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EDITED BY
Vasiliki Kioupi,
University of Leeds, United Kingdom

REVIEWED BY
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University of Education Upper Austria, Austria
Amanda Salvia,
Hamburg University of Applied Sciences, Germany
Rebecca Brunk,
University of Leeds, United Kingdom

*CORRESPONDENCE
Jesús López-Santiago
✉ jesus.lopez.santiago@upm.es

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Fostering sustainable development values among engineering students using Service-Learning

Jesús López-Santiago[1]*, Mónica de Francisco Alonso[2], Sergio Zubelzu-Minguez[1], Luis Ruiz-Garcia[1] and María Teresa Gómez-Villarino[1]

[1]School of Agricultural, Food and Biosystems Engineering, Universidad Politécnica de Madrid, Madrid, Spain, [2]Facultad de Educación, Universidad Nacional de Educación a Distancia, Madrid, Spain

In the majority of nations, environmental sustainability is an integral aspect of government policies, highlighting the criticality of equipping upcoming engineers with the necessary environmental awareness and skills to tackle this complex challenge. Higher education institutions assume a pivotal role in fulfilling this mission as their engineering programs aspire to generate graduates who possess the necessary competencies to effectively operate as "sustainable" engineers. Novel pedagogical methodologies, such as service learning, are currently being utilized to foster the cultivation of sustainable development values. Service-Learning represents a highly congruent approach to achieving Sustainable Development Goal (SDG) 4, insofar as it seamlessly integrates educational curricula with relevant community issues. As a result, it effectively contributes to the advancement of education for a sustainable future. This investigation sought to assess the impact of service learning projects developed in a rural school community on the boosting of social skills and environmental values among engineering students. The empirical evidence suggests that Service-Learning initiatives centered on environmental issues are efficacious in promoting the acquisition of social and environmental values among students. This, in turn, results in a positive transformation of their skill sets. Significantly, a substantial proportion of environmental engineering students who previously demonstrated a low awareness of these skills acknowledged their acquisition upon completion of the Service-Learning projects. Moreover, no less than 75% of the participants endorsed the attainment of each of the 11 competencies evaluated.

KEYWORDS
environmental sustainability, higher education institutions, Service-Learning, social and environmental values, environmental engineering, soft skills

1 Introduction

Higher education is widely recognized as a key driver in the global transition to environmental sustainability. As the world faces escalating environmental challenges such as climate change, resource depletion, and biodiversity loss, universities and other higher education institutions must prepare students to develop innovative solutions that address these issues. Engineering education is critical, as engineers are often at the forefront of designing technologies and systems that can mitigate environmental impacts.

The United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (quality education) and SDG 13 (climate action), underscore the importance of integrating sustainability into all levels of education (Prieto-Jiménez et al., 2021). Higher education plays a pivotal role in advancing these goals by equipping students with the skills, knowledge, and values needed to lead in a sustainable future. Filho et al. (2015) argued that universities must move beyond traditional disciplinary boundaries and adopt a holistic approach to sustainability education, incorporating interdisciplinary learning, practical experience, and collaboration with communities. This is particularly important in engineering education, where students must learn to balance technical expertise with an understanding of environmental ethics and social responsibility.

The European Green Deal (European Commission, 2019) further emphasizes the role of education in achieving the EU's goal of a climate-neutral continent by 2050. As part of this ambitious agenda, the EU is calling for the transformation of educational systems to ensure that all students, particularly those in technical fields such as engineering, develop the competencies required to contribute to the transition to a sustainable Europe. This aligns with the broader global trend towards Education for Sustainable Development (ESD), which aims to empower students to make informed decisions and take responsible action for environmental integrity, economic viability, and social justice, as outlined by UNESCO (2017).

Despite the growing recognition of these imperatives, engineering programs still face significant barriers to fully integrating sustainability into their curricula. Traditionally, engineering education has focused primarily on technical problem-solving, often neglecting the social, ethical, and environmental dimensions of engineering practice. Tejedor et al. (2018) suggested that embedding sustainability into engineering curricula through innovative teaching methods, such as Service-Learning and project-based learning, can significantly enhance students' understanding of sustainability and their ability to apply it in real-world contexts.

Moreover, research highlights that environmental education can have a profound impact on students' attitudes and behaviors. Cloquell-Ballester et al. (2008) found that the more qualified individuals are about environmental issues, the greater their commitment to sustainable practices, both personally and professionally. This finding was echoed by Ali et al. (2022), who emphasized that firms benefit significantly when employees are environmentally conscious, leading to enhanced corporate social responsibility (CSR) and improved environmental outcomes. Boyle (1999) similarly argued that incorporating sustainability into higher education creates a ripple effect as graduates enter the workforce and apply their sustainability knowledge to various sectors, fostering broader societal change.

Incorporating sustainability-focused curricula into engineering education is not only crucial for preparing students to tackle environmental issues but also for ensuring their employability in a rapidly evolving job market. As industries increasingly prioritize sustainability, engineers with a deep understanding of environmental issues and sustainable practices are in high demand. According to Obrecht et al. (2022), the integration of sustainability into higher education is essential to producing graduates who can meet the environmental challenges of the 21st century. They argued that engineering programs must shift from traditional approaches to a more systemic perspective, where sustainability is embedded in every aspect of the curriculum from theory to practice.

1.1 Barriers to engineering education

Engineering university studies programs are focused on preparing competent environmental awareness professionals. However, these programs present the following two important barriers (Isaias and Issa, 2013).

1.1.1 First barrier: lack of practical experience in environmental issues

A primary challenge in engineering education is the lack of practical, real-world experience in addressing environmental concerns (Gómez Villarino et al., 2021). While theoretical case studies are commonly used, they often fall short of providing the hands-on experience necessary for students to fully develop the practical skills required in their future roles (Lehmann et al., 2008). This gap becomes particularly significant in the field of sustainability, where engineers are required not only to have technical proficiency but also the ability to implement environmental solutions in real-world contexts.

Service learning (SL) has emerged as a pedagogical approach that can effectively bridge this gap by immersing students in real-world sustainability challenges while simultaneously developing their technical and soft skills. Previous sustainability-oriented Service-Learning projects, such as rainwater harvesting systems (Salam et al., 2019), graywater treatment designs (Swargiary, 2023), and renewable energy installations (Roakes and Norris-Tirrell, 2000), have shown promise in equipping engineering students with hands-on experience. These projects reflect the students' engagement in practical environmental solutions, fostering not only technical competencies but also teamwork, leadership, and problem-solving abilities, which are often underdeveloped in traditional curricula.

However, while these projects demonstrate success in providing practical learning experiences, they also reveal challenges such as the need for sustained mentorship, alignment with community needs, and integration within the academic curriculum to ensure continuity and deeper learning outcomes (Salam et al., 2019). Despite these challenges, service learning remains an adequate solution to overcome the lack of practical experience in engineering education. Students gain the opportunity to apply theoretical knowledge to tangible environmental problems by embedding these projects within the core engineering curriculum.

1.1.2 Second barrier: development of soft skills

Another significant barrier is the lack of development of soft skills, which are crucial for engineers working on complex, multidisciplinary projects that involve both technical and interpersonal challenges (Vukomanović et al., 2016). These soft skills, often referred to as "people-focused competencies," include leadership, self-management, and self-reflection; negotiation, integrity, and reliability; conflict and crisis management; results orientation, personal communication, teamwork, engagement, and relationships; and resourcefulness (Souza et al., 2022). The lack of these skills, such as leadership, teamwork, and communication, presents a significant challenge for engineering graduates entering the workforce (Caeiro-Rodríguez et al., 2021). Future engineers will need to possess a full range of these soft skills teams to successfully tackle complex technical challenges, create a more sustainable world, and work effectively in multicultural and multidisciplinary teams (Cukierman and Palmieri, 2014). The role of a modern leader is increasingly strategic and qualitative, rather than quantitative, emphasizing the importance of delegation, conflict management, problem solving, interpersonal relationships, and political skills (Tan, 1997). Engineering roles now require a balance of both hard and soft skills (Mateo et al., 2017). The importance of soft skills in engineering is essential to achieve success in environmentally sustainable development (Azim et al., 2010).

1.1.3 SL as a solution

SL is a pedagogical approach that integrates community service with academic learning, facilitating the development of both technical (hard) and interpersonal (soft) skills (Hart, 2021; Johnson and Notah, 1999). The method is based on the experiential learning cycle proposed by Kolb in 1984, which encompasses four stages, specifically concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 2014). Scholars have widely adopted this model as a theoretical framework for incorporating SL into course curricula (Roakes and Norris-Tirrell, 2000).

SL is frequently used as a pedagogical strategy to enhance student learning outcomes, such as critical thinking and problem-solving skills in higher skills (Astin, 2012; Castro et al., 2020). According to Bringle and Hatcher (1995), SL effectively connects classroom learning with real-world experiences, addresses community needs, and fosters relationships between college students and the community (Bringle and Hatcher, 1995, 1996).

The SL methodology typically involves three main components: preparation, action, and reflection. The preparation phase involves identifying community needs, setting learning goals, and preparing students for their service experience (Eyler and Giles, 1999; Kupietz et al., 2023). The action phase allows students to engage in community service, providing practical, hands-on experiences that enable them to apply classroom knowledge. Finally, the reflection phase requires students to critically assess their experiences and connect them to their academic learning (Brenner et al., 2023; Eyler and Giles, 1999; Jacoby, 1996).

SL can be applied across various disciplines, including education, business, engineering, social work, and health sciences (Salam et al., 2019). In these fields, SL offers students the opportunity to apply theories, concepts, and skills learned in the classroom to real-world situations (Astin, 2012). Furthermore, SL promotes the development of leadership skills, cultural competency, and a sense of civic responsibility among students (Bridgeland et al., 2006).

SL emerges as a promising solution to solve the barriers, offering students opportunities to engage with real-world environmental challenges through structured, community-based projects.

In the field of engineering, SL is particularly valuable for addressing environmental challenges such as water and air pollution, waste management, and climate change. A specific example in environmental engineering includes the design and implementation of sustainable infrastructure projects, such as rainwater harvesting systems, graywater treatment systems, and renewable energy systems (Salam et al., 2019). These projects not only provide students with hands-on experience in environmental problem solving but also directly address specific environmental needs within the community.

Integrating SL into the engineering curriculum can effectively bridge the gap between technical knowledge and the development of critical soft skills. As Keen and Hall (2009) suggested, involving students in real-world projects aimed at external clients is a powerful approach to achieving this goal.

The impact of SL is significant for both students and communities. For students, SL increases motivation and engagement, improves academic performance, and enhances critical thinking and problem-solving abilities (Lin et al., 2022). Research by Celio et al. (2011) highlighted that students involved in SL programs show notable improvements in self-esteem, perceptions of education, community involvement, interpersonal skills, and academic achievements (Celio et al., 2011). For communities, SL provides essential volunteer support, addresses unmet needs, and promotes overall community development, while also fostering stronger relationships between higher education institutions and the communities they serve.

Consequently, our primary objective in this research is to demonstrate how SL serves as an effective methodology for involving university students in real-world environmental issues, thereby enhancing their soft skills and promoting environmentally sustainable development.

2 Materials and methods

2.1 SLP case studies

The School of Engineering of Agronomy, Foods, and Biosystems trains future engineers through Bachelor of Engineering (B Eng.) degrees in Environmental Engineering, Agricultural Engineering, and Food Engineering. Specifically, students are trained in subjects such as environmental impact assessment (EIA), environmental engineering projects (EEPs), or environmental management systems (EMSs). These subjects emphasize the development of competencies linked to environmentally sustainable development. These soft skills must be developed by students during their coursework. Although theoretical environmental cases are often presented to simulate real professional experiences, they primarily serve as theoretical instruments that facilitate the practice of scientific and technical content. Consequently, it can be difficult for students to effectively develop their soft skills (Caeiro-Rodríguez et al., 2021).

Two SL projects (SLPs) were developed as the practical part of the EIA, EMS, and EEP courses. The SLP design was crucial, as they needed to offer students a compelling context for understanding environmental sciences. This included opportunities for team experience, sufficient time to learn and practice soft skills, personalized mentoring, exciting technical challenges, and robust community learning experiences (Coyle et al., 2005). These environmental experiences were carried out at the rural school named Isabel La Catolica (ISCA), located in a rural region of Spain. The SLPs were agreed upon and articulated together with the external stakeholders, ISCA, and the municipality. A university professor was the coordinator of both SLPs and they were funded by the University Polytechnic of Madrid (UPM). SLPs were carried out in 2021 and 2022. Table 1 shows the link among the B Eng Grades, subjects, and SLPs that were achieved.

2.1.1 Case 1: Ecocole 2030 project: "the path to a sustainable school" (ECO2030)

ECO2030 was the first SLP among UPM, ISCA, and the municipal government. The SLP consisted of designing and implementing an EMS for the primary education services in ISCA. Fourth-and third-year students of Agro-environmental Engineering Grade and Food

TABLE 1 Links among B Eng. grades, academic subjects, and Service-Learning projects.

B Eng. grade	Semester	Subject	Year	Service-Learning Projects
Agro-environmental engineering	8th	Environmental Management Systems	2021	Ecocole 2030 Project: The path to a sustainable "school"
Food engineering	6th	Environmental impacts assessment	2021	Ecocole 2030 Project: The path to a sustainable "school"
Agro-environmental engineering	7th	Environmental Engineering Projects	2022	StormTank: Collection and use of rainwater for irrigation of educational organic gardens

Engineering Grade developed this SLP as a practical part of the EIA and EMS subjects.

The students applied the technical methodology based on school data collection, mass and energy balance analysis, current situation diagnosis, identification of environmental aspects and impacts, and proposal of correction measures for environmental improvement. Furthermore, the implementation of environmental policies and objectives and its link with the Agenda 2030 and the SDG were studied. The students designed and implemented the EMS with a scope aimed at the educational management processes of the school. For 2 months, the students performed the following seven tasks: Facilitate the implementation of the environmental policy and environmental objectives, identify and quantify the environmental aspects of the educational management processes, determine the environmental impacts linked to the identified environmental aspects, identify the applicable environmental legislation, propose corrective measures to minimize severe environmental impacts, complete an environmental training program for school staff, and create a document system for the school's environmental management system.

In addition, the documents made for this environmental service were used by the professors to evaluate the practical work of the EMS subject. Students worked in five-member teams, and they had to deliver an EMS document system as a final product of their practical work.

At the same time, the student teams carried out a dissemination program about the results and corrective measures proposed in the EMS. To this end, they prepared and developed three workshops aimed at pupils in third, fourth, and fifth grade in May 2020. The design, realization, and pedagogical adaptation of the content of the workshops aimed at primary school pupils had the lead and advice of the teachers and the school director. These environmental education workshops helped increase pupils' knowledge of environmental issues and enhanced their pro-environmental attitudes (Kurokawa et al., 2023).

2.1.2 Case 2: StormTank project: "collection and use of rainwater for irrigation of educational organic gardens" (STORM)

STORM was the second SLP and consisted of the optimized design, construction, and commissioning of a 1,000-liter (1 m^3) tank to collect rainwater from the roof of the building of the kindergarten adjacent to the educational organic garden of the ISCA. The collected rainwater was used to irrigate the educational organic garden during the spring and summer seasons by connecting it to the installed drip system. This installation helped the schoolteachers in their practical natural sciences classes. Biology, ecology, and environmental awareness are the primary school subjects that benefit from the irrigation system carried out in the ecological gardens and the cultivation programming for the gardens developed by the university students. This SLP was a practical work in the EEP subject where the students learned the methodology of environmental engineering project formulation. Specifically, the students worked on the following five items: objectives, strategic alternatives, and goals; environmental project engineering (process engineering, design engineering, engineering of edification, infrastructure, and facilities); formulation; implementation and start-up plan; and budgeting.

University students designed a project consisting of a 1,000-liter water tank connected to the roof skirt of one of the buildings of the ISCA. In addition, the students prepared a Process Engineering, Implementation, and Start-up Report that included the design of the tank and all the components to implement an alternative organic garden for the winter period and/or the summer period.

These organic garden alternatives were designed according to the monthly average rainfall to irrigate only using the water stored in the tank.

The water tank installation and its roof connection were built by the municipality operators. Finally, the students developed three workshops to divulge the project among the school pupils. These workshops generated a school extracurricular activity for the management and reuse of water and its link with Sustainable Development Goal 6 to Ensure the availability and sustainable management of water and sanitation for all of Agenda 2030 (United Nations General Assembly, 2015).

2.2 Evaluation of SLP case studies

2.2.1 Data collection

Data collection was conducted using a pre-and post-survey methodology to measure students' self-perceived development of soft skills and environmental awareness. The surveys were administered at two time points: once at the beginning of the SL projects (before the students commenced their work) and again after the projects. A total of 75 students participated, with 61 students from the EMS course surveyed during the first semester of 2021 and 14 students from the EEP course surveyed during the second semester of 2022.

The surveys were distributed through the UPM Moodle Learning Management System (Moodle 4.0. Australia: Moodle Pty Ltd.), which is a digital platform for course delivery. The pre-survey was administered to gather baseline data on students' existing soft skills and environmental awareness, while the post-survey was used to evaluate any changes in these areas after the completion of the SLPs.

Both surveys had a 100% response rate, ensuring that all participants' data were collected and analyzed.

2.2.2 Survey design and reliability testing

The survey consisted of two main sections. The first section comprised five dichotomous (yes/no) questions designed to measure students' general perceptions about SL and its influence on their environmental awareness. These questions were administered at the last time point, after the SLP was achieved, to assess students' environmental commitment and understanding of sustainability. The questions are listed in Table 2.

The second section focused on assessing students' self-perceptions of their soft skills development. A total of 11 items were adapted from established scientific studies on soft skills (Aliu and Aigbavboa, 2021; Cimatti, 2016; Crosbie, 2005; Dixon et al., 2010; Munir, 2022; Schulz, 2007; Sparrow, 2018). The questions focused on various soft skills, including adaptability, capacity for concentration, creativity and imagination, effort, and emotional control. Respect and self-confidence were also emphasized, as they are critical for engineering students engaging in sustainability-oriented projects. These questions were administered at both time points (before and after the SLP) to assess shifts in students' self-perceptions of soft skills development. Case 1 questionnaires were given in the first semester of 2021, and case 2 questionnaires were given in the second semester of 2022. The response rate was 100%.

We opted to use a single-item measure for each of the 11 soft skills assessed. While it is widely recognized that multi-item scales are often preferable for measuring complex constructs (Hair et al., 2019; Hair et al., 2010), single-item measures are not uncommon in educational research, especially when the constructs are simple and clearly defined (Bergkvist and Rossiter, 2007). There is substantial evidence in the literature supporting the validity and reliability of single-item measures in certain contexts. For instance, Bergkvist and Rossiter (2007) demonstrated that single-item scales can achieve a level of predictive validity comparable to that of multi-item scales (Bergkvist and Rossiter, 2007), and previous studies in educational and social research have demonstrated that single-item measures can still yield valuable insights when evaluating skills or competencies (Croes and Bartels, 2021; Postmes et al., 2013; Reysen et al., 2013). The decision to use single-item measures was driven by several practical and methodological considerations:

TABLE 2 Questions and results about students' opinions regarding their SL work experience and their commitment to the environment and sustainable development at the end of the SLP.

Questions	No (%)	Yes (%)
Have you previously taken a subject with a service learning experience?	88	12
Have you felt comfortable working in a genuine experience in a rural community?	15	85
Has your environmental commitment increased after this community service experience?	18	82
Has the Service-Learning project helped you to better understand environmentally sustainable development?	21	79
Do you regard the Service-Learning approach as a fundamental element in your individual development as a prospective "sustainable" engineer dedicated to the principles of sustainable development?	22	78

- Clear and Unambiguous Constructs: The soft skills assessed in this study, such as effort, creativity and imagination, adaptability, or respect, are relatively well understood by students. These skills are commonly integrated into the curriculum and are familiar concepts in the field of engineering education. Research has shown that when constructs are unidimensional and clearly defined, a single-item measure can be as effective as a multi-item scale (Diamantopoulos et al., 2012; Sarstedt et al., 2016). The ability of students to reflect on their proficiency in these areas made single-item measures an appropriate choice.
- Minimizing Participant Burden: The context of the study cases study, in which students were engaged in SLPs in addition to their academic coursework, posed a unique challenge in terms of the time and effort required to complete the survey. Single-item measures reduced the cognitive load on participants, thus encouraging full participation and minimizing dropout rates. Research has shown that the use of single-item scales can lead to higher response rates in educational settings, particularly when participants are already managing multiple demands (Orben and Przybylski, 2019; Orth et al., 2018; Robins et al., 2001).
- Balancing Brevity and Precision: In educational assessments, there is often a trade-off between brevity and precision. While multi-item scales provide more detailed data, they can also lead to participant fatigue and increased non-response for longer surveys. Given the practical constraints of this study, we opted for brevity to maintain a high level of engagement from students, while ensuring that the core constructs were captured in a meaningful way. This approach has been validated in studies where time efficiency is paramount and the constructs are not overly complex (Diamantopoulos et al., 2012).

Responses in this section were recorded using a 4-point Likert scale ranging from "Not at all agree" (1) to "Strongly agree" (4). Although a 5-point Likert scale is typically recommended for surveys (Abascal and Grande, 2005), we opted for a 4-point Likert scale to eliminate the neutral option and force respondents to take a more definitive stance (Allen and Seaman, 2007; Wakita et al., 2012). Table 3 shows the skills and their explanations that were assessed in each of the questions. Each question is linked with a quantitative variable ($VARQ_n$, with n = 1 to 11) for statistical calculations.

Reliability testing was conducted on the two SLP case studies using Cronbach's alpha to measure internal consistency. A Cronbach's alpha score of 0.68 for case 1 and 0.71 for case 2 indicated an acceptable level of reliability for the items (Mallery and George, 2000). Additionally, factor analysis was used to ensure that the survey items accurately measured the intended constructs, confirming the validity

TABLE 3 Skills evaluated in each question.

Variable ($VARQ_n$) Soft professional skill	Explanation (as in questionnaire)
$VARQ_1$. Creativity and imagination	I can generate ideas, answers, and innovative and alternative proposals in relation to tasks and group work mainly related to planning and management of the environment and sustainable development.
$VARQ_2$. Self-confidence	I am confident in my own abilities to solve challenges regarding the environment and sustainable development. I discover my own capabilities, and it helps me to have confidence in myself.
$VARQ_3$. Concentration	I know how to keep my attention long enough to perform a task.
$VARQ_4$. Resilience	I know how to manage adversity and difficulties, with the ability to resist.
$VARQ_5$. Emotional control	I recognize and regulate my own emotions to properly adjust them to the needs of the moment and context, especially when I work with local communities.
$VARQ_6$. Effort	I insist on overcoming difficulties to achieve the intended achievements. This competence covers your physical, psychological, cognitive, and sociological aspects.
$VARQ_7$.Assertiveness	I know how to express my feelings, emotions, or thoughts freely and safely, without denying the rights of others and without others feeling attacked or manipulated.
$VARQ_8$. Adaptability	I adapt to any context, relationship, or situation in a positive way. Condition that allows me to accept and accommodate change, especially when I work with local communities.
VAQ_9. Empathy	I know how to perceive and understand the behavior, emotions, and feelings of another person group of people, group, or community.
$VARQ_{10}$. Respect	I have consideration for others according to their characteristics and personal and social situations.
$VARQ_{11}$. Self-criticism	I am willing to receive suggestions, ideas, evaluations, and criticism. I can self-analyze and recognize my own mistakes and limitations.

of the scale (Field, 2024). Responses were matched using unique student identifiers to ensure consistency and comparability between the pre-surveys and post-surveys, allowing for accurate tracking of changes in self-perception between the two time points.

2.2.3 Data analysis

The data analysis was performed using IBM SPSS Statistics (IBM Corp. 2020. IBM SPSS Statistics v 27.0. Armonk, NY, United States: IBM Corp.). (v. 27.0, IBM Corp., Armonk, NY, United States). Descriptive statistics, including frequencies, medians, and interquartile ranges (IQRs), were calculated for both the pre-survey and post-survey responses. The results were visualized using box plots to represent the distribution of scores before and after the SLPs. Non-parametric tests were used. Spearman's correlation coefficient and Kendall's Tau coefficient were calculated to assess relationships between students' soft skills and environmental values, with a significance level of $p < 0.01$ (Artusi et al., 2002) to explore correlations between variables.

The Yes/No questions from the first section of the survey were analyzed by calculating the percentage of positive and negative responses at both time points. Comparisons were made to determine any shifts in students' perceptions of SL and environmental commitment after participating in the SLPs.

2.2.4 Hypotheses

The main hypotheses evaluated in this study were hypothesis 1: "SL is an effective methodology for involving university students in real-world environmental issues," and hypothesis 2: "SL projects significantly enhance students' self-perception of their soft skills, which are critical for future work in promoting environmentally sustainable development."

3 Results

It is important to note that 88% of the students had not previously participated in a course that implemented an SL experience. This confirms the limited application of SL in the pedagogical approach of engineering studies, making it an innovative and relatively unfamiliar methodology. As such, the integration of SL has proven to be beneficial for students and should be further expanded to other subjects to promote the development of critical competencies that enhance environmental awareness. The results of the first section of the questionnaire are displayed in Table 2, which includes data collected after the SL project.

The second section of the questionnaire focused on the students' perceptions of their soft skills development. The analysis included the calculation of the median and interquartile range (IQR) for each variable (VARQn), representing each soft skill, in both study cases (pre- and post-SL). The Kolmogorov–Smirnov test was used to assess the normality of each variable's distribution, with the null hypothesis being that the distribution of VARQn is normal with the mean Xn and standard deviation σn. For all variables in both study cases, the null hypothesis was rejected, indicating that the variables follow a non-parametric distribution.

The data were compared to evaluate the students' self-perception before and after the project to assess the impact of the SL project on soft skills development. The results in Table 4 provide a detailed analysis of the self-perception of soft skills in the two cases, Ecocole (case 1) and StormTank (case 2), before and after the Service-Learning project (SLP). Overall, the analysis reveals that 7 out of the 11 soft skills showed no change in their median and interquartile range (IQR) values, indicating consistent perceptions before and after the SLP.

TABLE 4 Median and IR results for cases 1 and 2 before and after environmental service.

Variables $VARQ_n$		Case 1. Ecocole					Case 2. StormTank			
Professional soft skills	Median	Median	IR Q25–Q27	IR Q25–Q27	IR Q25–Q27	Median	Median	IR Q25–Q27	IR Q25–Q27	IR Q25–Q27
	Before	After	Before	After	Change	Before	After	Before	After	Change
Creativity and imagination	3	3	[2–3]	[3–4]	Yes	3	3	[2–4]	[3–4]	Yes
Self-confidence	3	3	[3]	[3–4]	Yes	3	3	[2–3]	[3–4]	Yes
Capacity of concentration	3	3	[2–3]	[2–4]	Yes	3	3	[2–3]	[3–4]	Yes
Resilience	3	3	[3]	[3–4]	Yes	3	3	[2–4]	[3–4]	Yes
Emotional control	3	4	[3–4]	[3–4]	No	3	3	[2–3]	[3–4]	Yes
Effort	3	3	[3]	[3–4]	Yes	3	4	[3]	[3–4]	Yes
Assertiveness	3	3	[3–4]	[3–4]	No	3	3	[3–4]	[3–4]	No
Adaptability	4	4	[3–4]	[3–4]	No	3	3	[3]	[3–4]	Yes
Empathy	4	4	[3–4]	[3–4]	No	4	4	[3–4]	[3–4]	No
Respect	3	4	[3–4]	[4]	Yes	4	4	[4]	[3–4]	Yes
Self-criticism	3	3	[3]	[3–4]	Yes	3	3	[3–4]	[3–4]	Yes

Three soft skills demonstrated changes in the median but maintained the same IQR, suggesting that while overall perceptions improved, the distribution of responses remained stable. One skill exhibited the same median but a shift in the IQR, pointing to increased variation in self-perception among the students.

For soft skills such as creativity and imagination, self-confidence, capacity of concentration, and resilience, both cases reported consistent medians and IQRs before and after the SLPs. The students' perceptions of these skills remained stable, as reflected by their scores on the Likert scale. In contrast, emotional control showed a notable improvement in Ecocole, where the median increased from 3 ("Agree") to 4 ("Strongly agree"), signaling a significant boost in students' self-perception of emotional control. However, in StormTank, the median remained the same, but the IQR expanded.

Respect also improved in Ecocole, with the median shifting from 3 to 4, indicating a stronger self-perception of this skill post-SLP. In StormTank, effort saw an increase in the median from 3 to 4, suggesting improvement in students' efforts after the project. Other skills such as assertiveness, empathy, and self-criticism remained constant in both cases, with no significant changes in median or IQR values, showing no major shifts in these areas.

These results highlight that, while many soft skills remained stable across both cases, certain skills such as emotional control, respect, and effort experienced notable improvements, particularly in Ecocole. The increase in IQR for some skills suggests that while the overall median perception of the group did not change, individual responses varied, indicating different personal experiences of the SLP.

The correlations between the variables related to the 11 soft skills were analyzed using Spearman's correlation coefficient (ρ) and Kendall's Tau coefficient (τ), with a significance level of $p < 0.01$ (Akoglu, 2018). Table 5 presents the results of Spearman's correlation coefficient (ρ) and Kendall's Tau coefficient (τ), which were used to examine the relationships between the soft skills measured before and after the SLP. These coefficients assess both the strength and direction of the associations between the variables (e.g., adaptability, creativity and imagination, effort, and self-confidence), offering insight into how these skills are interrelated. The analysis was conducted at a significance level of $p < 0.01$, meaning that correlations were considered statistically significant if there was less than a 1% chance that the observed relationships occurred by random chance. Each pair of soft skills was compared to determine if improvements in one skill were associated with improvements in another. For example, if students who reported an increase in creativity and imagination also reported an increase in assertiveness, this would result in a positive correlation between these two variables.

All of the pairs of professional skills reported in the table show statistically significant correlations, meaning that there are meaningful relationships between these skills. For example, skills such as self-confidence and emotional control exhibited a high positive correlation, indicating that students who improved in one of these areas also tended to improve in the other.

4 Discussion

The SL methodology effectively engaged students in community service activities while simultaneously integrating academic learning. The data collected from the student self-report surveys indicated that hypothesis 1 was supported. Students found SL to be an engaging and effective way to apply their theoretical knowledge to real-world sustainability problems. The novelty of the approach, given that 88% of the students had no prior experience with SL, underscores its potential for enhancing engagement in engineering education. In terms of hypothesis 2, the analysis of the pre-and post-SLP data does not allow for the matching of individual student responses, so the conclusions of this study should

TABLE 5 Spearman's correlation coefficient (ρ) and Kendall's Tau coefficient (τ) for $VARQ_n$ at a significance level of $p < 0.01$.

Correlated variables $VARQ_n$ significance level $p < 0.01$	τ	ρ
Case 1 Ecocole		
Creativity and Imagination—Self-confidence	0.590	0.612
Creativity and Imagination—Effort	0.523	0.555
Creativity and Imagination—Assertiveness	0.709	0.793
Self-confidence—Resilience	0.552	0.598
Self-confidence—Emotional control	0.681	0.769
Self-confidence—Effort	0.513	0.547
Self-confidence—Assertiveness	0.593	0.619
Self-confidence—Adaptability	–	0.529
Capacity of concentration—Respect	0.519	0.550
Resilience—Emotional control	–	0.544
Emotional control—Adaptability	0.571	0.620
Assertiveness—Empathy	0.575	0.614
Adaptability—Empathy	0.588	0.617
Adaptability—Respect	0.553	0.570
Empathy—Respect	0.608	0.627
Case 2 StormTank		
Empathy—Resilience	–	0.714
Empathy—Self-criticism	–	0.852

be interpreted within the framework of a correlational rather than a causal analysis.

This means that we cannot assert that participation in the SLP directly caused the observed changes in students' self-perceptions of soft skills. However, the results indicate a positive relationship between participation in the SLP and improvements in self-perceptions of several key competencies. A significant association was found between participation in the SLP and an increase in perceptions of skills like creativity and imagination, self-confidence, concentration, and effort.

While these findings suggest that the SLP may be linked to the development of these skills, we cannot confirm that the SL was the sole factor responsible for these changes. Specifically, students' self-perceptions of 10 out of the 11 evaluated competencies showed significant improvement, with more than 75% of participants reporting positive development in essential skills. These results suggest that the SLP may have provided students with a practical context in which to apply their academic knowledge, which in turn appears to be associated with improvements in their perceptions of professional skills. However, due to the correlational nature of the analysis, this association should not be interpreted as evidence of causality.

Our findings show that SL was perceived as an effective method for the value of experiential learning. Kolb's (1984) experiential learning theory emphasized that learning is most effective when students can apply theory to practice in real-world contexts (Kolb, 1984). SL provides this opportunity by allowing students to work directly with communities to solve environmental problems.

Our focus was on students' perceptions of their engagement and skill development. Future research could benefit from incorporating measures of environmental behavior to assess whether the increased engagement observed in SL projects translates into long-term actions. Additionally, our findings resonate with studies that highlight the value of community-based learning in enhancing students' understanding of complex social and environmental challenges. Eyler and Giles (1999) argued that SL not only deepens students' understanding of course content but also helps them develop a more profound connection to the community, fostering a sense of responsibility and civic engagement (Eyler and Giles, 1999). In our study, students worked with rural school communities, which likely helped them understand the real-world implications of sustainability and environmental protection.

The significant improvements in students' self-perceived soft skills, as seen in our findings, align with previous research showing that SL projects enhance critical professional competencies. Marshall et al. (2015) found that students who participated in SL reported higher levels of confidence in applying their knowledge to practical problems, which in turn improved their leadership, teamwork, and communication skills (Marshall et al., 2015).

This is consistent with Barth et al. (2014), who highlighted the role of SL in developing not only academic skills but also soft skills, such as critical thinking, problem solving, and empathy. In sustainability education competencies (Barth et al., 2014). These skills are crucial because they enable students to collaborate effectively across varied environmental disciplines and with different stakeholders. Our study's findings that students felt more competent in these areas after participating in SL support the thesis that SL bridges the gap between theoretical knowledge and practical application.

Moreover, Bowie and Cassim (2016) also found that SL helps students develop a more holistic understanding of their professional responsibilities and competencies. Students can see how their technical skills can be applied to solve societal problems by working on real-world projects, which enhances their sense of civic responsibility. Our findings mirror this, as students reported a stronger sense of purpose and engagement with community-focused solutions.

Our findings are in line with a growing body of literature that highlights the importance of integrating sustainability into engineering curricula. Nikolić and Vukić (2021) argued that sustainability education is essential for preparing engineers to tackle the complex environmental challenges of the future. They advocated for a curriculum that not only teaches technical knowledge, but also emphasizes the development of skills such as collaboration, leadership, and ethical responsibility. Our study supports this approach, as the SL projects gave students practical experience while fostering these critical soft skills.

Similarly, Salam et al. (2019) found that SL can lead to positive outcomes for all stakeholders involved—students, faculty, and community members (Salam et al., 2019). In our research, students gained practical experience in environmental management, while the rural school communities benefited from the implementation of sustainable solutions. This symbiotic relationship underscores the potential for SL to generate mutually beneficial outcomes, as highlighted by Roakes and Norris-Tirrell (2000), who showed that SL projects often result in lasting improvements for both students and the communities they serve.

The findings of our research have significant implications for engineering education. First, the positive effects of SL on student engagement and skill development suggest that SL should be integrated more broadly into engineering programs. By embedding SL into the curriculum, educators can provide students with opportunities to apply their academic knowledge to real-world problems, which enhances both their technical and professional skills.

Additionally, the development of soft skills is crucial for engineers working on sustainability projects. These skills enable engineers to work effectively with diverse teams, including community members, policymakers, and other stakeholders. Given the interdisciplinary nature of sustainability challenges, the ability to collaborate across sectors is becoming increasingly important. As such, SL can help prepare future engineers for leadership roles in sustainability by providing them with the competencies they need to navigate complex, multi-stakeholder environments.

Furthermore, this study underscores the importance of community engagement in sustainability education. Students gain a deeper understanding of the social dimensions of environmental challenges as they work directly with communities. This aligns with Eyler and Giles (1999), who found that SL projects enhance students' sense of civic responsibility by connecting them with real-world problems that require practical solutions. Engineering programs should therefore seek to build partnerships with local organizations to create meaningful, community-based learning opportunities for their students.

4.1 Limitations

While our research offers valuable insights into the impact of SL on engineering students, it is important to acknowledge several limitations. First, the research relied solely on self-reported survey data, which may introduce bias, as students may overestimate or underestimate their development in certain competencies. To address this limitation, future studies could incorporate additional methods such as interviews or focus groups to provide a more in-depth understanding of students' experiences and to triangulate the findings. Second, while we observed significant improvements in students' soft skills, the study did not include direct measures of environmental awareness or behavior change. Although we suggest that the development of soft skills may contribute to future environmental protection efforts, future studies should explicitly measure these outcomes to better assess the long-term impact of SL on students' environmental values and actions. The third limitation of the study is the inability to pair individual student's pre-test and post-test responses for the same skill, which would have allowed for a more accurate assessment of changes using the Wilcoxon signed-rank test. Instead, we used Spearman's and Kendall's Tau correlations to explore the associations between soft skills variables. Future research should aim to track paired responses to better assess the changes in students' soft skills over time. Finally, the design of our study did not allow for a direct comparison of different types of SLPs. Future research could explore whether the nature of the project (e.g., environmental vs. social) leads to different outcomes for students in terms of skill development and awareness. The relatively small sample size (75 students) limits the generalizability of the findings, and the short duration of this study limits the ability to assess the long-term impact of SL on students' competencies and sustainability practices.

5 Conclusion

The environment is becoming increasingly important in our society. Public institutions and private companies require future professionals who are committed to environmental respect and sustainable development.

It is the university's moral and social responsibility to facilitate the development of students who embody values aligned with the principles of environmental respect and sustainable development. To accomplish this objective, novel methodologies must be devised to help students cultivate these values and acquire the requisite competencies for their practical application.

SL is a valuable methodology that can be applied in higher education to enhance student learning outcomes and benefit communities. Through the integration of community service, academic instruction, and reflection, SL can provide students with opportunities to apply their knowledge, develop their skills and values, and contribute to their communities. In this context, SLPs contribute to Sustainable Development Goal 4 by promoting quality education for sustainable development. This is achieved by incorporating sustainability concepts and practices into the academic curriculum and by engaging students in community service activities that promote sustainable behaviors and values. By integrating these elements, SLPs help students to develop a deeper understanding of the interconnectedness of environmental, social, and economic systems and the importance of sustainable development in achieving global goals.

Further research endeavors can be conducted by using SLPs with local communities to address different areas of quality education. These may encompass human rights education, gender equality education, promotion of a culture of peace and non-violence, global citizenship, intercultural education, and inclusive education.

Data availability statement

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

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the patients/participants or patients/participants legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

JL-S: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. MF: Formal analysis, Methodology, Writing – review & editing. SZ-M: Supervision, Validation, Visualization, Writing – review & editing. LR-G: Methodology, Supervision, Validation, Writing – review & editing. MG-V: Methodology, Supervision, Validation, Writing – review & editing.

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Conflict of interest

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1408896/full#supplementary-material

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