtained for each indicator could be classified in a three-category system (bad-intermediate-good) and given a score (from 0 to 10). Such scores allowed to calculate partial marks – for each ecosystem service – and a global mark – for soil health.

Finally, each student work group elaborated a scientific report for their sampling point in the OLG, completing the following items:

- Location of the study area (including a Google Earth photograph).
- Visual characterisation of the soil (including photographs of both the plot and the soil).

Table 2. Main indicators to be measured to diagnose soil health, classified as Biological (BIO), Physical (PHYS), or chemical (CHEM), and the ecosystem services provided by them.

ECOSYSTEM SERVICES	#	INDICATORS	TYPE
Food production	1	Harvesting (g/plant)	BIO
	2	Pests (% of healthy plants)	BIO
Biodiversity conservation	3	Crop diversity (# species)	BIO
	4	Surrounding plant diversity (# layers)	BIO
	5	Diversity of macrofauna (# types)	BIO
Soil care	6	Biological status (# earthworms)	BIO
	7	Physical status (infiltration time, min)	PHYS
	8	Physical status (compaction, cm)	PHYS
	9	Chemical status (acidity/basicity, pH)	CHEM
	10	Chemical status (use of pesticides/pollutants)	CHEM
	11	Chemical status (organic matter content, reaction to H_2O_2, colour)	CHEM
Climate change mitigation	12	System of production (does it gain or lose carbon? Specify management practices)	CHEM

Note: BIO = Biological, CHEM = Chemical, and PHYS = Physical.
Own preparation, based on materials provided by *Agricultural Ecosystems Health Cards Manual* (CEA Vitoria-Gasteiz, 2021).

Figure 1. Measurements during the TLS: (a) Students taking measurements on the soil in the OLG, namely, sampling soil to add hydrogen peroxide to get a measure of the organic matter content. (b) Some of the instruments needed, and reaction of the soil in contact with hydrogen peroxide (intense).

- Results and analysis. Provide the completed data table. What do these results mean? (The CS programme included support material).
- Limitations of the study (data reliability, doubts during the measurement process, new questions, etc.).
- What measures could be taken to improve the health of this soil? (The CS programme provided support material).
- Conclusions: '*Can we grow vegetables in the soil of this garden?*' Argue your answer basing yourselves on data.

After this exercise, all the work groups shared their results and discussed their meaning, attempting to reach a consensus on an overall diagnosis based on evidence. A resulting single data table in Excel format was sent to the CS programme.

Finally, in the closing phase of the TLS and, as well as other activities, an individual 50-minute-long real-world task was proposed to students, which placed them in a professional situation where they needed to evaluate the suitability of a space to be used as a school garden (the task and its possible answers are provided as Supplementary Material 1).

Data collection instrument and analysis tools

This real-world task was first implemented at two participating universities as a pilot study, being subsequently considered sufficiently open for students' answers (*argumentative product*) to be analysed in depth (Crujeiras Pérez & Jiménez Aleixandre, 2015), and therefore used at all participating universities for assessment. This PISA-like task set a discursive context of decision-making based on evidence for a science-related situation (Brocos & Jiménez-Aleixandre, 2020; Jiménez-Aleixandre et al., 2014). Our aim was not so much to know whether students were capable of discerning between wasteland and arable land, as to assess their performance in argumentative practice, for which the task intentionally did not have a single, obvious solution, but instead aimed to place the learner in a situation of relative uncertainty.

To conduct analyses, a subsample consisting of 35% of the total sample (123 of 351 students) was randomly selected, being evenly distributed among participating universities. A rubric was designed *ad hoc* for grading students' level of achievement in the task. The design followed a three-step procedure:

(1) Initially, 50 answers were randomly selected from the subsample to be qualitatively analysed. A system of emerging categories and subcategories was established by consensus among researchers (Miles et al., 2014), starting from an initial proposal and following an iterative process to suitably fit the system to all the answers considered.
(2) Secondly, a frequency chart was used on the whole subsample. Its design was based on both the system of categories and subcategories obtained in step one and on the theoretical framework provided by the extended *Evidence-Explanation* (EE) *Continuum* approach to science education (Duschl et al., 2021). This approach emphasises transitional steps, for example, from raw data to evidence (after selection and analysis), and from evidence to scientific explanations (after selection, evaluation, and analysis). An adaptation of the EE to explain the process of building discourse in the case of our task is shown in Figure 2(a). The frequency of occurrence of each dimension was obtained.
(3) Finally, the assessment rubric was designed, considering these dimensions, and defining five levels of achievement for each one, from the lowest (Level 1) to the highest (Level 5), and with Level 3 being sufficient to pass (Table 3). The rubric was also designed based on an initial proposal and following an iterative process to concisely define levels of achievement and reach agreement among researchers. It was considered adequate when three different researchers applied it to 21 randomly selected answers, and statistical consensus was sufficient (Kappa value 0.84) (Viera & Garrett, 2005).

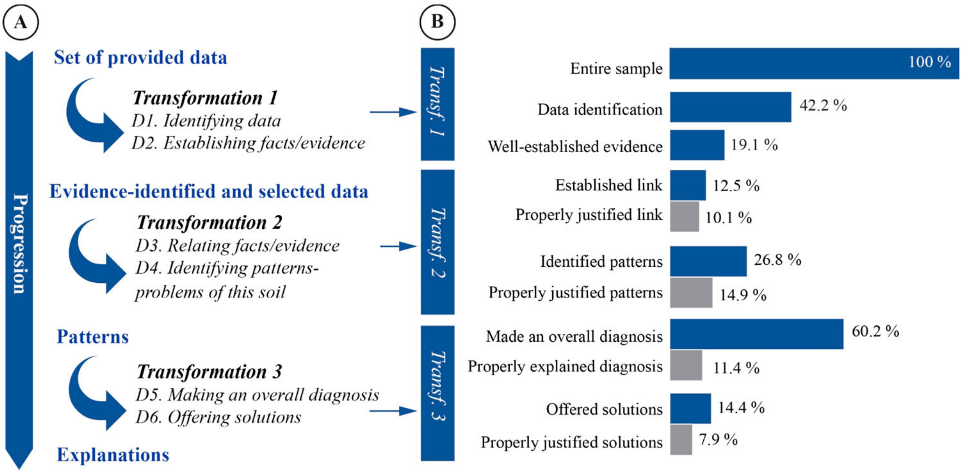

Figure 2. (a) Adaptation of the expanded Evidence-Explanation Continuum model (Duschl et al., 2021) to resolving the task. (b) Percentages of students who accomplished each dimension (*D1* to *D6*) in transformations (*Transformation 1–3*).

Results

Three main transformations were distinguished in the process of knowledge building discourse, each of which included two dimensions: transformation 1 consisted in identifying data from different sources (D1) and properly establishing evidence (D2), transformation 2 involved relating evidence (D3) and identifying the main problems of the soil for cultivation (D4), and transformation 3 entailed making an overall diagnosis (D5) and offering solutions (D6) (Figure 2(b)). After the rubric (Table 3) was applied, a certain percentage of students were placed in each level of achievement for each dimension (Table 4, Figure 2(b)). A weighted average value was also calculated for each dimension (Table 3); all were around 2 (over 5), with the highest ones being in D1 and D3, and the lowest ones in D2 and D4. According to our results, the process of building discourse that started from data and led to final explanations proved to be of increasing difficulty, since the percentage of students able to correctly accomplish each dimension decreased across the continuum.

In relation to *Transformation 1,* an average of 42.2% of students identified data (*D1*). In fact, they mainly identified data provided in the data table (an average of 53.7% of students), in relation to data provided in the descriptive text (37.0%) and the picture (11.4%) (Table 5). Thus, while 76.4% of students used the numerical value of the physical indicator ‘compaction’ provided in the data table to establish evidence of soil compaction, only 8.9% identified ponding. Moreover, of the data that should be identified from the table, students performed better in interpreting physical indicators (average of 34.6% of students) than biological (19.3%) or chemical ones (18.7%), with organic matter content being the least understood indicator (10.6%) (Table 4).

Regarding *Transformation 2*, Table 6 shows the percentages of students who established links between two (simple links) or more items of evidence (complex links), either to use them jointly or in the form of cause-and-effect relationships, and the percentages of students who properly justified such links (*D3-Relating evidence*). Again, students performed better when physical indicators were involved than in questions related to biological or chemical indicators. For instance, the link between compaction and time of infiltration (the most frequently recognised PHYS – PHYS simple link) was established by 39.8% of students, whereas the link between the number of earthworms and organic matter content (the most frequently recognised BIO – CHEM link) was determined by only 15.4%. Accordingly, properly justifying such links was in general easier in the first case (e.g. ‘*physical compaction is due to the former owner having levelled the land*’, ST04; or ‘*both infiltration time and centimetres of penetration evidence that it is a very compact soil, as we can corroborate by the ponding observed in the photograph*’, ST10) than in the second one (‘*22 earthworms is a bad result due to chemical stress caused by past use of pesticides*’, STU22). When it came to *D4* (*Identifying main problems of the soil for cultivation*, which were compaction, excess of organic matter, and foul odour), more than half the students (51.2%) identified compaction, and 29.3% properly justified it. However, the excess of organic matter and the foul odour were identified by only 14.6% of students in each case, and correctly explained by only 8.1% and 7.3%, respectively. Some examples: ‘*the first problem to be solved is that the previous owner used a steamroller to level the terrain. This caused the soil to be extremely compacted*’, STU23; ‘*there’s an excess of organic matter, we have to eliminate organic*

Table 3. Rubric used to determine whether pre-service teachers were able to draw conclusions using the logical development of generalisations from data, and assuming relative degrees of uncertainty (Duschl et al., 2021), in which 5 levels of performance were distinguished for 6 dimensions.

Transformations	Dimensions	Level 1 (lowest performance)	L2	L3 (sufficient)	L4	Level 5 (highest performance)
Transf. 1	*D1-Identifying data from different sources* *D2-Establishing evidence*	0–3 pieces of evidence	4–6 pieces of evidence	7–9 pieces of evidence	10–12 pieces of evidence	13–14 pieces of evidence
Transf. 2	*D3-Relating evidence*	Any link	1–2 simple links	≥3 simple links/1 complex link	≥4 simple links/≥2 complex links (with BIO evidence)	≥4 simple links/≥2 complex links (perfectly explained)
	D4-Identifying main problems	Any problem	Considers related issues as problems	1 problem	2 problems	The 3 main problems
Transf. 3	*D5-Making an overall diagnosis*	Does not	Grounded in incorrect transformations	Overall diagnosis without justification	Sufficiently justified	Arguments well-grounded in evidence
	D6-Offering solutions	Any solution	Not related or counterproductive	The main solution (tilling)	2 possible correct solutions	Identifies > 2 possible correct solutions

Note: Simple links between two pieces of evidence, complex link among three or more pieces of evidence/BIO = Biological/The 3 main problems were compaction, excess of organic matter, and foul odour.

Table 4. Percentages of students that performed at each level of achievement (Level 1–5) for the five dimensions (*D1* to *D5*), and weighted average value (scale from 1 to 5) for each dimension ($\sum$ (% of students × value at the scale)$_i$ /100).

	Level 1	Level 2	Level 3	Level 4	Level 5		
Dimension	(% of students)					mean value	SD
D1-Identifying data	22.8	35.0	33.3	8.1	0.8	2.3	0.9
D2-Establishing evidence	65.9	23.6	8.1	2.4	0.0	1.5	0.8
D3-Relating evidence	45.5	26.8	17.9	9.0	0.8	1.9	1.0
D4-Identifying main problems	41.4	9.8	35.0	10.6	3.2	2.2	1.2
D5-Making an overall diagnosis	50.4	17.1	30.1	2.4	0.0	1.8	0.9
D6-Offering solutions	43.1	13.8	36.6	5.7	0.8	2.1	1.0

Note: Mean value is at a scale from 1 to 5.

matter', STU01; or '*the foul odour is a problem that may be attributed to putrefaction of plant residues due to anaerobic decomposition*', STU11.

In *Transformation 3*, students were expected to make an overall diagnosis (*D5*) and offer solutions (*D6*). An average of 60.2% of students made an overall diagnosis, but only 18.9% of them (11.4% of total students) adequately argued the main reasons, e.g. '*in my opinion, it is perfectly possible to use this piece of land as a garden (…) tilling the land properly and thus eliminating decaying matter and reducing the number of worms, while soil decompaction is achieved (…)*', STU12. A variety of cases were observed among the rest of students: students who made a short, basic diagnosis without any justification in terms of evidence; students that performed inadequately in preceding transitions and, thus, based their diagnosis on erroneous evidence or links between evidence; and even students who performed well in preceding transitions, but finally failed to make a clear overall diagnosis. Lastly, 14.4% of students offered solutions, while only 7.9% offered solutions and properly justified them. The most frequently mentioned solution was tilling (45.5%), for example, '*A machine should be used to turn over the soil, at least minimally, which would help improve drainage and infiltration*', STU38. Other

Table 5. Percentages of students who identified data in different types of representation and of students who properly interpreted the data to establish evidence (Dimension *D1*).

Type of representation	Type of data	Evidence	*D1-Identifying data*	*D2-Establishing evidence*
			(% of students)	
Data table	PHYS	Physical status (compaction, cm)	76.4	39.8
Data table	BIO	Diversity of macrofauna (# types)	73.2	29.3
Data table	PHYS	Physical status (infiltration time, min)	72.4	29.3
Data table	BIO	Biological status (# earthworms)	60.2	21.1
Data table	CHEM	Chemical status (acidity/basicity, pH)	54.5	26.8
Data table	BIO	Surrounding plant diversity (# layers)	48.0	21.1
Data table	CHEM	Organic matter content (reaction to H_2O_2, colour)	42.3	10.6
Descriptive text	PHYS	Road roller	41.5	30.9
Data table	BIO	Crop diversity (# species)	33.3	14.6
Descriptive text	PHYS	Foul odour	32.5	10.6
Data table	BIO	Pests (% of healthy plants)	22.8	10.6
Photograph	PHYS	Abandoned vehicle	15.4	8.9
Photograph	BIO	Vegetation	9.8	7.3
Photograph	PHYS	Ponding	8.9	6.5
		Average value	42.2	19.1

Note: BIO = Biological, CHEM = Chemical, and PHYS = Physical.

Table 6. Percentages of students who could establish links between two or more pieces of evidence, and of students who properly justified such links (*D3*).

Type of evidence	Simple links between two pieces of evidence	Established link (% of students)	Properly justified link (% of students)
PHYS – PHYS	Compaction – time of infiltration	39.8	27.6
PHYS – PHYS	Steamroller – compaction	36.6	33.3
PHYS – PHYS	Steamroller – infiltration time	26.0	23.6
BIO – CHEM	# Earthworms – organic matter content	15.4	8.9
PHYS – BIO	Compaction – diversity of macrofauna	12.2	10.6
BIOCHEM – CHEM	Foul odour – organic matter content	4.9	3.3
PHYS – BIO	Compaction – vegetation	4.1	3.3
PHYS – BIOCHEM	Compaction – foul odour	3.3	2.4
PHYS – BIOCHEM	Ponding – foul odour	2.4	1.6
	Average value	16.1	12.7
Type of evidence	*Complex links among three or more pieces of evidence*	*Established link (% of students)*	*Properly justified link*
PHYS	Steamroller – compaction – infiltration time – ponding	19.5	16.3
PHYS – BIO	Compaction – ponding – vegetation – diversity of macrofauna	5.7	5.7
BIOCHEM	Organic matter content – # earthworms – foul odour – ponding	1.6	0.8
	Average value	8.9	7.6

Note: BIO = Biological, CHEM = Chemical, and PHYS = Physical.

solutions included adding sand to improve the texture of the soil by favouring its porosity (4.9%), for example, '*as soon as we plough it and add some sand as well, the infiltration times could decrease; as well as the "physical compaction" score*', STU12. The less frequently recognised solutions were promoting organic matter mineralisation through soil decompaction and oxygenation (4.9%) and conducting a more complete bio-chemical analysis to understand the origin of the foul odour (2.4%). Noticeably, adding the organic matter was proposed as a solution, despite being counterproductive, for example,

> first of all, we can observe that the number of worms is too high, which can be an indicator of an accumulation of fresh organic matter due to lack of microbiological decomposition (…) to solve it (…) we also need to provide organic matter, STU15.

Discussion and implications

In this work, OLGs at five Spanish universities were used as real contexts to implement a novel TLS that incorporated a CS programme aimed to assess soil health. We consider that the inclusion of CS programmes must be aligned, on the one hand, with the need and significance of considering certain scientific topics, as in the case of soil, which constitutes a key topic in science education (Field et al., 2017); and, on the other hand, with the challenges posed by the need to promote scientific literacy in PST (Leite & Mendes, 2020, p. 2).

Through the CS programme, PST developed basic aspects of scientific literacy related to the third PISA competency – interpreting data and evidence scientifically (OECD, 2019)-, such as reading and correctly interpreting data tables. However, aspects such as drawing evidence-based conclusions, which are nuclear in the practice of argumentation (Jiménez Aleixandre, 2010; Kuhn, 2005), were not sufficiently developed. Overall, regarding the utility of CS programmes for the purpose of enhance university students' scientific competence, our results are consistent with those obtained when evaluating the implementation of educational CS programmes in which involvement occurs fundamentally in data collection and reporting: fewer opportunities are provided to learners for improving scientific skills, developing positive attitudes towards science and the environment, or developing an adequate understanding of scientific processes (Bonney et al., 2009; Nistor et al., 2019). It is worth considering that, in our particular case, the CS programme was originally designed for professional farmers, people who have a vast experience of direct contact with soils for cultivation, whereas, for our students, the one provided by the TLS was probably the very first experience of evaluation of a real soil.

Although during instruction students had been required to draw conclusions grounded in evidence, only a very small percentage of them managed to provide a well-founded overall diagnosis in the final assessment task. The process of building knowledge (Duschl et al., 2021) from data was revealed to be of increasing difficulty, since the percentage of students able to correctly accomplish each dimension decreased along the process. Notably, most students tended to rely on less evidence than available to support their explanations, with only a small percentage of them successfully establishing complex links between types of evidence, namely they often failed to include a comparison of data from multiple sources, as previously observed (Sandoval & Millwood, 2005). Previous research on performance in argumentative practice has underlined two issues: the existence of a threshold value of knowledge on the topic, and the need for practice in using evidence; having knowledge on a topic is not sufficient to be capable of using evidence and learners do not develop the practice of using evidence unless tasks are specifically implemented to this end (Bravo & Jiménez Aleixandre, 2014; Sadler & Donnelly, 2006). Consequently, if the goal is to promote PST' ability to make evidence-based decisions in science-related topics, argumentation practices need to be included as regular activities – and not as one-off activities – in the science class.

Two main learning obstacles were revealed, which will be carefully considered to improve the TLS itself, as recommended in design-based research (Cobb et al., 2003; Guisasola et al., 2021). Firstly, dealing with chemical and biological data resulted challenging for PST; indicators such as a number of earthworms, diversity of macroinvertebrates, and organic matter content, were scarcely used to establish evidence. Previous educational research has highlighted that decay processes are difficult to understand because decomposers are frequently neglected in textbooks and study materials, and thus students tend to base mainly on physical and chemical processes, such as mechanical destruction or oxidation (Helldén, 1999; Leach et al., 1996). Secondly, offering plausible and well-founded solutions to make the problem soil suitable for cultivation proved to be difficult for students, since it involved not simply consulting the materials provided by the CS programme, but also mobilising their own mental model of soil and recalling their experiences on the soil. A primary goal of science education is to promote the personal construction of science-based simplified representations that focus attention on specific aspects and enable learners to interpret phenomena, and, through instruction, students' mental models should become increasingly powerful and allow them constructing progressively more complex explanations (Gilbert & Boulter, 2000). The understanding of ecological systems includes identifying their many discrete components and learning the complex relationships that are established among them, which is difficult

(Bravo & Jiménez Aleixandre, 2014). Thus, a science-based model of soil should consider and relate, at varying temporal and spatial scales, elements as diverse as rocks, climate, vegetation, or fauna, as well as physical, chemical, and biological processes and their consequences (Van Es, 2017).

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Ethics statement

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. The participants, who were students over 18 years-old, provided their written informed consent to participate in this study.

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