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Integrating sustainability perspectives through laboratory work on education of water treatment

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Abstract

Integrating sustainability perspectives into scientific and technical education is essential for equipping students with the knowledge and competencies needed to address complex sustainability challenges. This study aimed to link theoretical understanding of sustainability with laboratory-based learning. It presents the design, implementation and evaluation of a sustainability-focused teaching intervention in the course Water Treatment Systems - Drinking Water at a Swedish university. This distance-learning course provides foundational knowledge of drinking water treatment through an online learning platform and includes two days of on-campus laboratory work. To integrate sustainability perspectives, additional literature on the Sustainable Development Goals (SDGs) was combined with recorded lectures to form a standalone theoretical module. This was incorporated into the obligatory digital pre-laboratory session (Session 1). As an additional preparatory measure, SDGs icons were included in the laboratory instructions to highlight procedures relevant to SD. Depending on the year of implementation, group discussions in Session 2 were conducted either on campus immediately after the laboratory work (2024) or as a separate digital session one week later (2025).
Students rated both the Session 1 and Session 2 highly, and 88% reported that the integrated discussions enhanced their understanding of the link between laboratory work and sustainability. Student reflections indicated an initial focus on SDG 6 (Clean Water and Sanitation), which gradually expanded to encompass additional SDGs, highlighting that water-related issues are relevant to all 17 goals. The discussions emphasized the need to consider interactions across multiple sectors and scales, which motivated the introduction of the nexus concept, emphasizing interlinkages between interconnected systems. Overall, the results suggest that combining theoretical preparation, guided discussions, and sustainability-labeled laboratory materials enhances student engagement with sustainability issues and broadens students' multidisciplinary understanding.

Keywords: *Sustainability, laboratory-based learning, Sustainable Development Goals, higher education, water analysis*

1. Introduction

Education has been regarded by UNESCO both as one of the Sustainable Development Goals (SDG 4) and as a central instrument for supporting and implementing all of the SDGs [1]. In line with this, the national regulatory framework for higher education in Sweden explicitly requires higher education institutions to promote sustainable development (SD). According to the Swedish Higher Education Act (1992:1434) "Higher education institutions shall, in their activities, promote SD, meaning that present and future generations are ensured a healthy and sound environment, economic and social welfare, and justice" (Chapter 1, Section 5) [2]. The importance of education in SD has further been emphasized through the initiation of programmes that promote and implement Education for Sustainable Development (ESD) [3, 4]. ESD aims to "empower learners to take informed decisions and responsible actions for environmental integrity, economic viability and a just society for present and future generations." [1].
ESD does not only focus on integrating sustainability-related content in education, but also emphasizes sustainable teaching methodologies such as participatory teaching and learning, student-centered learning as well as action- and problem-oriented approaches [5]. One of the central pillars of ESD is the reorientation of existing education to address SD and to provide training that facilitates the acquisition of sustainable practices [6]. Education in this context should be transformative and lead to positive changes in the behavior of the learners. Moreover, ESD should be interdisciplinary, embedded across the curriculum, and designed to promote critical thinking and problem solving, involve participatory decision-making and focus on the applicability on day-to-day personal and professional life [7, 8].

Despite the strong emphasis on ESD, translating sustainability principles into concrete laboratory-based teaching practices remains a pedagogical challenge, particularly within scientific and technical education. Existing approaches commonly focus on the development of dedicated “green” or sustainability-themed laboratory exercises, rather than embedding sustainability considerations systematically across all routine laboratory activities [9]. Practical laboratory environments, however, offer significant opportunities to connect sustainability concepts to professional practice particularly in scientific and technical education. In addition, the sustainable practices may be transferred to future working environments as students progress in their professional careers. Coupling sustainability principles with laboratory work has the potential to influence both students’ and teachers’ attitudes and knowledge related to SD [10, 11].

Access to clean water is one of the central pillars of Sustainable Development Goal 6 (SDG 6) [12], and several of the Sweden’s 16 Environmental Quality Objectives, which describe the desired condition of the Swedish environment and guide national environmental work, are closely linked to water-related issues [13]. Therefore, it is important to foster sustainable attitudes regarding water use and to highlight the concept of hidden or virtual water [14, 15], defined as the water used directly and indirectly to produce a good or service, but does not appear in the finished product or in direct consumption. Furthermore, experimental laboratory work, even including analyses related to water monitoring, is often characterized by a high water footprint, associated directly with water use during the analysis and with virtual water associated to the manufacture of laboratory materials and chemicals [16-19]. Awareness of these aspects is particularly relevant for professionals working with environmental issues related to water or water treatment processes.

This paper examines the implementation and evaluation of a teaching intervention in a drinking water course within theprogram of Sustainable water Supply and Wastewater Technology for Technitians program at Kristianstad University. The intervention integrated sustainability concepts into existing laboratory exercises rather than introducing dedicated sustainability-themed experiments. The pedagogical goal was to increase students’ competence in sustainability by linking abstract sustainability concepts to concrete professional activities through hands-on laboratory work. The study aims to evaluate whether integrating SD concepts into existing laboratory practices positively influences students’ self-reported knowledge of water-related sustainability issues.

2. Course Context and Design of the Teaching Module

The course "Vattenreningsteknik – dricksvatten" (Water Treatment Systems- Drinking Water) aims to provide students with foundational knowledge of drinking water treatment processes. The course is delivered as a distance learning course via an online learning platform. Figure 1 provides a schematic overview of the original course structure and the two redesigned versions (2024 and 2025), highlighting how the Water and Sustainable Development (W&SD) module was progressively integrated into both the preparatory and laboratory-based sessions.

Before the intervention, the course included a laboratory component with an informative segment introducing the theoretical pre-laboratory preparation (Session 1), completed individually prior to the on-campus meeting. Session 2 consisted of a two-day on-campus laboratory component that included practical analyses of various parameters in the students’ own drinking water, followed by group discussions immediately after the laboratory work (Figure 1). SD was primarily addressed through recorded lectures and assessed as part of the written examination, with limited integration into laboratory activities.

Several preparatory measures were undertaken to support a sustainability-focused redesign of the laboratory component and to strengthen the alignment between theoretical content on SD and the practical laboratory work. As part of the redesigning, a standalone theoretical module entitled "Water and Sustainable Development (W&SD)" was introduced. This module supplemented the existing recorded lectures with additional literature on SD [20], which students completed prior to Session 1. The laboratory manual, used during the on-campus practical work, was revised to explicitly integrate SD perspectives. Key stages of the laboratory procedures that could be related to the United Nations Sustainable Development Goals (UN SDGs) were marked with SDG icons, following pedagogical principles developed within an internal higher education project at Kristianstad University [21] (Cabaleiro-Lago et al. paper in preparation).

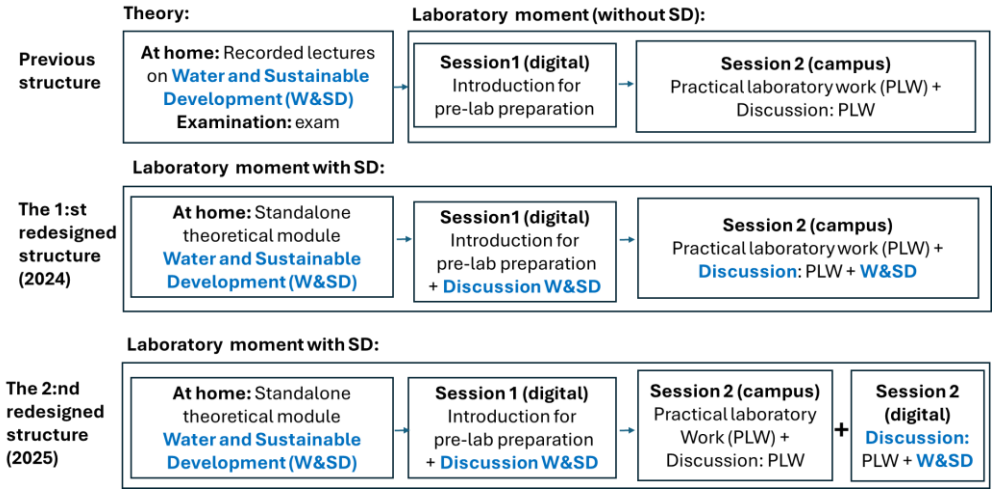

Fig. 1. Schematic overview of the original and redesigned course structure, illustrating the integration of the Water and Sustainable Development (W&SD) module to the practical laboratory work (PLW).

The obligatory digital session, Session 1, conducted via Zoom, was extended in the redesigned course structure from one hour to two hours (Figure 1). Session 1 comprised two main components. The first informative component introduced the theoretical pre-laboratory preparation, as in the previous curriculum, and furthermore, explained that the SDG icons were integrated into the laboratory instructions. These icons were used to indicate laboratory procedures with relevance to ecological, economic and social dimensions of SD at both local and global scales. The second component of Session 1 focused on discussions of W&SD. Students were provided with structured discussion questions and initially discussed in small breakout groups (4–5 students). This was followed by a plenary discussion in which insights from each group were shared and collectively discussed.

Session 2 in the new design consisted of 1.5 days of practical laboratory work followed by a half-day dedicated to group discussions (Figure 1). Depending on the year of the intervention, the discussion was conducted on campus immediately after the laboratory work (2024) or as a separate digital session one week after the laboratory work (2025).

To support students' preparation and to integrate SD perspectives, the discussion questions in Sessions 1 and 2 were carefully designed to cover different aspects within SD. In Session 1, discussion questions explored the conflicts that might arise in water supply and how lifestyle choices affect access to clean drinking water. Discussions extended to water availability in light of climate change and urbanisation, covering topics like global water access, water conflicts, and how consumer behaviour might need to adapt. Each question (Table 1) was explored across different levels (local, regional, national, and global), as well as different sustainability dimensions (environmental, social, and economic) and perspectives (individual, societal, and professional) within SD.

Table 1: Selected discussion questions for Sessions 1 and 2

Session 1
How do the Sustainable Development Goals (SDGs) and individual lifestyle choices, including virtual water use, contribute to sustainable water management?
How is water availability affected by climate change and urbanisation?
How can access to clean water affect humans in a positive or negative way? What risks are associated with raw water contamination and its effects on health?
How clean does water need to be for different purposes?
Session 2
Which analyses used the most chemicals/energy/time and which were most sustainable?
Which laboratory steps impact SD and how could these steps be modified to improve sustainability?
What challenges arise when analysing drinking water in low-resource settings compared with Sweden, and what ethical considerations are involved?
Is drinking water reasonably priced in Sweden, and what are the consequences of higher prices?

Similar questions and thematic areas of SD were taken again up during Session 2. In addition, the feasibility of conducting water analyses in different countries, the costs of laboratory equipment and

reagents, and sustainable alternatives for water quality assessment were addressed within the same sustainability dimensions. In particular, the professional perspective could be more easily linked to the activities carried out during the laboratory sessions (Table 1).

3. Data collection and analysis

The design changes, intended to strengthen the integration of sustainability perspectives throughout the laboratory sessions and to support deeper student reflection, were implemented on two occasions with 17 students enrolled in 2024 and 9 students in 2025. Student perceptions of the revised design were evaluated using an anonymous survey administered via Microsoft Forms. The survey aimed to capture students' prior knowledge, perceived learning outcomes and evaluation of the teaching activities. All students participating in the course activities were invited to respond voluntarily and anonymously and the survey was distributed after each session.
The surveys included open-ended questions (Table 2), multiple-choice questions, and 5-point Likert-scale items, where 1 indicated low agreement or satisfaction and 5 indicated high agreement or satisfaction. The survey was conducted in Swedish and English translations of the questions and students' responses are provided in this paper.

Table 2. Open-ended survey questions used to collect qualitative student reflections

Session	Survey question
1	What aspects of today's online session did you find particularly positive? Please give an example.
1	Please reflect on the session: Was there any information or fact that surprised you? What did you learn from this activity?
2	What were the most interesting aspects, facts, activities, or knowledge that you learned, became aware of, or carried out during the on-campus laboratory sessions?

Survey data were analysed using descriptive statistics. Mean values were calculated for Likert-scale items. Open-ended responses, when applicable, were reviewed and used to provide illustrative qualitative insights. Ethical approval was not required for this study as the study involved anonymous, voluntary student feedback collected as part of routine educational evaluation. All participants were informed about the purpose of the study and consented to the use of their responses for research purposes.

4. Results

4.1 Results and student reflections from Session 1

Survey responses indicated varying levels of prior knowledge of Sweden's 16 Environmental Quality Objectives and the SDGs among students (Figure 2). Four percent of the students reported being well-informed due to their jobs, 23% had encountered these topics in a previous coursework, and 58% indicated general familiarity with without in-depth understanding. Overall, familiarity with Sweden's 16 Environmental Quality Objectives and the SDGs was higher than understanding of their specific relevance to water-related issues.

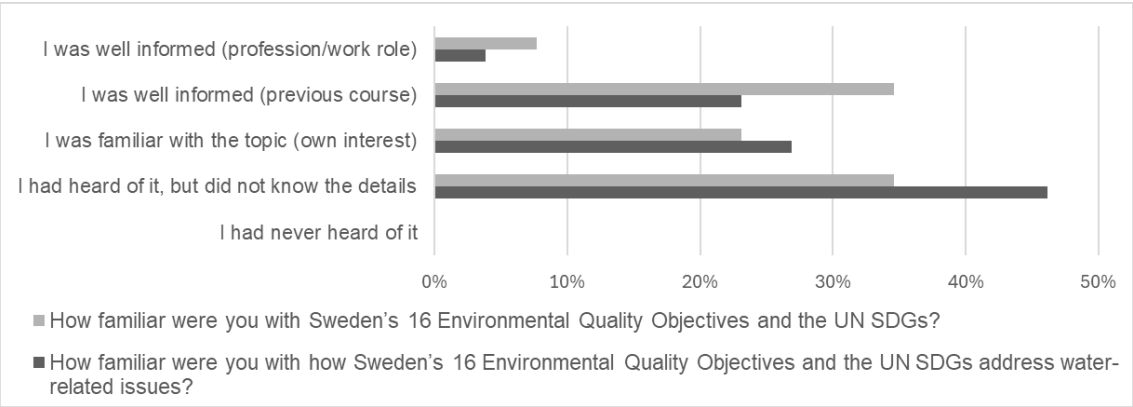

Fig. 2. Students' self-reported familiarity with Sweden's 16 Environmental Quality Objectives and the UN SDGs. (n= 17 year 2024 and n= 9 year 2025)

On a 5-point Likert scale (1 = not much, 5 = very much), students rated their increased understanding of water-related issues at both the national and global levels with mean values of 3.9 and 3.6 for 2024 and 2025, respectively, which they attributed to the course materials and the digital sessions. Self-reported engagement during the digital session was rated at 4.2 and 3.9, while the pedagogical and content quality of the session was rated at 4.4 and 3.1 (Table 3).
Qualitative data from open-ended survey responses and students' reflections during the session provided additional insights into their learning experiences. Students described the group discussions as enjoyable and engaging, particularly because being part of a group encouraged active participation. Different viewpoints emerged during the smaller group discussions, making the sessions both interesting and informative. Discussions were lively, especially regarding "invisible" (virtual) water, which provided a deeply revealing moment for five students. Several students expressed a wish for more time or additional opportunities for discussion and suggested that preparatory materials could further help them engage more deeply.

Table 3: Students' self-reported learning outcomes and perceptions after session 1. Mean score in Likert scale 1-5 (1 = *not much* / *can be improved*, 5 = *very much* / *very good and interesting*).

Survey question	**Mean score 2024 (n=17)**	**Mean score 2025 (n= 9)**
To what extent did the course materials increase your knowledge of how water-related issues are linked to Sweden's 16 Environmental Quality Objectives and Agenda 2030 (UN SDGs)?	3.9	3,6
To what extent did the course materials increase your knowledge of important global water-related issues?	3.9	4,3
To what extent did the Zoom meetings increase your knowledge of water-related issues at the national and international level?	3.9	3,4
How would you rate your own contribution during the digital session?	4.2	3,9
How would you rate Zoom meeting for Session 1 overall?	4.4	3.1

4.2 Results and student reflections from Session 2

Regarding the laboratory session, students rated the hands-on water analysis work highly, with mean score of 4.5 and 4.2 out of 5. Students reported that the laboratory work contributed to their understanding of drinking water quality and the relevance of different analytical parameters (Table 4). Students also indicated that the combination of Session 1 and Session 2 increased their awareness of how water quality analyses and lab work can be linked to Sweden's 16 Environmental Quality Objectives and the SDGs (mean value 3.4 and 4.0; Table 4).
Students found the final whole-group discussion particularly valuable, noting that brought forward perspectives and angles they had not previously considered such as "*what can we do and must do in the future to avoid risk of running of water*". In response to the open-ended question, "What were the most interesting things, facts, or activities you learned or performed during on-campus lab days?" students highlighted the water analysis, microbiological parameters, and the hands-on experience with professional laboratory equipment. Several students also found it interesting to see the differences in the results and the amount of work required for each analytical method. The use of atomic absorption spectroscopy for metal analysis of water samples was also mentioned.

Table 4: Students' self-reported learning outcomes and perceptions for Session 2. Likert scale 1-5 (1 = not much / not satisfied, 5 = very much / very satisfied).

Survey question	**Mean score 2024 (n=8)**	**Mean score 2025 (n= 6)**
To what extent did the laboratory activities increase your knowledge of issues related to your own drinking water (e.g. water quality and drinking water supply)?	4.5	4.2
To what extent did the on-campus laboratory sessions increase your knowledge of the analysis of different water parameters?	4.3	4.2
To what extent did the on-campus laboratory sessions increase your understanding of how laboratory analyses can be linked to Sweden's 16 Environmental Quality Objectives and Agenda 2030 (UN SDGs)?	3.4	4.0
How would you rate your own contribution during the on-campus laboratory sessions?	4.5	4.3
How would you rate the laboratory session?	4.3	4.5

Students rated their personal contributions during the laboratory session with mean scores of 4.5 and 4.3 out of 5, while the pedagogical and content quality of the on-campus session received a mean value above 4 (Table 4).
The students from course spring 2024 suggested that the final group discussion linking sustainability issues and the laboratory work (Session 2) could be held as a separate, longer digital session. According to the students, this format would allow more time for initial small-group discussions followed by a deeper whole-group collective reflection. Following those suggestions, in spring 2025 the discussion for Session 2 was conducted as a digital session a week after the laboratory. In response to a question regarding the format of the discussion in Session 2, student responses were consistent throughout 2024 and 2025. The most frequently selected option (54% of respondents) was a mandatory half-day digital discussion after the on-campus laboratory session, indicating that students value structured reflection following practical work. Additional preferences included allocating more discussion time during the on-campus session by reducing analytical workload (23%), as well as extending the on-campus session (23%). Overall, the results highlight the importance of dedicated time for sustainability-focused discussion rather than integrating them into already time-constrained activities.

5. Discussion

According to the principles of ESD, sustainability should be interdisciplinary and integrated into the curriculum. However, many educational interventions are restricted to isolated moments, often driven by particularly engaged staff or teachers who feel confident in sustainability concepts. Isolated actions may lead to limited integration of sustainability concepts with the main theoretical content of the course and to limited understanding of relevance of sustainability principles for students' future professional roles [22, 23]. Re-designing an entire curriculum from a sustainability perspective is challenging, particularly as many teachers and lecturers have not received formal training in sustainability, transformative learning or ESD [24, 25] even though the attitudes towards incorporating sustainability in teaching are generally positive [26].
The present study shows an accessible approach to the integration of sustainability concepts into existing curriculum. By analysing existing laboratory course materials from a SD perspective, sustainable concepts could be linked to real-world problems, one of the central pillars of ESD. This analysis was conducted collaboratively and involved discussions among course lecturers regarding the relevance of specific analytical methods and laboratory procedures in relation to the UN SDGs. Importantly, the workload associated with the intervention was considered low and was distributed between preparation of teaching materials and routine course administrative tasks regarding the digital group sessions. Based on students' feedback, the instructional design could be further improved by providing some of the discussion questions as preparatory material prior to the sessions.
One of the usual models for ESD in the natural sciences involves adopting principles from sustainable practices for hands-on laboratory work [26]. However, when such practices are not connected to broader discussion or to real-world sustainability challenges, they may contribute poorly to the development of key competencies in sustainability [7]. In the present study, by integrating sustainability aspects in the laboratory instructions and introduced dedicated moments for discussion and reflection, the laboratory sessions were transformed into a learning activity that presents key elements of experiential learning, active experimentation, reflective observation, and abstract conceptualization. Through guided reflection and discussion students linked the practical work not only to sustainable practices within the laboratory environment but to broader global sustainability challenges. During the discussions, students answered and justified the questions by linking their reasoning to economic, social, and environmental perspectives. The discussions revealed that relating water issues to the SDGs is complex, as water is relevant to all 17 SDGs. With the teachers' support, students identified both synergies and trade-offs among the goals, highlighting the need to simultaneously consider interactions across multiple sectors and scales.This complexity motivates the introduction of the nexus concept, which emphasizes interlinkages between distinct systems. As shown by Estoque [27], water-related challenges can be understood through a six-node nexus framework, encompassing water, energy, food, economy, society, and the environment, with inherent synergies and trade-offs across all discussion topics. Students' reflections emphasized the value of guided discussions and reflection for achieving a deeper understanding of the SDGs and their relevance to future professional practices, in line with previous observations [28]. Teachers reflections indicate that conducting the Session 2 discussion as a separate digital session one week after the laboratory work (2025), rather than immediately on campus (2024), is more effective. This format

allows students time to process their laboratory experiences and supports more extended and deeper reflection beyond on-campus time constraints.

Translating increased awareness into behavioral change remains a key challenge and was beyond the scope of the present study. According to Sipos et al. [28] and based on Bloom's framework, transformative education that results in changes in behavior should engage three learning domains, the cognitive, the experiential/psychomotor and the affective domain. The approach presented here clearly engages the first two domains and has the potential to engage the affective domain through reflection on global sustainability problems. Further research would be required to examine whether such engagement translates into longer-term changes in attitudes or professional practice.

In conclusion, the proposed teaching module, which combined hands-on laboratory activities with structured discussions and reflections, demonstrates a low-threshold approach to incorporating ESD into technical and natural sciences courses. The implementation was associated with positive effects on the students' self-reported knowledge of Sweden's 16 Environmental Quality Objectives and the UN SDGs. This approach may be transferable to other laboratory-based courses seeking to integrate sustainability without extensive curricular redesign.

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