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Article

Incorporating Ecosystem Services into STEM Education

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Abstract: The framework of ecosystem services (ES) and disservices (ED) has increasingly been used in various science, technology, engineering, and mathematics (STEM) disciplines, including soil science. The objectives of this study were to use ES/ED concepts to extend and test an existing lecture and laboratory exercise on soil organic carbon (SOC) in an online introductory soil science course (FNR 2040: Soil Information Systems) taught to Clemson University students from various STEM disciplines (forestry, wildlife biology, and environmental and natural resources) in Fall 2020. The laboratory exercise was extended with a series of reusable learning objects (RLOs), which are self-contained digital modules commonly utilized in e-learning. The laboratory exercise consisted of identifying ES and calculating the avoided social cost of carbon (SC-CO_2) from soil organic carbon stocks in the assigned soil's topsoil horizon. The laboratory exercise effectively increased student familiarity with ES/ED as indicated by the post-assessment survey with a +24.4% increase in the moderately familiar category and a +36.1% increase in the extremely familiar category. The graded online quiz consisted of ten questions and was taken by 51 students with an average score of 8.7 (out of 10). A post-assessment survey indicated that most of the students found that the laboratory was an effective way to learn about ES/ED with examples from soil science. Detailed students' comments indicated enjoyment of learning (e.g., calculations, applying new knowledge), the value of multimedia (e.g., PowerPoint, video), the flexibility of learning (e.g., different parts in the laboratory), the applicability of content (e.g., real-world examples), and criticism (e.g., tedious calculations). A word cloud based on students' comments about their experience with the laboratory exercise on soil ES indicated the most common words used by students to describe their experience, such as "soil services", "learning", "enjoyed", and "ecosystems", among others. Incorporating ES/ED into an undergraduate STEM course enabled students to connect ES/ED provided by soil with the societal systems reliant on the soil resources.

Keywords: e-learning; environment; interdisciplinary; learning; reusable learning object (RLO); soil; sustainability; Sustainable Development Goals (SDGs)

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1. Introduction

The framework of ecosystem services (ES) and disservices (ED) is increasingly being used by various government and non-government entities in policy and decision-making, creating a need for educational materials for a wide range of audiences (e.g., employees, students, the public, etc.) [1]. Ecosystem services are defined as benefits humans obtain from nature (provisioning, regulating/maintenance, and cultural benefits) [2,3]. In contrast, ED are defined as damages to humans from nature (e.g., flooding, soil erosion, etc.) [2,3]. Despite the importance of the ES/ED framework for human society [1], there are limited examples of ES/ED applications in science, technology, engineering, and mathematics (STEM) education because there has been little research on how to integrate them. Traditional STEM education focuses on the biophysical context (ecosystem structure, function, and processes) and not the link to ES/ED and human benefits/damages, as the idea of ES/ED is a relatively recent advancement (Table 1). The ES framework integrates the biophysical context with the socio-economic context [4]. This integration results in an interdisciplinary teaching/learning approach because students learn about the subject matter (e.g., soil systems and their properties) from a biophysical and socio-economic viewpoint (Table 1).

Table 1. Interdisciplinary teaching/learning approach to ecosystem services (ES) with examples from soil systems and their properties (based on the cascade model adapted from Potschin and Haines-Young (2011) [4]).

Ecosystem Services Framework			
Biophysical Context		**The Socio-Economic Context**	
Ecosystem Organization	**Function(s)**	**Service(s)/Disservice(s) Benefit(s)/Damage(s)**	**Value(s)**
Soil systems Soil properties: -SOC -SIC	C sequestration pH regulation	Regulating Provisioning	Social costs of C Liming costs
Interdisciplinary Teaching/Learning Approach			

Note: SOC, soil organic carbon; SIC, soil inorganic carbon.

This approach allows students to learn not just about ecosystem organization and function but also about the corresponding ES/ED using market and non-market values (Table 1). For example, soil systems can contain soil organic carbon (SOC), which regulates C sequestration in the soil (regulating ecosystem service) and can be valued based on the social cost of carbon [5]. Another important soil property is soil inorganic carbon (SIC), commonly found in the soil in the form of calcium carbonate ($CaCO_3$), which provides provisioning services (e.g., food production) and can be valued based on liming replacement costs [5]. This type of integration has broad implications for sustaining the environment because it can give students a direct understanding of the linkages between ecosystems and their value.

Incorporation of ES/ED in soil science education is particularly important since soil science is an interdisciplinary science (Figure 1a,b) used by numerous fields (e.g., forestry, wildlife biology, etc.), and undergraduate students are often required to take an introductory soil science course early in their curriculum (e.g., sophomore year). Soil and the pedosphere form from interactions of Earth's various spheres (atmosphere, biosphere, hydrosphere, lithosphere within ecosphere, and anthroposphere), and their physical and chemical properties are the products of these interactions (Figure 1a,b). These soil physical and chemical properties provide ecosystem goods (e.g., sand, calcium carbonate, etc.) and services (provisioning, regulating/maintenance, and cultural services) through soil functions for societal welfare [2,3,5]. In market-based economies (e.g., the United States of America), the value and distribution of these ecosystem goods and services are mediated by the market and non-market institutions, and "these transformations and mediations can result not only in welfare but damages as well (e.g., social costs of carbon emission, SC-CO_2)" [5]. Mikhailova et al. (2020) [5] demonstrated various business applications of ES/ED of soil systems, and these applications can be integrated into soil science teaching and learning.

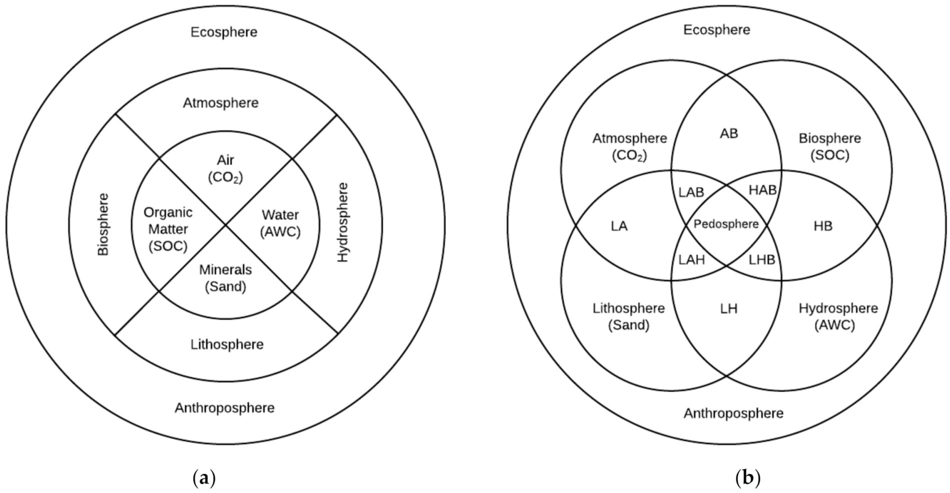

Figure 1. (**a**) The interdisciplinary scope of soil and the relationship between soil components originating from Earth's various spheres; (**b**) formation of two-sphere, three-sphere, and four-sphere (e.g., pedosphere) systems in nature (**A** = atmosphere; **B** = biosphere; **H** = hydrosphere; **L** = lithosphere, ecosphere, and anthroposphere). Adapted from Mattson (1938) [6] and Mikhailova et al. (2020) [5]. Examples of soil properties are listed in the parentheses (SOC = soil organic carbon, AWC = available water capacity, etc.).

The interdisciplinary nature of soil science [6], ecosystem services [2], and their values [5] require an interdisciplinary teaching/learning approach [7] (Table 2). Helmane and Briška (2017) [7] define interdisciplinary teaching/learning as teaching/learning across disciplines, where "disciplines are identifiable, but they assume less importance than in the multidisciplinary approach". Based on this definition, Figure 1b can be adapted to describe the interdisciplinary approach to teaching/learning about soil ecosystem goods and services and their values, which can help designing effective teaching materials, exercises, and activities (Figure 2).

Table 2. Features of the interdisciplinary approach to integrated teaching/learning (adapted from Helmane and Briška (2017) [7]).

Features	Description
General description	Includes more than one subject. Can be more effective than learning each subject separately. Builds a holistic system. Students are active learners.
Basis for integration	Skills and concepts common for several disciplines.
Connections	Disciplines help understanding each other.
Focus	Student oriented. Focused on student's skills development.
Aim	To indicate, use and develop general skills.
Results	Concepts and skills of one discipline change the methods of other disciplines. Adaptive interdisciplinary expertise.
Learning outcomes	Deeper levels of conceptual coherence, varied set of reasoning and metacognitive strategies.

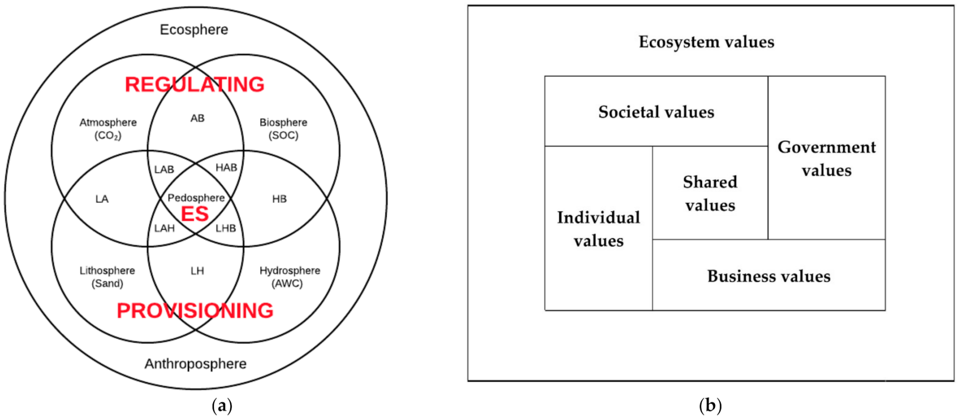

Figure 2. An interdisciplinary approach to teaching/learning about soil ecosystem goods and services (**a**) and its values (**b**), which can aid in designing useful teaching materials, exercises, and activities (adapted from Mattson, 1938 [6] and Mikhailova et al., 2020 [5]). Examples of soil ecosystem goods (in the parentheses) and services (ES) are shown within the figure.

For example, information about soil organic carbon in the tables of soil physical properties can be used to demonstrate the value of regulating ES by estimating the associated avoided social costs of carbon emission (SC-CO_2) if this carbon is not released into the atmosphere (Figure 2a), showing the connectedness between the pedosphere, atmosphere, and biosphere. An interdisciplinary teaching/learning approach is also important in illustrating the value of ecosystem goods and services from different perspectives (e.g., ecosystem values, societal values, government values, business values, etc.) (Figure 2b). For example, the social costs of carbon emission (SC-CO_2) are government-set values, which can be used for various applications in policy and decision-making (Figure 2b). It is important to note that the total value of ecosystem goods and services is impossible to determine because some of them are "priceless" [8].

Previous studies on ES and education span various fields and applications but rarely involve soil science directly. For example, Taylor et al., 2016 [9] used ES valuation as an opportunity for inquiry learning in geosciences. Geologic processes produce many environmental services; therefore, ES must become integrated into geology and earth science courses. This study developed two variations of an inquiry-based learning exercise in which students used the ES approach to assign a monetary value to eight different ecosystem services generated by four ecosystems. One version of the exercise had students do these valuations in the field, while the other was completed solely in the classroom. In both cases, the students scored significantly better on a post-exercise assessment, demonstrated a deeper understanding of the ES approach, and reported that the exercise was preferable to a traditional lecture. After doing the exercise, many students had a greater understanding of ES and were able to see the strengths and limitations of the ecosystem services. This exercise increased student knowledge of ES and had them consider the implications of assigning a monetary value to ES. It encouraged collaboration between students, and it can be implemented with minor modifications in a wide variety of learning environments. The exercise did not help students distinguish between ecosystem services and ecosystem processes or functions. The field version of the exercise has limitations because it is not always possible to have multiple ecosystem types in proximity, and it poses logistical problems in getting the students to the location of the exercise. This exercise was more effective than a traditional lecture and was successful as a field-based laboratory and in-class activity.

Several studies used simulation games that integrate research, entertainment, and learning around ecosystem services [10,11]. Video games have been used to research human behavior with regards to ES. With proper framing, video games can be used to analyze the value players put on ES in a way that is both educational and entertaining for the player. The limitation of this video game approach is the transferability of the results to real-life: will players value things in the game context the same as they do in real life and will the structure of the game sway them to specific responses?

Soil science is increasingly being taught online using reusable learning objects (RLOs), which can also be utilized in teaching ES/ED [12,13]. Reusable learning objects are digital learning modules that are self-contained, focused on specific learning objectives, and can be reused and scaled for a large audience [12,13]. Reusable learning objects can be used to construct an integrated teaching/learning sequence that includes both pre-and post-assessment that tests students' prior knowledge about ES/ED and the effectiveness of lecture and laboratory exercise modules. Each RLO can be used as a self-contained learning object for a specific ES/ED topic or as a whole course on soil ES/ED if several RLOs are aggregated.

Soil is a finite resource, which is often underappreciated and undervalued, especially in urban areas where people are disconnected from soil resources [14]. Increasing urbanization and population growth will further exasperate the disconnect between soil and the value it provides to humans; therefore, it is critical to develop and test educational strategies to help students understand soil ES/ED and their values from multiple perspectives (Figure 3).

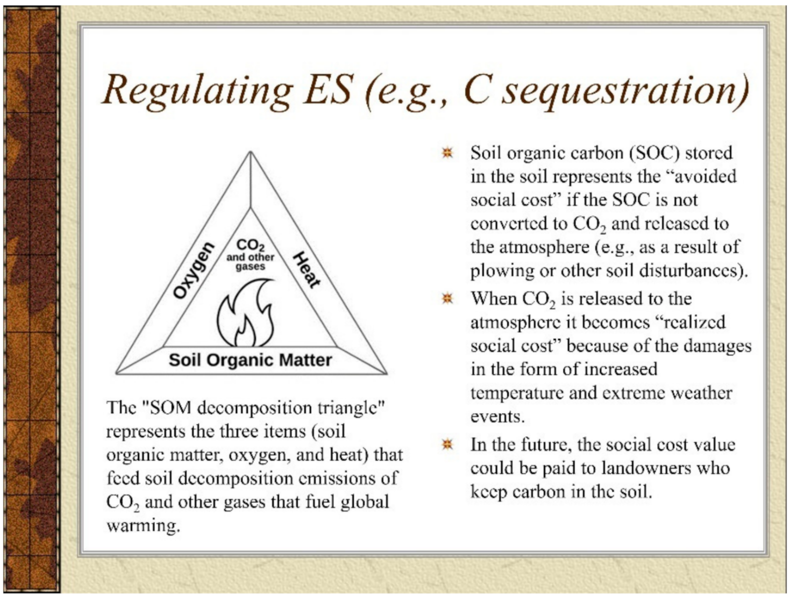

Figure 3. An example of a lecture/laboratory slide used to explain regulating ecosystem services and the social cost of soil organic matter (SOM) and soil organic carbon (SOC) from multiple perspectives ("avoided" versus "realized" social costs) adapted from Mikhailova et al. (2021) [15].

This study proposed using an interdisciplinary approach to teaching/learning about soil ES/ED and their values (Figure 2) using existing soil databases and tools (e.g., Web Soil Survey, etc.). The specific objectives were to use ES/ED concepts to extend and test an existing lecture and laboratory exercise on soil organic carbon and hands-on activities in an online introductory soil science course taught to Clemson University students from various STEM disciplines in Fall 2020. The laboratory exercise consisted of identifying ES and calculating the avoided social cost of carbon (SC-CO_2) from soil organic carbon stocks in the topsoil horizon of the assigned state/representative soil. The research questions for this study were: (1) Did incorporation of ES/ED into a lecture and hands-on laboratory activity enable students to understand ES/ED? (2) Did the students find the exercise format and content an effective way to learn about ES/ED?

2. Materials and Methods

2.1. Design

The laboratory exercise consisted of a series of reusable learning objects, which are self-contained digital modules commonly utilized in e-learning. In this study, the following sequence of RLOs was used in Learning Management System (Canvas): (1) pre-assessment web-based survey (Google Forms); (2) lecture on ES and ED in PowerPoint and video formats; (3) laboratory exercise in PowerPoint and video formats; (4) graded online quiz; and (5) post-assessment web-based survey (Google Forms). The laboratory exercise consisted of identifying ES and calculating the avoided social cost of carbon from soil organic carbon stocks in the topsoil horizon of the assigned soil. The experimental design of the study is presented in Tables 3–5. Tables 4 and 5 show instructions for the laboratory exercise provided to the students.

Table 3. Design steps of the study, which used interdisciplinary teaching/learning utilizing various reusable learning objects (RLOs).

Steps	Description of Activities
1. Pre-assessment	Students complete a general Google Forms web-based survey of familiarity ecosystem services and disservices (Table 7).
2. Lecture	Students are presented with a lecture on ecosystem services and disservices entitled "Soil Ecosystem Services and Soil Health" in PowerPoint and video formats (Figure 3).
3. Laboratory exercise	Students complete the laboratory exercise consisted of identifying ES and calculating the avoided social cost of carbon from soil organic carbon stocks in the topsoil horizon of the assigned soil in the State/Representative Soil Project [16]. Students add two slides to the State/Representative Soil Project [16] and upload them in Canvas (Tables 4 and 5).
4. Graded online quiz	Students complete an online quiz (ten questions, ten points) within Canvas (Table 8).
5. Post-assessment	Students complete a follow-up Google Forms web-based survey on their experience with the laboratory on ecosystem services and disservices (Table 7).

Table 4. Instructions for the laboratory exercise.

Soil Ecosystem Services Laboratory Exercise
Ecosystem services (ES) are defined as any positive benefit that is provided by the ecosystem to people. Ecosystem disservices (ED) are defined as any adverse effects caused by the ecosystem towards people. **Objectives:** • To gain knowledge about ES and ED related to soil science using various reusable learning objects (RLOs) (e.g., online lectures, PowerPoint presentation, and video). • To identify examples of ES (provisioning, regulating/maintenance, cultural services) provided by the assigned state/representative soil [16] using Official Soil Series Descriptions (OSDs) [17] and tables of soil physical properties [18]. • To conduct a monetary valuation of soil organic carbon (SOC) (listed in the tables of soil physical properties) using the avoided social cost of carbon (SC–CO_2) of USD 42 per metric ton of CO_2, which is applicable for the year 2020 based on 2007 U.S. dollars and an average discount rate of 3% [19]. According to the EPA, the SC–CO_2 is intended to be a comprehensive estimate of climate change damages, but it can underestimate the true damages and cost of CO_2 emissions due to the exclusion of various important climate change impacts recognized in the literature. • To test the acquired knowledge using an online graded quiz. • To evaluate the effectiveness of the laboratory exercise using pre-and post-assessments. **Rationale**: The framework of ecosystem services (ES) and disservices (ED) is increasingly being used in various fields, including forestry, wildlife biology, and environmental sciences. **Procedure**: The soil ecosystem services laboratory exercise consists of a series of reusable learning objects (RLOs) (e.g., pre-assessment, lecture, etc.), which need to be completed sequentially.

Table 5. Instructions for the specific slides in the laboratory exercise.

Slides

Slide: Instructions for the Soil Ecosystem Services (ES) Slides.

- Please use the following slides as a template.
- Copy and paste them into your PowerPoint presentation.
- Add examples (e.g., suitability for crops, soil properties, etc.) of services found in your state/representative soil.
- Hint: Sometimes, a cultural ES is the name of the state soil (e.g., Casa Grande = large house in Spanish).
- If your soil does not have an obvious example for ES, use N/D for not determined.
- Upload your completed state/representative soil PowerPoint to Canvas.

Slide template: Soil ecosystem services.

Soil Ecosystem Services (Type)	Examples based on State/Representative Soil
Provisioning (e.g., food, fiber, etc.).	
Regulating/Maintenance (e.g., water, gases: CO_2, etc.).	
Cultural (e.g., historical significance, recreation, etc.).	

Slide: Explanation of regulating ecosystem services (e.g., C sequestration).

Soil organic carbon (SOC) provides regulating ES by keeping carbon in the soil instead of it being released to the atmosphere as CO_2 gas, which contributes to global warming. A monetary valuation for SOC can be calculated using the avoided social cost of carbon (SC–CO_2) of USD 42 per metric ton of CO_2, which is applicable for the year 2020 based on 2007 U.S. dollars and an average discount rate of 3% [19]. According to the EPA, the SC–CO_2 is intended to be a comprehensive estimate of climate change damages. Still, it can underestimate the true damages and cost of CO_2 emissions due to the exclusion of various important climate change impacts recognized in the literature.

Slide template: Instructions for calculating a monetary value of SOC, based on the avoided social cost of emitting carbon dioxide to the atmosphere.

Instructions: Use the table of soil physical properties to find the midpoint soil organic matter (SOM) percent for the topsoil layer.

- Convert the percent SOM to percent organic carbon (SOC): SOC (%) = SOM (%)/1.72.
- Calculate the quantity (i.e., mass) of SOC in one hectare of the top layer of your soil:
- Find the thickness of the topsoil layer in cm by taking the lower depth and subtracting zero and by converting this number from inches to cm (multiply by 2.54 cm/inch).
- Find the midpoint soil bulk density for the top layer of soil.
- Calculate the mass of soil organic carbon in one kg total soil by using the following formula:
- Grams C in one kg of soil = SOC (%) × 10 = g C/kg soil.
- Kilograms of soil in the top horizon of one hectare = bulk density (g/cm^3) × thickness of the top layer (cm) × 100,000.
- SOC in one hectare (grams) = (grams C in one kg of soil) × (kilograms of soil in the top horizon of one hectare). SOC in one hectare (metric tons) = SOC in one hectare (grams)/1,000,000

Example: So, for example, if you had SOM of 1% and a top horizon depth of 3.94 inches, and a bulk density of 1.6 g/cm^3.

- Depth of topsoil layer = 3.94 incles × 2.54 cm/inch = 10 cm.
- SOC (%) = 1 (%)/1.72 = 0.58 (%). Grams C in one kg of soil = 0.58 × 10 = 5.8 g C/kg soil.
- Kilograms of soil in the top horizon of one hectare = 1.6 (g/cm^3) × 10 (cm) × 100,000 = 1,600,000 kg soil/ha.
- SOC in one hectare (g C/ha) = 5.8 g C/kg soil × 1,600,000 kg soil/ha = 9,280,000 g C/ha.
- SOC in one hectare (metric ton C/ha) = 9,280,000 g C/ha /1,000,000 = 9.28 t C/ha.

The monetary value of soil organic carbon (SOC): $ = (SOC in one hectare, t C/ha) × (44 tons CO_2/12 tons SOC) × $42 per ton CO_2; $ = 9.28 t C/ha x (44/12) × $42/t C = $1429/ha.

2.2. Background of the "Test" Course

"Test" course: Soil Information Systems (FNR 2040) is a 4-credit course in the Department of Forestry and Environmental Conservation at Clemson University, Clemson, SC, USA [20]. FNR 2040 is "an introductory soil course that focuses on the input, analysis, and output of soil information utilizing geographic information technologies (Global Positioning Systems, Geographic Information Systems, direct/remote sensing) and soil data systems (soil surveys, laboratory data, and soil data storage). Soil Information Systems course is a required course for forestry, wildlife, and environmental science majors" [20]. The course was taught for the first time online because of COVID-19. General information about the course based on the survey indicated that students (29 females and 26 males) were from forestry, environmental science, and wildlife biology majors at the sophomore, junior, and senior levels (Table 6).

Table 6. General survey information about the course (FNR 2040: Soil Information Systems, n = 55).

Survey Questions	Responses			
What is your major program?	FOR (11)	ENR (18)	WFB (25)	Other (1)
How would you best describe your academic classification (year)?	Sophomore (26)	Junior (23)	Senior (5)	Other (1)
How would you describe yourself?	Female (29)	Male (26)		
Did you take online courses before?	Yes (37)	No (18)		

Note: FOR = Forestry, ENR = Environmental and Natural Resources, WFB = Wildlife and Fisheries Biology.

3. Results

The purpose of this study was to enhance soil science education with ES/ED using an interdisciplinary approach and RLOs. The laboratory exercise topic (social costs of carbon) was selected because it had direct applications across each of the STEM disciplines, represented by the students' majors required to take the course. Pre-assessment results indicated a wide range of students' familiarity with the concept of ES/ED, with most students suggesting that they were somewhat familiar (42.6%) with this concept (Table 7). Most students could identify basic ES/ED examples provided in the pre-assessment (Table 7). All students agreed that determining the value of ES/ED is useful in decision-making concerning natural resources management (Table 7). Most of the students (70.4%) thought it was not possible to determine the total value of ES/ED (Table 7).

The quiz was designed to assess students' retention of the materials presented in the lecture and laboratory exercise, and most of the questions were successfully answered by the students (Table 8). This was supported by an 87% correct average quiz score for 51 students. One of the questions ("What type of ecosystem service does soil pH refer to?") had a wide range of responses, with most students (49%) identifying soil pH with regulating ES and some students (20%) choosing provisioning ES (Table 8). Soil pH provides various ES/ED, and this quiz question was potentially confusing in its structure.

Post-assessment results indicated that the lecture and laboratory exercise were effective in educating students about soil ES/ED with an increase in the proportion of students classifying their familiarity with the concept of ES/ED as moderately familiar (+24.4% increase from pre-assessment) and extremely familiar (+36.1% increase from pre-assessment) (Table 7). Students were consistently correct in identifying examples of ES/ED in the post-assessment compared to pre-assessment answers. Most students (60.4%) agreed that the laboratory was an effective way to learn about the ES/ED with examples from soil science (Table 7). Detailed student comments (Table 9) were mostly positive (e.g., enjoyment, granularity, etc.) with some criticism (e.g., tedious calculations, etc.) and requests for more examples, including examples on how to incorporate this information into the management and practices (Table 9 and Figure 4). Some of the criticism referred to the calculations being tedious; however, these calculations, which were successfully completed by the students, likely contributed to their understanding of the topic. Other students' comments may provide insights for future improvements, including the suggestion of increasing the number and variety of examples, which could be implemented by having students select major-specific ES/ED topics and exercises. Students could see the value of the ES/ED by suggesting the possibility that ES/ED could be incorporated into upper-level courses (e.g., Forestry Management Plans). Incorporating ES/ED into an undergraduate laboratory exercise within a multi-week student project enabled students to connect ES/ED provided by soil with the societal systems reliant on these soil resources.

Table 7. Pre- and post-assessment results from the laboratory exercise on soil ecosystem services in the FNR 2040: Soil Information Systems course.

	Responses		
Survey Questions and Answers	**Pre-Assessment (%) (n = 54)**	**Post-Assessment (%) (n = 50)**	**Difference (%)**
Please, rate your familiarity with the concept of ecosystem services or disservices on the following scale:			
1 = not at all familiar	1.9	0	−1.9
2 = slighlty familiar	24.1	0	−24.1
3 = somewhat familiar	42.6	8.0	−34.6
4 = moderately familiar	29.6	54.0	+24.4
5 = extremely familiar	1.9	38.0	+36.1
Which of the following is not an ecosystem service provided by soil?			
Food production	0	0	0
Water storage	0	0	0
Carbon sequestration	1.9	0	0
Clay for pottery	11.1	4.0	−7.1
Sunlight	**87.0**	**96.0**	**+9.0**
Which of the following is an ecosystem service provided by soil?			
Pollution	3.7	2.0	−1.7
Climate regulation	**94.4**	**96.0**	**+1.6**
Wind	0	0	0
Rain	0	0	0
Sunlight	1.9	2.0	+0.1
Which of the following is an ecosystem disservice provided by soil?			
Snow	0	0	0
Soil erosion	**100**	**100**	**0**
Rain	0	0	0
Sunlight	0	0	0
How can ecosystem services and disservices be valued?			
Monetary	0	14.0	+14.0
Non-monetary	3.7	4.0	+0.3
Both (monetary and non-monetary)	**94.4**	**80.0**	**−14.4**
Cannot be valued	1.9	2.0	+0.1
Determining the value of ecosystem services or disservices is useful in decision-making with regard to natural resources management.			
True	**100**	**100**	**0**
False	0	0	0
Is it possible to determine the total value of ecosystem services and disservices?			
Yes	29.6	34.7	+5.1
No	**70.4**	**65.3**	**−5.1**
The laboratory was an effective way to learn about the ecosystem services and disservices with examples from soil science:			
1 = strongly disagree	-	-	-
2 = disagree	-	-	-
3 = neither agree nor disagree	-	6.3	-
4 = agree	-	60.4	-
5 = strongly agree	-	33.3	-

Note: Correct answers are indicated in bold.

Table 8. Responses to the quiz questions for the laboratory exercise on soil ecosystem services in the FNR 2040: Soil Information Systems course (n = 51; average score: 8.7; high score: 10; low score: 7; standard deviation: 0.86; average time: 09:34).

Quiz Questions and Answers	Respondents	Responses (%)
Carbon sequestration by soil is part of regulating ecosystem services.		
True	**49**	**96**
False	2	4
Ecosystem services are defined as any positive benefit that is provided by the ecosystem to people.		
True	**49**	**96**
False	2	4
Which of the following services are provisioning ecosystem services?		
Gas regulation	0	0
Water regulation	2	4
Food production	**49**	**96**
Playgrounds	0	0
Which of the following services are regulating ecosystem services?		
Forest production	1	2
Cemeteries	0	0
Food production	0	0
Carbon sequestration	**50**	**98**
Which of the following services are cultural services?		
Carbon sequestration	0	0
Wildlife food plots	1	2
Monuments	**49**	**96**
Forest production	1	2
Which of the following is an ecosystem disservice?		
Carbon dioxide release	**50**	**98**
Carbon sequestration	0	0
Playgrounds	0	0
Wildlife food plots	1	2
What type of ecosystem service does saturated hydraulic conductivity refer to?		
Cultural ecosystem service	1	2
None	5	10
Provisioning ecosystem service	1	2
Regulating ecosystem service	**44**	**86**
What type of ecosystem service does soil pH refer to?		
Regulating ecosystem service	25	49
Cultural ecosystem service	1	2
None	15	29
Provisioning ecosystem service	**10**	**20**
From a wildlife biologist's point of view, which type of ecosystem service is critical for feeding animals?		
Cultural ecosystem service	2	4
None	0	0
Regulating ecosystem service	5	10
Provisioning ecosystem service	**44**	**86**
When people use forests for recreation, what type of ecosystem service is being provided?		
Provisioning ecosystem service	2	4
Cultural ecosystem service	**49**	**96**
Regulating ecosystem service	0	0
None	0	0

Note: Correct answers are indicated in bold.

Table 9. Post-assessment students' comments, grouped by theme [21], about their experience with the laboratory exercise on soil ecosystem services in the FNR 2040: Soil Information Systems course.

Responses
T1. Enjoyment of learning
I enjoyed getting a chance to see how the calculation for finding the actual monetary value of ecosystem services was and getting to practice that.
I enjoyed working on the state soil project and applying my new knowledge of ecosystem services to the project.
I enjoyed learning how to do calculations on my own, specific soil.
I enjoyed calculating the monetary value of my soil series.
I liked being able to calculate it for the soils that I have been working with all semester.
I always enjoy relating one topic to multiple different answers. For example, my soil is sometimes used for woodland growth, which can be a regulatory service for carbon sequestration, a cultural service when used for recreation, and a provisional service for feeding the animals that live within the stand.
I enjoyed researching into what ecosystem services my state soil provided for the state.
I enjoyed doing the equation aspect of the lab report and figuring out how to get the answers to the equations.
T2. Value of multimedia
The google survey/quiz are interesting.
I found the PowerPoint slides to be helpful.
Watching the video lecture was very informative.
I enjoyed the video.
I liked listening to the narrated PowerPoint.
The videos are super helpful.
Honestly, I like the way the lab was set up between the quizzes and power point slides.
T3. Flexibility of learning
The information was easy to find and clear.
I liked the different parts to the lab it was easy to follow and kept me interested.
I like it being split up to work in parts.
I like how this was broken up into parts, it made it easier to manage time wise.
I enjoyed the multiple small parts to this lab.
T4. Applicability of content
Learning more about ecosystem services is just very interesting to me because I want to go into this field. I think it is also just important for anyone to understand what soil can help and hurt with.
The real-world examples of ecosystem services in the PowerPoint.
My favorite activity was doing the lab for my soil as I could do my own research.
I liked the different parts to the lab it was easy to follow and kept me interested.
Learning about the different types of soil services.
Learning to think of the climate impact soils can have regarding global warming.
T5. Criticism
I can't think of anything except maybe providing our answers to this and the first survey to see how our knowledge changed or didn't change after completing the lab.
The calculations for the lab were tedious.
More examples would be nice.
I think the portion for the state soil project could have been explained in a better way. I also don't think the lecture really contained a full list of provisional, cultural, and regulating service like it should have. Other than that, I think that this was an easy way to tie in a lecture and lab combined.
I found that doing the calculations helped me understand how to put a monetary value of an ecosystem service or disservice, but I would've liked to learn more about how that value is then incorporated into the management and practices.
Go over carbon sequestration way more.

Figure 4. Word cloud based on students' comments about their experience with the laboratory exercise on soil ecosystem services in the FNR 2040: Soil Information Systems course. The larger the word in the word cloud, the more common the word in the students' comments.

4. Discussion

Sustainable management of natural resources requires continuous improvement of educational content with various innovations, such as ES/ED, which are increasingly being used in policy and decision-making [22]. They provide education with a framework to (a) understand the relationship between humans and nature, (b) enable trans- and interdisciplinary research, (c) identify the trade-offs between various ES, and (d) help stakeholder groups to create management strategies for ecosystems [21]. The implementation of ES/ED in soil science education is challenging because of the interdisciplinary nature of soil science, ES/ED, and their values (Table 10). It requires a high level of integration in teaching/learning and application for various STEM disciplines, that utilize soil science (e.g., forestry, wildlife biology, environmental science, etc.). In order to successfully incorporate the ES/ED in STEM education, a special effort should be made to design educational and assessment materials based on pedagogical knowledge (Table 10). Table 10 provides examples of how to conceptualize applications of ES/ED based on increasing levels of integration.

It is common for many applied STEM disciplines to use laboratory exercises to amplify and illustrate lecture material. In the case of this study, each student was required to perform calculations on their unique soil using step-by-step instructions. This allowed the students to complete the exercise within the allotted time, while also having a unique solution relevant to the soil, that they had studied in their semester-long project. Students understood the importance of ES and ED because they calculated the monetary value of ES/ED. This exercise was developed, deployed, and tested during a global pandemic, which forced in-person laboratory exercises into an online mode. This type of activity could be increased in complexity by limiting the step-by-step instructions but instead requiring students to research the subject and determine appropriate calculations, particularly if employed in intermediate or advanced courses.

Table 10. Possible levels of integration in teaching/learning (adapted from Kaufman et al., 2003 [23]).

Teaching/Learning Approaches			
- - - - - - - - - - - - - - - **Increasing levels of integration** - - - - - - - - - - - - - - ->			
Disciplinary	**Multidisciplinary**	**Interdisciplinary**	**Transdisciplinary**
Students learn concepts and skills separately in each discipline.	Students learn concepts and skills separately in each discipline but in reference to a common theme.	Students learn concepts and skills from two or more disciplines that are tightly linked so as to deepen knowledge and skills.	By undertaking real-world problems or projects, students apply knowledge and skills from two or more disciplines and shape the learning experience.
Examples using ecosystem services (ES)			
Limited due to the interdisciplinary nature of ES/ED.	Limited due to the interdisciplinary nature of ES/ED.	The soil fertility lecture and laboratory exercise can be extended with ES/ED based on calculations using data on liming, carbonates ($CaCO_3$), and soil inorganic carbon (SIC) to assess provisioning ES (e.g., liming) and regulating ES (e.g., carbon sequestration).	Wildlife students can estimate SIC's contribution to provisioning ES in food plots in a specific location and target wildlife species.

Presented research and a case study demonstrated the effectiveness and value of ES/ED in soil science education, which has implications for future research and development. In terms of soil science education, more soil properties can be used to expand the application of ES/ED to various applications and courses in soil science and beyond. For example, calcium carbonate content reported in the tables of soil chemical properties can be used to demonstrate the value (e.g., replacement cost) of naturally present soil liming material [24] in the soil fertility laboratory of the introductory soil science and soil fertility courses. Students' interests are vital in designing effective and meaningful learning experiences in soil science [25,26]. Students' feedback from this study showed the need to provide more examples of the applicability of soil ES/ED to other STEM disciplines (e.g., forestry). Baskent (2020) [27] described a framework for characterizing and regulating ecosystem services in a forestry management planning context and stressed the importance of "adopting a broad and transdisciplinary perspective to address ES properly in a management planning context". Soil ES/ED can be integrated into a forestry management context, which generally involves "the identification, quantification, valuation, assessment, and monitoring of ecosystem services over time." Ruppert et al. (2017) [28] provide an example of an experimental study using a Delphi technique to define and characterize ES in education by a panel of experts in a domain. Forestry experts can conduct similar studies to identify important ES/ED and soil properties applicable to forestry management plans and students' interests [29]. Besides forestry, there are numerous other applications of ES/ED (e.g., agriculture, etc.), primarily used by the United States federal agencies (e.g., the Department of Agriculture (USDA); the Department of Interior (DOI); the Environmental Protection Agency (EPA); the Department of Commerce (DOC); etc.), which are responsible for managing public lands and waters, and administering environmental regulations [30]. These agencies require a workforce, which is educated in ES/ED science.

Teaching and learning about ES/ED in soil science can have an increased level of integration, from interdisciplinary to transdisciplinary, where students undertake real-world problems or projects and apply knowledge and skills from two or more disciplines and help to shape the ES/ED learning experience (Table 10). Soil ES/ED can be incorporated into problems and projects at various scales, from the local scale for relatability to the global scale for complexity [31–34]. Furthermore, soil ES/ED and associated educational activities can relate to Sustainable Development Goals (SDGs) demonstrating how the functioning of ecosystems contributes to human well-being [35,36]. Continuous technological advances in educational multimedia provide new opportunities to expand the variety of RLOs used for ES/ED teaching, including digital story maps to bring a spatial component into teaching and learning [37]. Course syllabi provide a topical outline for selecting and integrating appropriate ES/ED when planning and designing educational activities related to ES/ED [38].

5. Conclusions

Enhancing STEM disciplines (e.g., soil science) with ES/ED requires an interdisciplinary approach because of the interdisciplinary nature of soil science, ES/ED, and their values. ES/ED provide education with a framework to understand the relationship between humans and nature, enable trans- and interdisciplinary research, identify the trade-offs between various ES, and help stakeholder groups create management strategies for ecosystems. Interdisciplinary ES/ED teaching/learning approach was tested by a newly developed online module consisting of multiple RLOs for teaching and assessment in an introductory soil science course, required for students from various disciplines. Assessments of student learning revealed the effectiveness and limitations of this exercise. Incorporation of ES/ED into a lecture and hands-on laboratory activity resulted in an 87% correct average quiz score and increased familiarity with ES/ED concepts. Overall, the exercise was an effective learning experience and revealed new opportunities for research and development. Students found the exercise content and format to be an effective way to learn about ES/ED, as demonstrated by detailed student comments. Integrating ES/ED into soil science classes is particularly valuable because it helps to prepare students to apply this knowledge to the interdisciplinary field of ecosystem services. This methodology could easily be applied to a range of STEM disciplines through in-person or online education. While this exercise was introduced as part of an introductory course, the complexity of ES/ED and the calculations involved could be extended in other course levels and disciplines and could range from step-by-step instructions to more project-based research and learning.

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Abbreviations

AWC	Available water capacity
DOI	Department of Interior
DOC	Department of Commerce
ES	Ecosystem services
ED	Ecosystem disservices
ENR	Environmental and Natural Resources

EPA	Environmental Protection Agency
FOR	Forestry
RLO	Reusable learning object
SC-CO_2	Social cost of carbon emissions
SDGs	Sustainable Development Goals
SOC	Soil organic carbon
SIC	Soil inorganic carbon
STEM	Science, technology, engineering, and mathematics
USDA	United States Department of Agriculture
WFB	Wildlife and Fisheries Biology

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