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Oinez Basoa: Using school-managed afforested land for soil education in Navarre, Spain

Oinez Basoa*: uso de un bosque escolar para la educación en suelos en Navarra, España*
Oinez Basoa*: uso de um bosque escolar para educação em solos em Navarra, Espanha*

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ABSTRACT

The study of soils in secondary education is a topic of debate because it remains little considered in official curricula and programs at pre-university education, despite the increasing concern about soil in environmental studies. In this work, we present the results of a case-study conducted with a class of the 4th grade of compulsory secondary education (10th school year), where a didactic sequence was used that included actual data obtained in an afforestation chronosequence. The afforestation was part of the activities conducted by the network of schools to which the school belonged, with the aim of mitigating greenhouse gas emissions resulting from their annual fund-raising event. In a first step, a series of indicators related to soil and vegetation were determined in the afforested soil using a space-for-time approach with a nearby cultivated soil (corresponding to the original situation of the afforested soil) and a mature forest (similar to the target situation of the afforested land). Plant biodiversity, soil microbial biomass C and total organic C, and organic matter decomposition indicators were determined and observed to be in an intermediate situation in the afforested land between the cultivated soil and the mature forest, seven years after afforestation. In particular, an effective atmospheric C sequestration was verified from a difference of 12.41 ± 1.06 Mg of organic C per hectare in the afforested soil compared to the cultivated control. Data issued from this analysis were used to prepare a collaborative *jigsaw* activity that was integrated into the didactic sequence designed to introduce the concepts of *ecosystem successions* and *the carbon cycle*. This project had a special focus on the role of soil both as a component of the ecosystem and within the carbon cycle. The success of the implementation of this sequence was tested using an initial and final test. The results of these tests showed a general improvement (42.8 points in the final test vs 23.3 in the initial test) in relation to the concepts tested. However, differences were observed in relation to the progression done by the students, which was better for ecosystems than for soil, likely as a consequence of the poor previous knowledge. From those results, we conclude that the development of educational tools that allow secondary school students to address real cases in which the soil is considered as a key component of the ecosystem can be effective in moving towards meaningful learning about soils and soil properties, since these seem still poorly understood by secondary school students.

RESUMEN

El estudio del suelo en la educación secundaria es un tema de debate ya que, a pesar de la creciente preocupación por el suelo en las ciencias ambientales, sigue siendo poco considerado en los planes de estudio y programas oficiales de educación preuniversitaria. En este trabajo presentamos los resultados de un estudio de caso realizado con una

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clase de 4º grado de educación secundaria obligatoria, donde se utilizó una secuencia didáctica que incluye datos reales obtenidos en una cronosecuencia de reforestación. La repoblación forestal formó parte de las actividades realizadas por la red de escuelas a las que pertenecía la escuela, con el objetivo de mitigar las emisiones de gases de efecto invernadero resultantes de su actividad anual de recaudación de fondos. En un primer paso, se determinaron una serie de indicadores edáficos y de la vegetación en el suelo reforestado, utilizando un enfoque de espacio por tiempo con un suelo cultivado cercano (correspondiente a la situación original del suelo reforestado) y un bosque maduro (similar a la situación objetivo de la reforestación). Se observó que los índices de biodiversidad de plantas, carbono de la biomasa microbiana y C orgánico total, y los de descomposición de la materia orgánica en el suelo reforestado se encontraron en una situación intermedia entre el suelo cultivado y el bosque maduro. En particular, se verificó un secuestro efectivo de C atmosférico a partir de una diferencia de 12,41 ± 1,06 Mg de C orgánico por hectárea en el suelo reforestado en comparación con el control cultivado. Los datos emitidos a partir de este análisis se utilizaron para preparar una actividad de aprendizaje cooperativo de tipo puzzle, que se integró en la secuencia didáctica diseñada para introducir los conceptos de sucesiones ecológicas *y el* ciclo del carbono. *Esta propuesta se centró especialmente en el papel del suelo como componente del ecosistema y dentro del ciclo del C. El éxito de la implementación de esta secuencia se probó utilizando test de conocimientos previos y finales. Los resultados de estas pruebas mostraron una mejora general (42,8 puntos en la prueba final frente a 23,3 en la prueba inicial) en relación con los conceptos evaluados. Sin embargo, se observaron diferencias en relación a la progresión realizada por los estudiantes, que fue mejor en las preguntas relacionadas con los ecosistemas que en las directamente relacionadas con el suelo como consecuencia del peor conocimiento previo sobre el suelo. A partir de estos resultados, llegamos a la conclusión de que el desarrollo de herramientas educativas que permitan a los estudiantes de secundaria abordar casos reales en las que el suelo se considera un componente clave del ecosistema, puede ser eficaz para avanzar hacia un aprendizaje significativo sobre los suelos y las propiedades del suelo, que parecen no suficientemente entendidos por los alumnos de educación secundaria.*

RESUMO

O estudo dos solos no ensino médio é uma questão em debate, uma vez que, apesar da crescente preocupação com o solo nas ciências ambientais, o tema continua sendo pouco considerado nos currículos oficiais e nos programas educacionais pré-universitários. Neste artigo, apresentamos os resultados de um estudo de caso realizado com uma turma do 4º ano do ensino médio obrigatório, onde foi utilizada uma sequência didática que inclui dados reais obtidos em uma cronossequência de reflorestamento. O reflorestamento faz parte das atividades realizadas pela rede de escolas a que pertence a escola, com o objetivo de mitigar as emissões de gases de efeito de estufa decorrentes da sua atividade anual de captação de recursos. Inicialmente foram determinados indicadores de solo e vegetação da área reflorestada, utilizando uma abordagem espaço-tempo com um solo cultivado próximo (correspondente à situação original do solo reflorestado) e uma floresta madura (semelhante a uma situação objetiva do reflorestamento). Observou-se que os índices de biodiversidade de plantas, C orgânico total e biomassa microbiana, e de decomposição da matéria orgânica no solo reflorestado estão em situação intermédia entre o solo cultivado e a floresta madura. Em particular, foi observado um sequestro efetivo do C atmosférico a partir de uma diferença de 12,41 ± 1,06 Mg de C orgânico por hectare no solo reflorestado comparado com o controlo cultivado. Os dados emitidos a partir desta análise foram utilizados para preparar uma atividade de aprendizagem cooperativa do tipo quebra-cabeça, que foi integrada na sequência didática projetada para introduzir os conceitos de sucessão ecológica e do ciclo de carbono. Esta proposta focou especialmente o papel do solo como componente do ecossistema e dentro do ciclo do C. O sucesso da implementação desta sequência foi testado utilizando testes de conhecimento prévio e final. Os resultados desses testes mostraram uma melhoria geral (42,8 pontos no teste final versus 23,3 pontos no teste inicial) em relação aos conceitos testados. No entanto, foram observadas diferenças na progressão feita pelos alunos em relação ao conhecimento prévio; um melhor desempenho foi observado em questões relacionadas com os ecossistemas, do que em questões diretamente relacionadas com o solo. Com base nestes resultados, concluímos que o desenvolvimento de ferramentas educacionais que permitem aos alunos do ensino médio abordar casos reais nas quais o solo é considerado um elemento chave do ecossistema, pode ser eficaz em avançar para uma aprendizagem significativa sobre os solos e as suas propriedades, que ainda parecem pouco compreendidas pelos alunos do ensino médio.

KEY WORDS
Forest soils, ecosystem services, carbon cycle, cooperative learning, TeaBag index.

PALABRAS CLAVE
Suelos forestales, servicios ecosistémicos, ciclo del carbono, enseñanza del suelo, aprendizaje cooperativo, índice Teabag.

PALAVRAS-CHAVE
Solos florestais, serviços ecossistémicos, ciclo de carbono, educação em solos, aprendizagem cooperativa, índice TeaBag.

1. Introduction

The study of soils in compulsory education remains marginal in many places (Margenot et al. 2016; Hallett and Caird 2017) despite the increasing relevance given to soils as key elements of the environment (Hartemink and McBratney 2008) and the growing awareness about soil conservation and quality (Brevik et al. 2019), its role within terrestrial ecosystems and its potential to provide essential services such as climate regulation (ex. Rumpel et al. 2019).

In Spain, Compulsory Secondary Education (CSE) is structured in four grades. In the official curriculum of this educational phase, concepts related to soils are introduced in a fragmented way (Alcalde-Aparicio 2015; SECS 2017), and are only mentioned within the subject *Biology and Geology* of the 3rd grade (14-15 years), especially in relation to their functions in ecosystems (Block 6 of the official curriculum: *The Soil as an Ecosystem*). The assessment criteria include concepts related to soil components, formation processes and degradation risks, in addition to its role within terrestrial ecosystems. The extension of each block is not determined by law, but a general overview indicates that Block 6 would be the fourth part of the total content extension, and the topic *Soil as an Ecosystem* one out of seven topics within the block. The teaching schedule for this subject is 2 h week^{-1}.

The concept of ecosystem, its components, and the basic ecological processes are better developed. In the 3rd grade there is a complete block dedicated to ecosystems (includes the abovementioned soil approach), and in the 4th grade (15-16 years) an entire block of the subject *Biology and Geology* is dedicated to *Ecology and the Environment*, including aspects related to limiting factors in an ecosystem, biogeochemical cycles and energy flows, biogeochemical cycles, *ecological successions* and actions to improve the environment (MECD 2015).

From the point of view of educational research and innovation in Soil Science, important synthesis works have been developed on the discipline's own philosophy (Churchman 2010) and on its teaching at the level of higher education (Field et al. 2011; Hartemink et al. 2014; Bosch-Serra et al. 2016; Diochon et al. 2017; Brevik et al. 2018; Álvarez et al. 2019). In secondary education, however, although a significant number of proposals have been raised to approach soils (Alcalde-Aparicio 2015; Hallett and Caird 2017; Cohen and Strohl 2019), there are few available teaching materials addressing soil as an object of learning (Badía 2008; Hayhoe et al. 2016; Margenot et al. 2016). Research related to teaching and learning on topics related to soils (Fernández et al. 2017), and in particular to some of the soils' most relevant properties, such as their role in the carbon cycle (Zugazagoitia and Villarroel 2016), is also very scarce.

As a consequence, CSE students, who may have adequate knowledge on ecosystems and ecosystem services (Torkar and Krasovec 2019), are generally less aware of the dependence of terrestrial ecosystems and human activities on soils, than on other elements of the environment such as water or air (Martínez-Peña et al. 2016), and show, in many cases, outdated and more static ideas about soil (Rebollo et al. 2005; Francek 2013).

In this context, this paper introduces an experience related to a unique situation in the Autonomous Community of Navarre (Spain). For over 10 years, a network of educational centers (Asociación de Ikastolas Cooperativas de Enseñanza de Navarra, NIE) have created and maintained a network of forests (*Oinez Basoa*) associated with their schools. The main objective of these forests is mitigating the greenhouse gas (GHG) emissions generated by their annual fund-raising event (*Nafarroa Oinez*; NIE 2019). This means that there is a network of forests created and maintained by educational centers that are an adequate resource for the development of educational initiatives as they are accessible and integrated into the different regular activities of these centers. Many of these forests are an example of ecological restoration and 'accelerated progressive succession' (EIP-AGRI 2014), where it is possible to study the processes associated with the recovery of ecosystems of different types, and of all their components such as the soils. In relation to vegetation, the succession associated with this change implies an activation of the dynamics of plant populations, which can be studied from the frequency and distribution of species. In relation to the soils, the change of use associated with afforestation means a change in the soil properties over time. These property changes are not alien to changes in the ecosystem, and evolve as the ecosystem moves from intensely cultivated land to mixed vegetation and forest ecosystems. One generalized consequence of this change can be, for instance, the accumulation of soil organic C (Lal et al. 2007), following increased C inputs and reduced soil disturbance. Other effects such as an improvement of diversity, nutrient cycling and water balance have been reported (Cunningham et al. 2015; Gutiérrez-Rodríguez et al. 2016), all processes related to soil functions and soil ecosystem services delivery (Dominati et al. 2010). Recent research also reports changes in soil microbial populations and a site-specific effect in the transition from agricultural to natural land uses (Kurganova et al. 2019).

The educational use of these resources is therefore an opportunity to be the subject of a scientific study, which can result in effective teaching tools in natural sciences at the CSE level by combining scientific practices, outdoor learning, and social activity structures (Kali et al. 2018). This type of initiative creates opportunities to connect school learning and science production, leading to positive effects on student's motivation (Hellgren and Lindberg 2017). Still, the fundamental objective of this teaching and learning process has to be the generation of useful explanatory models that give answers to questions (Martínez-Peña et al. 2016), such as those related to the observed changes in ecosystem soil indicators following a change in land use.

In this context, teaching strategies that allow meaningful learning are necessary. Among them we find those framed within the so-called cooperative learning (Herrada and Baños 2018), based on work in small groups to achieve common objectives, in which each member collaborates at the same time towards his or her own learning, and to the other members of the group. According to Johnson et al. (2013), cooperative learning methodologies must incorporate five basic elements: positive interdependence (one student cannot succeed if the others fail), face-to-face interaction so that students assist and support each other, individual accountability, social skills and group processing instead of individual processing of the different tasks addressed. Thus, cooperative learning not only fosters interpersonal relationships, but also helps to develop skills in the gathering, selection, analysis and evaluation of information, improving the perception of reality.

Problem- or project-based learning (PBL) is one of the methods that can be applied in cooperative learning strategies. In these methods, learning takes place in the process of answering a more or less complex question, which will serve as a starting point for the acquisition and integration of new knowledge. In particular, some strategies of cooperative PBL (CPBL; Yusof et al. 2012) such as the jigsaw structure seem especially effective, as they foster students' interaction for solving the problem.

In this framework, the objectives of this research were:

- To assess, by means of standard indicators, the changes related to the ecosystem as a consequence of afforestation in one of the forests of the *Oinez Basoa* network, especially those referring to the accumulation of organic C in the soil (for GHG emissions mitigation) and other site-dependent responses of the soil

- To propose, develop and evaluate a CPBL project in the subject *Biology and Geology* of the 4th grade of CSO, which uses the soil and vegetation properties assessment in the same school that maintains the forest.

This project fits into the principles outlined in SECS (2017) for soil education in secondary schools: the generation of attractive projects for students, their cross-discipline character, and the contribution of resources that allow for different subjects to be developed.

2. Materials and Methods

2.1. Assessment of soil and environmental indicators

2.1.1. Soil characterization and experimental design

The *Oinez Basoa* forest object of this study was started in 2012 as afforestation of a plot that had been under rainfed, conventional cereal cultivation for decades. The tree species used were holm oak (*Querqus ilex* L.) and Portuguese oak (*Querqus faginea* L.). Climate is Mediterranean semi-arid (Csb in the Köppen classification). The plot is located on a Quaternary terrace of the river Cidacos, which is the base of the Monte Plano, with an average altitude of 470 m a.s.l. (IGME 1987). These are alluvial materials 3040 m thick, with a mixed but rather homogeneous granulometry of gravel and sand, and a flat surface. The uniformity of the granulometry and composition of sediments, and its scarce or null slope, have favored the development of homogeneous soils. Natural vegetation corresponds to mixed forests of *Querqus coccifera* L., *Querqus faginea* L. and/or *Querqus rotundifolia* L. and different shrubs such as *Juniperus oxycedrus* L., *Ligustrum uvlgare* L., or *Viburnum lantana* L., all corresponding to the supramediterranean and mesomediterranean conditions of soils developed on calcareous materials (Peralta et al. 2013). The 1:25,000 Soil Map of Navarre classifies the soil as a Petrocalcic Palexeroll (Soil Survey Staff 2010), with a surface horizon of approximately 30 cm, over a horizon of variable thickness in which the accumulation of carbonates has cemented sedimentary bedrock materials. In these soils, root development is very limited in the deeper horizons, except for larger trees. Most of the biological and organic C cycling takes place in the upper A horizon (approx. 0-30 cm) of the soil.

The existence of a plot that continues to be conventionally cultivated and an older mature forest area (hitherto referred to as *control* and *forest*) in the vicinity of the afforested area allowed the use of a *space for time* substitution approach (Pickett 1989; **Figure 1**) for the determination of dynamic environmental and soil indicators. This approach assumes that the soil of the afforested plot had the same conditions as the one still cultivated (control, **Figure 1**) before afforestation. It is also understood that as the new *Oinez Basoa* forest develops, it will form a forest similar to the one currently existing in the adjacent plot (forest, **Figure 1**).

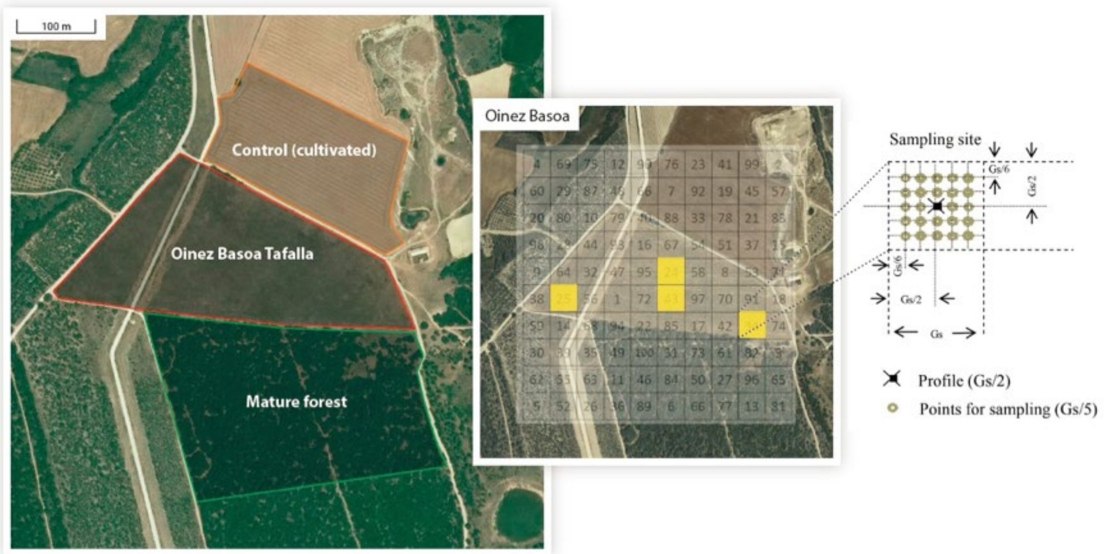


Figure 1. Location of the afforested plot of *Oinez Basoa* in Tafalla (Navarre, Spain), and the two plots used for comparison (cultivated control and mature forest). Right: Detail of the implementation of the randomized grid for the sampling protocol from the afforested plot corresponding to *Oinez Basoa*. Source: own elaboration based on images from IDENA (http://sitna.navarra.es/geoportal/?lang=) and Stolbovoy et al. (2007).

To verify this situation, a routine characterization of the surface horizon of the soil in the three plots was first carried out. Soil clay (%), pH, electrical conductivity (EC), carbonate content expressed as $CaCO_3$ equivalent, cation exchange capacity (CEC) and exchangeable bases were analyzed using standard protocols (Norman 1965; Klute 1986).

2.1.2. Assessment of indicators related to afforestation

The environmental indicators selected included aspects directly related to the vegetation, soil, and the dynamics of the ecosystem. They are: plant abundance and biodiversity, microbial biomass C in the soil, decomposition of organic matter (Keuskamp et al. 2013), and amount of organic C stored in the upper horizon.

The methodology employed required the design of a specific sampling protocol. First, control areas were defined in each of the three study areas (control, afforested and forest, **Figure 1**). For this purpose, three georeferenced sample areas were generated in each of the zones, using the grid described by Stolbovoy et al. (2007). **Figure 1** shows an example of the application of the sampling protocol grid to the afforested plot. This protocol allows random and representative samples to be collected from the studied plots. Then, standard methodologies were used for the analysis of the selected parameters cited above.

Plant biodiversity was assessed by estimating the coverage of the species present in a 4 m^2 area (very small, intermediate or dominant). The sampling areas corresponded to the center of each georeferenced control area previously determined. The results were expressed in range-abundance curves, which provide information on the number of species, the equitability or distribution of total cover among the different species, dominance and densities.

For the determination of soil parameters, one disturbed composite sample (from 25 sub-samples) and one undisturbed sample (100 cm^3 cylinders) were collected in each of the three representative areas per plot. Part of the composite samples was air-dried and sieved at 2 mm for the analysis of total organic C, and another part was gently forced through a 4-mm sieve, ensuring that the entire sample passed the sieve, and was kept cold for the determination of MBC. Undisturbed samples were used to determine bulk density.

The protocols used for the determination of total organic C stocks and soil C sequestration were those indicated by Stolbovoy et al. (2007). Due to the abundant presence of carbonates, wet oxidation was used for the analysis of organic C (Tiessen and Moir 1993; Apesteguía et al. 2018). Bulk density data were used to determine the stock of organic C.

The content of accumulated C in the soil microbial biomass (MBC) was analyzed by fumigation-extraction (Vance 1987) on fresh samples stored at 4 ºC, shortly after collection. Finally, the dynamics of organic matter decomposition in the short term was studied using the protocol designed for the Tea Bag Index (Keuskamp et al. 2013) as an indicator of nutrient recycling and stabilization of soil organic C. This methodology determines two parameters associated with the kinetics of degradation of tea samples buried in the soil for a given period of time. The idea is to use two well-known sources of organic matter (green tea and rooibos), which differ in their decomposability (green tea contains more soluble elements and N, which makes it easier for microbial degradation to occur more rapidly). Comparing the loss in mass of the two types of samples over a given period of time makes it possible to estimate the constants S (stabilisation factor) and *k* (decomposition rate) that characterize soil ecosystems in terms of of nutrient recycling and stabilisation of organic matter. In the study area, three replicates of each type of tea (green and rooibos) were introduced in each of the three plots (control, afforested, and forest) at the end of June, and collected 71 days later.

2.2. Secondary education soil research project

2.2.1. Curriculum screening and program

As described by Fernández et al. (2017), the project developed and evaluated in this work constitutes a case study, since it is based on a singular, unique and unrepeatable reality, with the intention of describing, identifying and understanding the situation in its own context. This reality corresponds to the teachers and students of the academic year in the school where it was carried out that are co-responsible for the maintenance of the afforested area in *Oinez Basoa*.

The development of the project considered, on the one hand, the conditions required for a cooperative learning activity and, on the other, the particular context of the school where it was developed. First, it was necessary to review the contents associated with the topics under study (*ecosystem succession and soil in the ecosystem*) in the official curriculum of CSE. As mentioned above, these contents appear within the subject *Biology and Geology*, in the 4th and 3rd grade, respectively (MECD 2015). The project was constructed for the *Biology and Geology* program in the 4th grade, considering the descriptors and learning standards corresponding to these two concepts, and because the introduction of this project requires the students to have a previous knowledge of the basic concepts related to the subject. It focused on the two topics more directly related to the process of transformation of the ecosystem in this grade's curriculum, in which soils play a relevant role (*ecological successions and the carbon cycle*).

The learning standards set both by the official curriculum and by the school's program for the 4th grade, in relation to these topics, include: (i) identifying and interpreting interactions between living beings, (ii) analyzing trophic structures, energy flows and matter cycles, and (iii) analyzing the equilibrium of ecosystems, their self-regulation and the causes and consequences related to their degradation. Finally, they also aim students to (iv) identify and propose initiatives that promote ecosystems balance. It is important to point out that, in developing this project for the 4th grade of SCE (10th school year), the students had already had the opportunity to deal with the topic of *soil* under an ecological perspective in the subject *Biology and Geology* of the 3rd grade (9th school year), in which the objectives to be achieved are: (i) analyzing terrestrial ecosystems and soil characteristics and functions, and (ii) analyzing a natural space in Navarre and identifying the characteristics of its ecosystem, the problems it may have and proposing conservation proposals. These standards can therefore be considered pre-requisites for the development of the project described for the 4th grade, that in principle are attained in the 3rd grade.

Finally, the contents of the textbook about these topics (Ikaselkar 2017), and their position in the program, were reviewed to check the correspondence with the official curriculum and the standards considered in the project.

2.2.2. Development of the project and cooperative activities

As a central activity of this project, a learning strategy was developed based on a driving question and using the *jigsaw* technique. This cooperative learning technique, originally developed by Aronson et al. (1978), consists of dividing the driving question or problem into sections, one for each group member. Each student receives resources to complete and understand only his/her section and becomes an "expert" in it. The students who are responsible for the same section join together and form a new, temporary "expert group", where students master the concepts, and develop a strategy for teaching what they have learned to the other students in their initial collaborative learning group. In the final step, after having shared the knowledge gained by each member, the group provides a consensus answer to the question. The final product of this activity is a reasoned response to the question that serves, on one hand, the assessment of the learning process, and on the other hand, the development of future projects both within and outside the classroom.

The first step in the elaboration of this activity was the set-up of the learning objectives. From the general standards described above for the 4th grade, it was decided to focus on those described above as “ii” (analyzing energy flows and matter cycles), and “iii” (analyzing the equilibrium of ecosystems, their self-regulation and the causes and consequences related to their degradation or aggradation), based in the example of the ecological succession in *Oinez Basoa*. From this, next step was the definition of the *driving question*, and of the different experts within the group. The main objective of this question was that the students could integrate the knowledge about the carbon cycle and the ecological succession obtained in the first part of this work, experiencing a real and close situation. The driving question was then defined as "how does *Oinez Basoa* contribute to changing the Monte Plano ecosystem and mitigating climate change?" From this question, with the results in the previous section, four "specialist files" or cards that allowed to develop a *jigsaw* activity were created. They corresponded to the four observations made (number and diversity of plants, soil microorganisms, decomposition of organic matter and soil organic C).

Each collaborative group therefore had four members, who would be the specialists in each of these topics. Based on the information collected in each of these cards, each collaborative base group had to draw up a diagram relating the different observations of each expert in the group. This diagram should represent a hypothesis of the processes that relate the generated change (input information: the afforestation of *Oinez Basoa*) and the final result (the mitigation of climate change by sequestration of atmospheric C in the soil), and of how each observation relates to those around it. It should be noted that since these are hypotheses, more than one result may be valid, provided that it is well reasoned. Figure 2 shows a model of the type of diagram required.

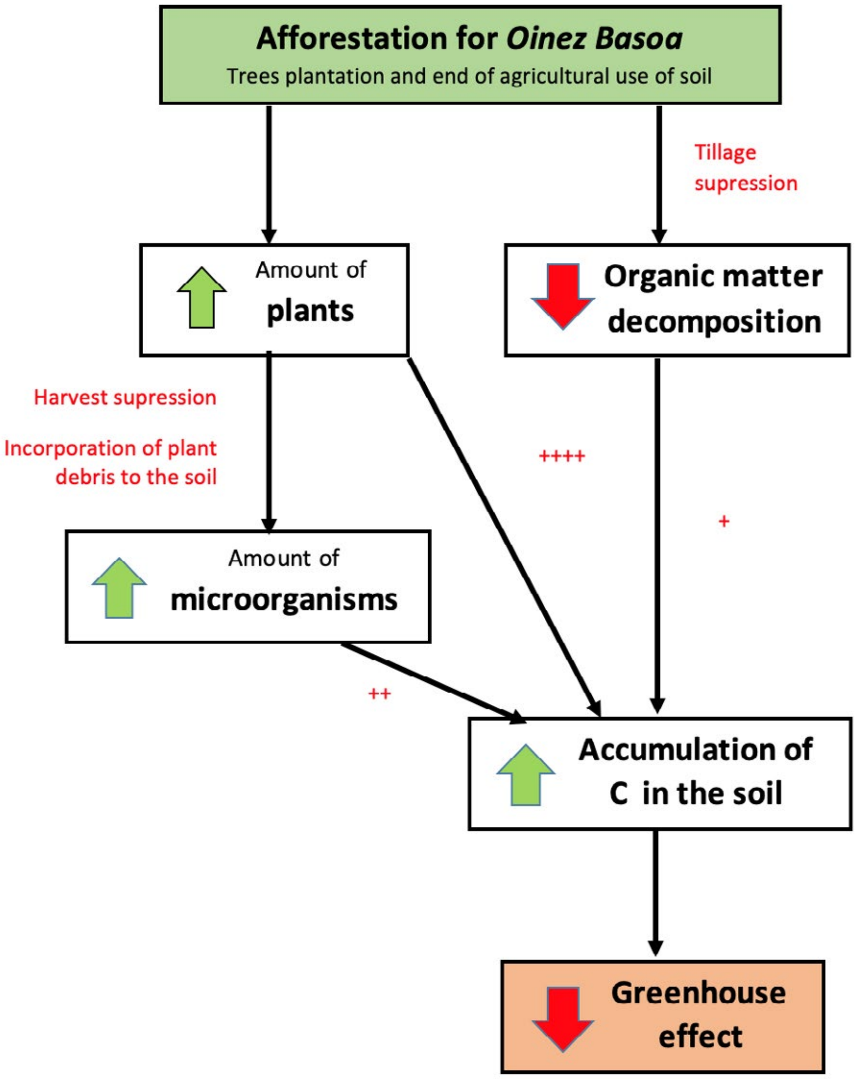


Figure 2. Diagram designed as the final product of the jig-saw activity.

Once this activity was established, a complete didactic sequence was designed, which allowed the introduction of the *jigsaw* activity in the program of the subject *Biology and Geology* of the 4th grade of SCE in this school. With this aim in the first place, considering the need to reaffirm previous knowledge, and to introduce the new concepts corresponding to the chosen topics, prior to the development of the *jigsaw* activity, an introductory class was designed for the explaining the concepts of *ecological successions* and *carbon cycle* using the materials provided by the textbook (Ikaselkar 2017).

In addition, in order to facilitate the understanding by students of the relationship between the new concepts introduced in the project and the reality of the afforested plot in *Oinez Basoa*, a field visit to this plot was designed and made a few days after testing the project in the classroom. During this visit, the students were divided into groups and were asked to make the following observations:

- Measurement of plant biomass and diversity from a protocol similar to that described in section 1.2, adapted for educational use.

- Observation of soil parameters in samples from the three plots studied: (i) organic matter from color (Munsell tables) and the reaction to H_2O_2 (Badía 2008), (ii) soil structure from descriptions of the type and size of aggregates, and their mechanical resistance, and (iii) diversity of macrofauna from a reference guide (Ayuntamiento de Vitoria-Gasteizko Udala 2019). In addition, the determination of the TeaBag index (Sarneel et al. 2017) was explained and developed *in situ*.

2.2.3. Assessment of the project

The participants in this study were 16 students of the 4th grade (15-16 years) of CSE who were taking the subject *Biology and Geology*, which is an optional one in 4th grade.

In addition to the activities described above (introductory session, *jigsaw activity*, field visit), in order to evaluate the effectiveness of the project as a whole, students need to perform simple knowledge tests before and after implementing it. For this, it was necessary to develop a questionnaire. This was done based on the proposal made by Fernández et al. (2017) for the study of mental models about the soil of secondary school students in Spain, as well as the descriptors of the official curriculum for the selected topics (*ecosystem succession* and *carbon cycle*). The questionnaire had 6 questions: 3 focused on knowledge about the soil, and in particular its functioning as an ecosystem (corresponding to the prerequisites supposedly learned in the 3rd grade) and the carbon cycle, and 3 corresponding more to the contents related to the idea of ecosystem succession. These questions were:

1. What is the soil for you?
2. What do you think the soil is made of?
3. What are the changes that you think soils can experience?
4. How do you think an ecosystem can change when a forest is planted?
5. Do you think that when a forest is planted, there may be consequences for the soil? Which ones?
6. How does the presence of plants in a soil change when we plant a forest?

This questionnaire was applied to the 16 participating students both as an initial test (before the beginning of the sequence) and two weeks after the project execution.

Following the scheme presented by Fernández et al. (2017) for a questionnaire with open questions, the analysis of the results was developed first qualitatively based on the identification of the explanatory elements provided by the students for each question before and after the sequence, and on their correspondence with the expected learning standards described above. Once this correspondence was established, a quantitative allocation of points was made, so that scores between 0 and 2 were established for each of the answers (0 representing an incorrect answer, 1 a correct but incomplete answer, and 2 a correct and complete answer). On average, a notation of 0 represents total absence of expected concepts in the response, 2 total agreement, and 1 at least 2/3 of expected concepts included in the answer. From these scores, it was possible to add the total points for each answer of all students, and with that value calculate the percentage of success obtained in each question.

Finally, following the dynamics of cooperative learning activities, an open self-evaluation session was established at the end of the sequence.

3. Results and Discussion

3.1. Assessment of soil and environmental indicators

The results of the characterization of the surface horizon of the three plots are shown in **Table 1**. Texture (% clay), pH and electrical conductivity were similar in the three zones. Differences in carbonate content and cation exchange capacity (CEC) were observed between the forest plot and the control and afforested ones. These differences can be explained, in the first case, by the effect of continuous tillage over decades, which resulted in the reincorporation of fragments of the underlying petrocalcic horizon into the cultivated upper horizon (in the control and afforested plots). In the second case, the higher CEC can be associated with the higher organic matter content. As this parameter (organic C) is the subject of the study of dynamic properties, it is described below.

The homogeneity between the three zones observed in relation to texture and pH, the most limiting intrinsic soil properties in the organic carbon cycle in the study area (Rowley et al. 2018; Rasmussen et al. 2018; **Table 1**), allowed us to understand the differences observed in dynamic indicators (plant biodiversity, microbial biomass, stock of organic matter and tea bag indices) among the three studied plots as a consequence of the change of land-use (afforestation).

Table 1. Basic soil properties in the upper horizon (0-30 cm) of three studied plots in

	Depth (cm)	Clay (%)	pH_{H_2O} (1:2.5)	E.C[a].H²O (1:2.5)	$CaCO_3$	CEC[b]
				(µS/cm)	(%)	($cmol_c$/kg)
Control (cultivated)	0-5	22.8 ± 0.0	8.0 ± 0.1	485 ± 68	39.6 ± 2.4	15.3 ± 5.2
	5-15	23.4 ± 0.5	8.0 ± 0.0	488 ± 65	39.1 ± 1.5	19.7 ± 0.7
	15-30	22.8 ± 0.0	8.0 ± 0.1	501 ± 54	42.1 ± 0.6	18.0 ± 0.7
Afforested (*Oinez Basoa*)	0-5	18.4 ± 1.5	7.9 ± 0.1	168 ± 6	42.4 ± 7.3	18.3 ± 1.5
	5-15	20.4 ± 1.9	8.1 ± 0.1	162 ± 5	40.3 ± 3.5	18.7 ± 1.4
	15-30	20.4 ± 1.9	8.3 ± 0.0	156 ± 5	43.8 ± 3.6	17.2 ± 1.1
Forest	0-5	23.4 ± 4.2	7.9 ± 0	253 ± 28	31.8 ± 2.1	31.8 ± 2.1
	5-15	27.1 ± 2.1	8.1 ± 0	180 ± 45	29.3 ± 1.6	29.3 ± 1.6
	15-30	23.4 ± 2.4	8.2 ± 0	94 ± 0	23.6 ± 0.1	23.6 ± 0.0

[a]E.C.: Electrical conductivity. [b]CEC: Cation Exchange Capacity.

Table 2. Measured soil indicators seven years after the afforestation of *Oinez Basoa* in Monte Plano (Tafalla, Navarre, Spain) (Means ± std. error; *n* = 3)

	Control (cultivated)	Afforested (*Oinez Basoa*)	Mature forest
Organic C (Mg C ha^{-1})	41.5 ± 0.3	53.9 ± 1.4	80.3 ± 15.0
Microbial biomass C (mg C kg^{-1})	336 ± 38	487 ± 69	1340 ± 34
Stabilization factor (S)	0.204 ± 0.01	0.249 ± 0.01	0.259 ± 0.01
Decomposition rate (k x 1000)	9.53 ± 0.69	10.5 ± 0.35	8.51 ± 2.84

Monte Plano (Tafalla, Navarre, Spain). Average ± std. error (n =3).

The relative differences observed in these indicators are shown in **Figures 3 and 4**. The actual values are provided in **Table 2**.

Regarding plant biodiversity (**Figure 3**), the lowest number of plant species was found in the control plot (cultivated, 9 species), followed by the afforested plot (16 species) and finally, the forest (23). The line of greater slope in range-abundance curves corresponded to the control, indicating that this plot had a few very dominant species, and the rest of species with relatively little coverage, while the afforested plot and the forest had a greater similarity to the cultivated plot. The coverage, for the ranges in which the lines of each treatment overlapped, was generally slightly greater in the afforested plot than in the forest, and remarkably greater in these two treatments than in the control plot.

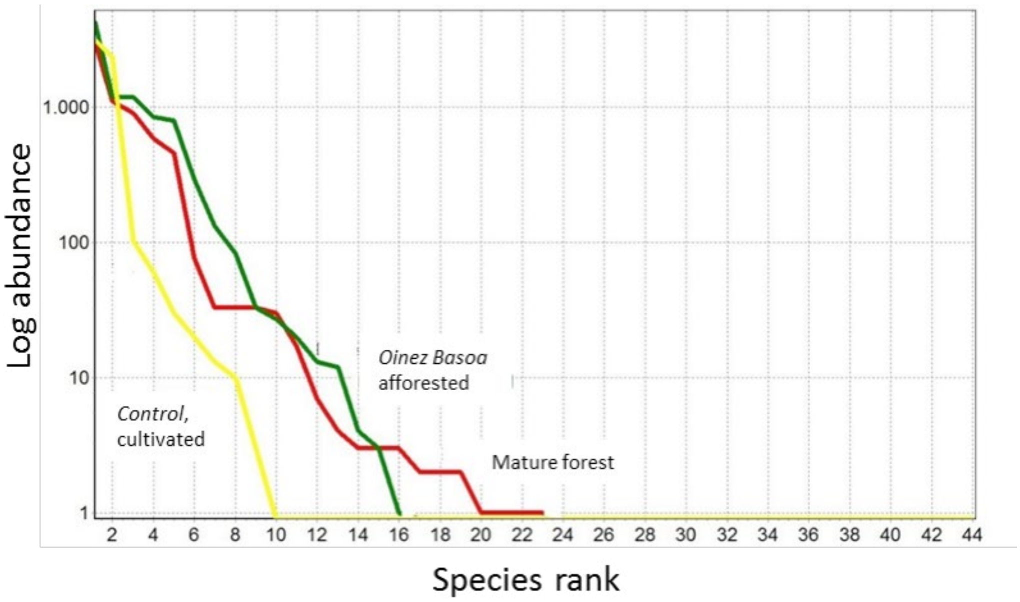


Figure 3. Rank-abundance curves in the cultivated (control), afforested (*Oinez Basoa*) and forest plots.

In relation to the parameters associated with organic C cycling, seven years after the afforestation in *Oinez Basoa*, a clear difference was observed between the organic C stored in this plot and that of the control, although still far from the forest. The values of organic C storage (**Table 2**) were within the range observed in soils of the region and the Iberian Peninsula (Rodríguez-Martín et al. 2016). Considering that the initial objective of the afforestation was the mitigation of GHG emissions associated with the activity of the school network, these data can be translated into estimates of atmospheric C sequestration, based on the difference observed between the soil at the afforested plot and the control, with the precaution that requires the use of a *space for time* approach. This value would be of 12.41 ± 1.06 Mg organic C hectare^{-1}. Considering the total surface of these plots (82,769 m^2) and the CO_2 equivalence, this would correspond to 376.62 ± 32.16 Mg of equivalent CO_2 accumulated in the soil of the afforested *Oinez Basoa* compared to the control.

The amount of C in the microbial biomass (MBC) accumulated in the afforested plot (both in total terms and in relation to the total organic C) presented somewhat higher values than those observed in the control soil, although still far from those of the forest (**Table 2**). The values observed in the cultivated and afforested soil were higher than those observed in vineyards under different management conditions in the region (Virto et al. 2012), probably due to the

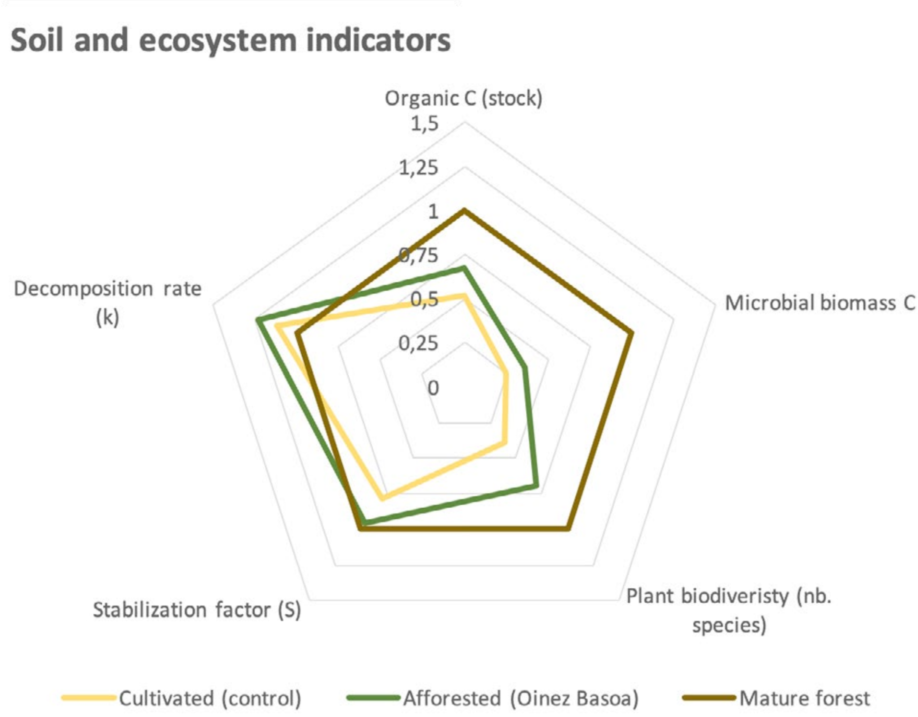


Figure 4. Representation of soil and ecosystem indicators in the cultivated (*control*) and afforested (*Oinez Basoa*) plots in relation to the forest after normalization for their value in the forest (score = 1), in average values for the total studied depth (0-30 cm).

less intensive management conditions in these plots. This study also observed a trend towards an increase in this parameter when cultivated soils changed to less disturbed uses that allow the natural regeneration of vegetation.

Finally, regarding the dynamics of mineralization, as evaluated using the Teabag Index, **Figure 4** and **Table 2** show the results obtained for the constants S (stabilization factor) and *k* (decomposition rate), in the three plots. Although there were small differences, the afforested soil and the forest presented a greater decomposition of the green tea, which resulted in somewhat higher values of the *S* index than in the control. Green tea is used in this experiment as a representation of the organic fractions that reach the soil from natural or cultivated vegetation, and that can be broken down in a relatively short time, being easily biodegradable. Rooibos represents the most difficult to degrade fraction (Keuskamp et al. 2013). Mass loss values (close to 60% for green tea and 15% for rooibos, on average, data not shown), were within the range of those observed in Mediterranean and temperate conditions (Djukic et al. 2018). The *S* index represents the proportion of the actual decomposition of green tea against the hydrolysable fraction of this tea. It is an indicator, therefore, of the deviation of the decomposition of green tea due to the inhibitory effects of the conditions of the environment in which it occurs (in this case, the soil of the different plots). Higher values of S, such as those observed in the afforested soil and the forest, would mean a greater potential to stabilize organic carbon than in the control plot.

From these observations, it can be concluded that significant changes occurred in the vegetation and soil of the afforested *Oinez Basoa* plot, which places it in an intermediate situation between its original condition (reflected in the control plot) and the “target” condition of the forest. These results were therefore considered of interest for the development of the educational project, by providing quantitative evidence of the changes associated with the ecological succession following afforestation, and its consequences for the carbon cycle.

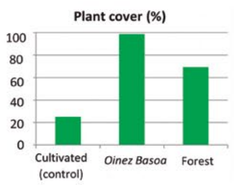
3.2. Project for secondary education

The "specialist cards" corresponding to the jigsaw activity were prepared using the data and indicator values reported above (**Figure 5**). In each of these files, the corresponding data shown in **Table 2** were included, together with a brief explanation of the meaning of the indicators, except for those corresponding to the *S* and *k* indices, which, due to their complexity, were replaced by the values of mass loss in green tea bags (64.6 ± 1.0%, 60.6 ± 0.7% and 59.6 ± 1.1% in the control, afforested and forest, respectively).

SPECIALIST CARD 1:
PLANTS

Many organisms live in the soil of Monte Plano, as in any other soil. Plants are the most visible ones, and their presence is directly affected by the use given to the soil. In this way, a change in land-use can bring many changes in the populations of these living beings. But in our specific case, **how has the planting of Oinez Basoa changed the presence of plants?**

The following figure shows the vegetation cover of the soils of the cultivated control cereal field (after harvest), in Oinez Basoa and in the mature forest. In other words, the graph represents the amount of plants in each of the soils.



Complementary information:

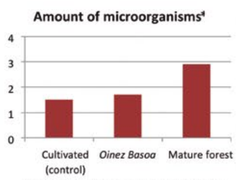
- Every year, a great amount of the plants cultivated **in the cropped field** is removed with the harvest, taking away most of organic matter from the ecosystem.
- **In forests**, plants develop freely, until they die and their remains fall to the ground, providing a large amount of organic matter.
- As the ecological succession progresses, the forest trees become more vigorous, and this implies less light available for the vegetation growing below the trees, decreases with time (so in the **mature forest** there are fewer plants below the trees). In turn, the contribution of organic matter to the soil by leaves and branches that fall from the trees is greater when trees are old and mature.

SPECIALIST CARD 2:
MICROORGANISMS

Many organisms live in the soil of Monte Plano, as in any other soil. In addition to plants, which are the most visible ones, and some animals such as rabbits, mice or worms, thousands of microorganisms live in the soil, such as fungi or bacteria. The latter are very important because they deal, for example, with decomposing the remains of dead plants, and thus making available to the following generations of plants the nutrients that their predecessors have accumulated (nutrient recycling).

Soil use significantly affects the presence of these microorganisms, so a change in land-use can bring many changes in their populations. Therefore, in our case, **how has the creation of the new forest at Oinez Basoa changed the presence of microorganisms in the soil?**

In the following graph we can see the amount of microorganisms present in the soil of the cultivated control field, the Oinez Basoa plot, and the mature forest.



*Proportion (%) of C in the microbial biomass over total organic C in the soil.

Complementary information:

- As the ecological succession progresses, the amount of soil microorganisms increases.
- Microorganisms feed on organic matter, so the higher the presence of organic matter in the soil, the more microorganisms there will be.

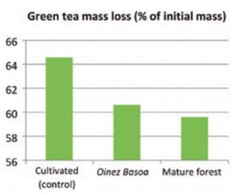
SPECIALIST CARD 3:
ORGANIC MATTER DECOMPOSITION

Soil microorganisms feed on organic matter present in the soil. By doing so, they decompose the remains of dead plants and animals in the soil, expelling CO_2 into the atmosphere.

There are many factors that influence this process, and they are very conditioned by the use given to the soil. In this case, **how has the implementation of Oinez Basoa changed the decomposition of organic matter in the soil?**

This can be measured by seeing how well-known materials of plant origin as green tea break down in the soil. There is a way to control how green tea bags (which simulate leaves) decompose after several months in the soil.

The following figure shows how much green tea mass was lost after three months in the soil of the cultivated control field, Oinez Basoa and the mature forest.



Complementary information:

- The presence of oxygen (O_2) accelerates the organic matter decomposition process.
- Soil tillage, which is carried out in the cultivation control field annually, increases the decomposition process by aerating the soil and increasing the soil microbial activity.

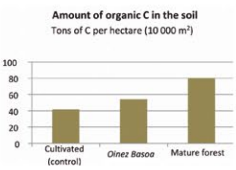
SPECIALIST CARD 4:
THE CARBON CYCLE

All the plants that grow in the soil of Monte Plano do photosynthesis, using carbon (C) from CO_2 in the atmosphere to build their own tissues. Within this cycle, when they die, or their leaves fall, soil microorganisms can break them down, and in this process some of the C is released back into the atmosphere as CO_2.

However, in this process, a part of the C in dead plant tissues can be retained in the soil for many years. This part corresponds are the parts of plants that are protected in the soil from total decomposition. This is a very interesting characteristic of soils, since this part of the CO_2 that was used to form the plants will not return to the atmosphere, but will remain "sequestered" in the soil.

The use given to the soil determines its ability to retain organic carbon in this way. **But in the specific case of Monte Plano, how has Oinez Basoa changed the amount of soil carbon?**

The following graph shows the amount of organic carbon retained in the soil of the cultivated control field, the Oinez Basoa plot, and the mature forest.



Complementary information:

- The greater the inputs of organic matter into a soil, the greater the carbon content in it.
- The populations of soil microorganisms constitute an important contribution of soil carbon in the form of biomass.
- The decomposition of organic matter involves carbon losses, which is expelled into the atmosphere in the form of CO_2.
- Carbon accumulation or "sequestration" in the soil reduces greenhouse gas emissions.

Figure 5. The specialist cards produced from measured data for the *jigsaw* activity.

Table 3. Summary of concepts expected and provided in the answers of the questionnaire, and proportion of responses provided to each question

Question (% of responses)	Concepts in answers Expected*	Initial test	Final test
# 1 *What is the soil for you?* (initial, 87%) (final, 100%)	- Surface of the crust - Factors and processes of soil formation - Soil functions	- Piece of land - Surface of the crust - State of the surface of the crust - Thinnest layer of the Earth - The Earth's "sole" or "skin" - A layer of stone - Support for plants and living beings - What we step on	- Piece of land - The crust - Lower part of the crust - Space between the crust and the mantle - Support for plants - What we step on
# 2 *What do you think the soil is made of?* (initial, 93%) (final, 100%)	- Minerals (rocks), water, air, organic matter, organisms	- Rocks - Sand - Minerals - Plants - Compost - Mud - Water - The ocean - Magma, lava - The Sun - Everything on the crust	- Rocks - Sand - Plants - Mud - Air - Water - Microorganisms - Oxygen, Carbon - Magma
# 3 *What are the changes that you think soils can experience?* (initial, 93%) (final, 100%)	- Gains or losses of any of its components and functions	- Changes in moisture - Changes in organisms - Changes in temperature - Changes in its components - Wind or water erosion - Plants loss - Pollution - A fire - Folds, faults - Friction - Tectonic plate movements - Earthquakes - Works - Mountain	- Changes in plants - Changes in moisture - Changes in organic matter - Changes in gases - Changes in use weathering - Earthquakes - Explosions - Works - Tectonic plates movements
# 4 *How do you think an ecosystem can change when a forest is planted?* (initial, 70%) (final, 70%)	- Changes in plant amount and diversity - Changes in the biogeochemical cycles in the ecosystem, including that of C - Changes in soil condition	- Greenhouse effect - Increase in biomass (animals and plants) - Increase in biodiversity - Increase in CO_2 - Increase in O_2 - "Positive changes" - Changes in light and water - Changes in soil	- Increase in biomass - Increase in biodiversity - Changes in O_2, CO_2 … - Increase in soil organic matter - Soil "enrichment"
# 5 *Do you think that when a forest is planted, there may be consequences for the soil? Which ones?* (initial, 93%) (final, 87%)	Yes. - Changes in the soil composition. - Changes in soil condition.	- "Land" enrichment - Soil improvement - Changes in weather - More roots - More living beings - Increased biodiversity - Creation of CO_2	- Increase in CO_2 - More CO_2 sequestration - More O_2 use - Increase in organic matter - Changes in light available - More (micro)organisms - More fertility
# 6 *How does the presence of plants in a soil change when we plant a forest?* (initial, 80%) (final, 93%)	- Progressive colonization - Ecosystem succession - Reduction of herbaceous vegetation as trees grow - New equilibrium	- Depends on climate - Plants accommodate - "Positive" changes - More plants - Longer roots - More animals - Better conditions for life - Changes in oxygen - Changes in plants diversity	- Plants interact - More plants - Better plant condition - Small plants decrease as the forest grows

* From learning standards in the official curriculum and textbook used.

The educational project was evaluated from the results obtained after the jigsaw activity, and from those obtained in the previous and final tests.

The four cooperative learning groups satisfactorily answered the driving question (data not shown), producing diagrams similar to that shown in **Figure 2**, and establishing causal relationships between the observed data in relation to vegetation, soil microorganisms, decomposition of the organic matter and the storage of organic matter in the soil.

Regarding the results of the evaluation tests, **Table 3** shows a summary of the first qualitative analysis of the concepts present in the answers provided in the previous and final tests, from the explanatory elements used by students and their correspondence with the expected learning standards (Fernández et al. 2017), as well as the proportion of non-responded answers to each question. It can be seen in this table that while most significant concepts related to each question appeared in the answers, other misconceptions were also evident. Also, between 7 and 30% of the students left the responses blank or responded “I don’t know” to the questions in the initial and final tests, respectively.

Table 4 shows the quantitative values obtained before and after the execution of the project. The percentage of total success of the final test was higher than that in the initial test. Still, it was 42.8%, less than half the possible points. The group of questions related to *ecological successions* (questions #4, #5 and #6) obtained higher levels of correct answers than those related to soil, both in the previous and the final tests, and the difference between both tests was also greater in this group of questions than in those referred directly to the soil. This means that the students' prior knowledge was also broader in relation to *ecological successions* than to *soil*.

The results indicate that the knowledge standards about soil as an ecosystem, which should be achieved in the previous grade (3rd year), do not seem to have been achieved effectively. The low understanding of the dynamic nature of the soil, and its role in the ecosystem by secondary school students is also described in detail by Rebollo et al. (2005) and Fernández et al. (2017). The project seemed to contribute more to the improvement of knowledge in relation to the composition of the soil and its behaviour within the ecosystem (questions #2 and #3), than to the concept of soil itself (question #1). In the test conducted by Fernández et al. (2017) with the same question, only 6% of students defined

Table 4. Summary of the scores (over 100) obtained in the initial and final tests

% Total score	Questions on *soil*				Questions on *ecological succession*				Total test
	#1	#2	#3	Total	#4	#5	#6	Total	
Initial test	26.7	13.3	13.3	**17.8**	30.0	30.0	26.7	**28.9**	**23.3**
Final test	26.7	33.3	33.3	**31.1**	43.3	56.7	63.3	**54.4**	**42.8**

the soil as important for life (2%) or as a support for plants (4%). The results obtained in this project (26.7% of the maximum possible score in both the initial and the final test for question #1) showed that most students were not able to explain and improve their understanding of soils. Different reasons could explain this observation. On one hand, the questionnaire itself was relatively open (although a maximum length was provided for the written responses to be provided), and this may have mislead some students. Also, and in relation to the project, it can be seen in **Table 3** that a relevant number of concepts present in the answers did not connect with those expected or expectable.

In the questionnaire made in the study by Fernández et al. (2017), a question similar to our question #3 (*What are the changes that you consider soils can experience?*) resulted in variable but not high percentages of students explaining changes in fertility (8%) or in the amount of water (15%). The improvement observed in the scoring of this question after the implementation of the project (**Tables 3 and 4**) was in line with the idea that didactic sequences based on inquiry, in the use of real models (Alcalde-Aparicio 2015; Fernández et al. 2017) and in attractive projects for students (SECS 2017) can be a successful strategy to move towards a better understanding of soils and soil functions in the ecosystem.

In this context, within the questions related to *ecosystem successions*, the two that had the most relevant improvement after the execution of the project were those related to changes in soil and vegetation associated with a change such as afforestation (questions #5 and #6), included in both the jigsaw project and the subsequent field visit.

Finally, in relation to the questions more focused on *ecological successions* (especially questions #4 and #6), a higher level of previous knowledge and a significant improvement were observed after the execution of the project, which can be associated with the correct resolution of the *jigsaw* exercise discussed above. The concepts related to ecosystems and their components are in fact included in more detail than those related to soil both in the previous courses of secondary education (MECD 2015) and in primary education (MECD 2014).

4. Conclusions

The establishment of a network of forests managed by NIE, an association of primary and secondary education schools, allowed an assessment of the environmental consequences of this afforestation to be carried out by one of these schools. The project focussed on the soil and its relationship with the ecosystem.

The studied indicators related to plant diversity, soil properties linked to biological activity and the decomposition of organic matter, and carbon sequestration. This allowed for the observation of changes in the development and typology of vegetation, and an improvement in soil condition. After seven years of forest implantation, these were closer to those of the same soil under a forest than those corresponding to the soil in its initial condition (dryland cereal cultivation). In relation to the sequestration of atmospheric carbon, an accumulation of soil organic C equivalent to that obtained with similar strategies in Mediterranean semi-arid conditions was observed.

These observations allowed us to develop, in the same school, a didactic sequence that included a project of cooperative learning through the *jigsaw* technique, and a field visit, using measured data of the indicators in this forest. This sequence was applied in a 4th grade class of CSE, as a complement for the introduction of the concepts of *ecosystem successions* and *the carbon cycle*. The project revealed the poor knowledge of students about the concept of soil before the project and the improvement of their knowledge in relation to ecosystems and soils (which was lower for the latter) after its implementation.

These observations represent a case study in which the use of active methodologies, and the use of resources close to students allowed for some improvement in their understanding of the relationship between the soil and the functioning of terrestrial ecosystems, particularly in relation to the carbon cycle. The development of educational tools that allow secondary school students to approach real experiences in which the soil is considered as a key element of the ecosystem is necessary to move towards meaningful learning about soils and soil properties.

5. Acknowledgements

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REFERENCES

• Alcalde-Aparicio S. 2015. Boost momentum and outreach of Soil Science in 2015, International Year of Soils (I YS2015). Enseñanza de las Ciencias de la Tierra 23.3:330-343. [In Spanish].

• Álvarez LSJ, Vega N, Mora EDC, Jaramillo NDF, Miquitama PQ. 2019. Learning teaching styles and strategies of university students of soil science. Revista Electrónica de Investigación Educativa 21 (10.24320/redie.2019.21.e04.1935). [In Spanish].

• Apesteguía M, Plante A, Virto I. 2018. Methods assessment for organic and inorganic carbon quantification in calcareous soils of the Mediterranean region. Geoderma Regional 12:39-48.

• Aronson E, Blaney N, Stephan C, Sikes J, Snapp M. 1978. The jigsaw classroom. Beverly Hills, CA, USA: Sage Publications.

• Ayuntamiento de Vitoria – Gasteizko Udala. 2019. Programa de Conservación de Suelos. Guía de identificación de macrofauna. [cited 2019 May 4]. Available from: https://www.vitoria-gasteiz.org/docs/wb021/contenidosEstaticos/adjuntos/es/35/99/83599.pdf.

• Badía D. 2008. El suelo como herramienta didáctica. II Seminario del Geoparque de Sobrarbe. Investigación Geológica y Recursos Didácticos. Boltaña, Huesca, Spain. [In Spanish].

• Bosch-Serra AD, Estudillos G, Yagiie MR, Virgili JM. 2016. Digital tools in soil science related field studies: Training support and lifelong learning. Span J Soil Sci 6(3):159-175.

• Brevik EC, Steffan JJ, Rodrigo-Comino J, Neubert D, Burgess LC, Cerdà A. 2019. Connecting the public with soil to improve human health. Eur J Soil Sci. 70(4):898-910.

• Brevik EC, Vaughan KL, Parikh SJ, Dolliver H, Lindbo D, Steffan JJ, Weindorf DC, McDaniel P, Mbila M, Edinger-Marshall S. 2018. Trends in undergraduate soil science education at selected universities in the USA from 2009 to 2013. Soil Sci Soc Am J. 82(2):295-306.

• Churchman GJ. 2010. The philosophical status of soil science. Geoderma 157:214-221.

• Cohen W, Strohl C. 2019. The soil story curriculum. Rebuilding Healthy Soil for Carbon Cycle Balance. Ed. Kiss the Ground Foundation and Life Lab. [cited 2019 July 24]. Available from: https://kisstheground.com/education-program/#curriculum

• Cunningham SC, Mac Nally R, Baker PJ, Cavagnaro TR, Beringer J, Thomson JR, Thomson RM. 2015. Balancing the environmental benefits of reforestation in agricultural Regions. Persp Plant Eco Evol System 17:301-317.

• Diochon A, Basiliko N, Krzic M, Yates TT, Olson E, Masse J. 2017. Profiling undergraduate soil science education in Canada: Status and projected trends. Can J Soil Sci. 97(2):122-132.

• Djukic I, Kepfer-Rojas S, Kappel-Schmidt I, Larsen KS, Beier C, Berg B, Verheyene K. 2018. Early stage litter decomposition across biomes. Sci Total Environ. 628-629:1369-1394.

• Dominati E, Patterson M, Mcay A. 2010. A framework for classifying and quantifying the natural capital and ecosystem services of soils. Ecol Econom. 69:1858-1868.

• EIP-AGRI (Agriculture and Innovation). 2014. Creating diverse forests with multiple benefits. What can forests offer you? [cited 2019 July 24]. Available from: https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_brochure_forestry_2014_en_web_1.pdf

• Fernández A, Sesto V, García-Rodeja I. 2017. Secondary students' mental models about the soil. Enseñanza de las Ciencias 35.2: 127-145. [In Spanish].

• Field DJ, Koppi AJ, Jarrett LE, Abbott LK, Cattle SR, Grant CD, McBratney A, Menzies NW, Weatherley AJ. 2011. Soil Science teaching principles. Geoderma 167-168:9-14.

• Francek M. 2013. A compilation and review of over 500 geoscience misconceptions. Int J Sci Educ. 35(1):31-64.

• Gutiérrez-Rodríguez L, Hogarth NJ, Zhou W, Zhang K, Putzel L. 2016. China's conversion of cropland to forest program: a systematic review of the environmental and socioeconomic effects. Environ Evid. (2016):5-21.

• Hallett SH, Caird SP. 2017. Soil-Net: Development and impact of innovative, open, online soil science educational resources. Soil Sci. 182(5):188-201.

• Hartemink AE, Balks MR, Chen Z-S, Drohan P, Field DJ, Krasilnikov P, Lowe DJ, Rabenhorst M, van Rees K, Schad P, Schipper LA, Sonneveld M, Walter C. 2014. The joy of teaching soil science. Geoderma 217-218:1-9.

• Hartemink AE, McBratney A. 2008. A soil science renaissance. Geoderma 148:123-129.

• Hayhoe D, MacIntyre J, Bullock S. 2016. Soil science education for Grades K-12 in Canada. Can J Soil Sci. 96(3):336-345.

• Hellgren JM, Lindberg S. 2017. Motivating students with authentic science experiences: changes in motivation for school science. Res Sci Technol Educ. 35(4):409-426.

• Herrada RI, Baños R. 2018. Aprendizaje cooperativo a través de las nuevas tecnologías: una revisión. Revista d'Innovació Educativa 20:16-25. [In Spanish].

• IGME (Instituto Geológico y Minero de España). 1987. Mapa Geológico de España 1:50.000. Hoja 173 (Tafalla) y 206 (Peralta). [cited 2018 September 14]. Available from: http://www.igme.es/infoigme/catalogo/catalogo.aspx?tab=0

• Ikaselkar. 2017. Biologia eta Geologia 4 DBH. Donostia-San Sebastián, Spain: Series EKI Proiektua. [In Basque].

• Johnson DW, Johnson R, Holubec E. 2013. Cooperation in the classroom (9th ed.). Edina, MN, USA: Interaction Book Company.

• Kali Y, Levy KS, Levin-Peled R, Tal T. 2018. Supporting outdoor inquiry learning (SOIL): Teachers as designers of mobile-assisted seamless learning. Brit J Educ Technol. 49(6):1145-1161.

• Keuskamp JA, Dingemans BJ, Lehtinen T, Sarneel JM, Hefting MM. 2013. Tea Bag Index: a novel approach to collect uniform decomposition data across ecosystems. Methods Ecol Evol. 4:1070-1075.

• Klute A, editor. 1986. Methods of Soil Analysis: Parts 1&2 —Physical and mineralogical methods. SSSA Book Ser. 5.1. Madison, WI, USA: SSSA, ASA.

• Kurganova I, Merino A, Lopes de Gerenyu V., Barros N, Kalinina O, Giani L, Kuzyakov Y. 2019. Mechanisms of carbon sequestration and stabilization by restoration of arable soils after abandonment: A chronosequence study on Phaeozems and Chernozems. Geoderma 354:113882.

• Lal R, Follett F, Stewart BA, Kimble JM. 2007. Soil carbon sequestration to mitigate climate change and advance food security. Soil Sci. 172(12):943-956.

• Margenot AJ, Alldritt K, Southard S, O'Geen A. 2016. Integrating soil science into primary school curricula: Students promote soil science education with Dig It! The Secrets of Soil. Soil Sci Soc Am J. 80(4):831-838.

• Martínez-Peña MB, Gil-Quílez MJ, de la Gándara M. 2016. Contribution of experiences to the construction of models: the soil as a system. Enseñanza de las Ciencias de la Tierra 24.2:182-189. [In Spanish].

• MECD (Ministerio de Educación, Cultura y Deporte). 2014. Real Decreto 126/2014, de 28 de febrero, por el que se establece el currículo básico de la Educación Primaria. [cited 2019 July 25]. Available from: https://www.boe.es/buscar/pdf/2014/BOE-A-2014-2222-consolidado.pdf [In Spanish].

• MECD (Ministerio de Educación, Cultura y Deporte). 2015. Real Decreto 1105/2014, de 26 de diciembre, por el que se establece el currículo básico de la Educación Secundaria Obligatoria y del Bachillerato. [cited 2019 July 25]. Available from: https://www.boe.es/boe/dias/2015/01/03/pdfs/BOE-A-2015-37.pdf [In Spanish].

• NIE (Nafarroako Ikastolen Elkartea). 2019. ¿Qué es Oinez Basoa? [cited 2019 July 24]. Available from: http://www.nafarroaoinez.eus/basoa/indexES.asp. [In Spanish].

• Norman AG, editor. 1965. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Agron. Monogr. 9.2. Madison, WI, USA: ASA, SSSA.

• Peralta J, Biurrun I, García-Mijangos I, Remón JL, Olano JM, Lorda M, Loidi J, Campos JA. 2013. Manual de hábitats de Navarra. Departamento de Desarrollo Rural, Medio Ambiente y Administración Local. Pamplona, Spain: Gobierno de Navarra. [In Spanish].

• Pickett STA. 1989. Space-for-time substitution as an alternative to long-term studies. In: Likens GE, editor. Long-term studies in ecology. New York, NY, USA: Springer.

• Rasmussen C, Heckman K, Wieder WR, Keiluweit M, Lawrence CR, Berbe AA, Blankinship, JC, Crow S, Druhan JL, Pries CEH, Marin-Spiotta E, Plante AF, Schadel C, Schimel JP, Sierra CA, Thompson A, Wagai R. 2018. Beyond clay: towards an improved set of variables for predicting soil organic matter content. Biogeochemistry 137:297-306.

• Rebollo M, Prieto T, Brero V. 2005. Aproximación a la historia y epistemología del concepto de suelo: Implicaciones didácticas. Enseñanza de las Ciencias (Número extra: VII Congreso):1-5. [In Spanish].

• Rodríguez-Martín JA, Álvaro-Fuentes J, Gonzalo J, Gil C, Ramos-Miras JJ, Grau-Corbí JM, Boluda R. 2016. Assessment of the soil organic carbon stock in Spain. Geoderma 264:117-125.

• Rowley MC, Grand S, Verrecchia EP. 2018. Calcium-mediated stabilisation of soil organic carbon. Biogeochemistry 137:27-49.

• Rumpel C, Amiraslani F, Chenu C, García-Cárdenas M, Kaonga M, Koutika L-S, Ladha J, Madari B, Shirato Y, Smith P, Soudi B, Soussana J-F, Whitehead D, Wollenberg, E. 2019. The 4p1000 initiative: Opportunities, limitations and challenges for implementing soil organic carbon sequestration as a sustainable development strategy. Ambio 2019:1-11. https://doi.org/10.1007/s13280-019-01165-2.

• Sarneel J, Broneus F, van Hamersveld I, Carlbourg E. 2017. Teatime for Science. Teacher's manual. Instructions & background material. [cited 2019 May 4]. Available from: http://www.teatime4science.org/wp-content/uploads/Teachers-manual_2017.pdf.

• SECS (Sociedad Española de la Ciencia del Suelo). 2017. Libro Blanco sobre el tratamiento del suelo en los libros de texto de Enseñanza Secundaria Obligatoria y de Bachillerato en España. 2nd edition. Lleida, Spain: Diputació de Lleida.

• Soil Survey Staff. 2010. Keys to Soil Taxonomy. 11th edition. Natural Resources Conservation Service. Washington, D.C., USA: United States Department of Agriculture.

• Stolbovoy V, Montanarella L, Filippi N. 2007. Soil sampling protocol to certify the changes of organic carbon stock in mineral soil of the European Union. Version 2. EUR 21576 EN/2. Luxembourg: Office for Official Publications of the European Communities.

• Tiessen H, Moir JO. 1993. Total and organic C. In: Carter MR, editor. Soil Sampling and Methods of Analysis. Ottawa, ON, Canada: CRC Press. p. 187-199.

• Torkar G, Krasovec U. 2019. Students' attitudes toward forest ecosystem services, knowledge about ecology, and direct experience with forests. Ecosys Ser. 37:100916.

• Vance ED, Brookes, PC, Jenkinson DS. 1987. An extraction method for measuring soil microbial biomass C. Soil Biol Biochem. 19:703-704.

• Virto I, Imaz MJ, Fernández-Ugalde O, Urrutia I, Enrique A, Bescansa P. 2012. Soil quality evaluation following the implementation of permanent cover crops in semi-arid vineyards. Organic matter, physical and biological soil properties. Span J Agric Res. 10:1121-1132.

• Yusof KM, Hassan SAHSS, Jamaludin MZ, Harun NF. 2012. Cooperative Problem-based Learning (CPBL): Framework for integrating Cooperative Learning and Problem-based Learning. Procedia-Social and Behavioral Sci. 56:223-232.

• Zugazagoitia D, Villarroel JD. 2016. Studying the importance of soil organic matter: An educational proposal for secondary education. Educación Química 27:37-42. [In Spanish].