Part 19 / Strand 19

Teaching And Learning Science At The University Level

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Part 19 / Strand 19 Teaching And Learning Science At The University Level

Science teaching and learning theories, methods, pedagogies and empirical studies at the university level. Includes discussion, interpretation, implication and reflection of praxis, as well as innovative proposals and policies of teaching and learning science at university.

Sub-themes:

1) Undergraduate Teaching
2) Undergraduate Learning
3) Graduate Teaching
4) Graduate Learning

Contents

Strand 19: Teaching And Learning Science At The University Level

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Introduction

Strand 19 of ESERA focuses on teaching and learning in higher science education, encompassing research and practice across various curricular, pedagogical, and sociocultural aspects of science beyond K-12. Given the academic structure of higher education, the themes covered in this strand are typically discipline-based, such as Chemistry, Physics, and Pharmaceutical Science, but also inter- and transdisciplinary, such as STEMM (science, technology, engineering, mathematics, and medicine) and involving HASS (humanities, arts, and social sciences).

Overview

The ESERA 2025 conference theme, "Transitions in Science Education: Sustainability and Digital Advances," invites us to reflect on how profound ecological and technological transformations are actively reshaping higher education. In Strand 19, the contributions centred on how higher education navigates these shifting landscapes as they prepare the next generation of scientists, educators, and citizens to combat environmental crises, and adapt to the rapidly advancing digital technologies that shape modern learning.

The research papers presented in this strand show how transitions between academic, professional, and/or civic realms can be navigated from five perspectives. These perspectives include examining the cross-disciplinary boundaries of environmental (ocean) literacy, evaluating the entrepreneurial framing of chemistry topics for teacher education, and assessing the evidence-based digital tools used to scaffold students through high-stakes academic transitions, characterising students' learning-goal orientations and motivation in the analytical chemistry laboratory, and tracing how students perceive and coordinate multiple visual representations of electric fields. Collectively, they show how science teaching and learning at the university level can embed rigorous disciplinary knowledge with real-world technological, societal, and ecological relevance to support the transitions students face in higher education.

Is It Really Science *Vs.* The Humanities? A Cross-Discipline Study Mapping University Students' Knowledge, Attitudes, And Behaviour Toward Ocean Sciences Issues

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The ocean environment is an integral part of the Earth's interconnected global ecosystem. Despite its immense scale and capacity to buffer changes, the ocean faces severe environmental challenges. Under the prism of Sustainable Development Goal 14 of the Agenda 2030 focusing on conserving and sustainably using the oceans, seas and the marine resources, and the United Nations Decade of Ocean Science for Sustainable Development (2021-2030), the present study attempts to highlight the persisting deficit in the Ocean Literacy field by focusing on two major categories of university students: those enrolled in Science and Humanities disciplines. Based on current research, the study argues that both fields can support ocean protection and sustainable management of its resources as content science knowledge is only one dimension that leads to pro-environmental attitudes and behaviour. In this regard, a structured questionnaire was administered to 495 university students from eight Science and Humanities Departments in Greece and Italy. The results showed low to moderate content knowledge, favouring science students, as expected, but common misconceptions were present. However, all students showed satisfactory pro-environmental attitudes and behaviour. These findings suggest that not only natural science experts, but anyone interested in the ocean can be receptive to scientific concepts, even if unfamiliar, such as those in ocean sciences.

Keywords: Ocean Literacy, Science students, Humanities students

Introduction

Marine and Aquatic Education has its roots in the environmental movement of the 1960s and 1970s, while its necessity had already been underlined and studied in parallel with the progress in Environmental Education, following a similar path in the 1970s and 1980s (Mogias et al., 2022). However, in the mid-1990s, a lack of ocean-related subjects was realised in the US formal science education standards, and the need for a more comprehensive framework to encourage the inclusion of ocean sciences emerged (Payne et al., 2022).

The concept of Ocean Literacy (OL) was defined in the early 2000s as an "*understanding of the ocean's influence on humans and our influence on the ocean*" (Cava, 2005). A series of workshops brought together governmental and non-governmental organisations, educators, scientists, and policymakers to define important concepts about the ocean and its resources. This effort led to a comprehensive framework with a set of seven principles and, initially, forty-four concepts about ocean issues. An updated version added a forty-fifth concept almost a decade later (NOAA, 2013). The framework also included a pedagogical guide for teachers to use ocean content in teaching science from kindergarten to high school. It gave recommendations about when and how to insert ocean concepts into the K-12 science curriculum. These guidelines are now widely accepted and have inspired many initiatives worldwide. Although OL started as a knowledge concept, it has evolved into a multi-perspective approach, aiming at a society that understands, values, and cares for the ocean (Glithero et al., 2024). Current research in OL suggests several dimensions: awareness, knowledge, attitude, communication, behaviour, activism, emotional connections, access and experience, adaptive capacity, trust and transparency. These should also be considered when designing OL initiatives and interventions (McKinley et al., 2023).

To this aim, the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, included 17 Sustainable Development Goals (SDGs), among which a stand-alone goal focusing on the ocean (i.e., SDG 14) has been a major achievement for the global ocean community. In parallel, the United Nations declared the Decade of Ocean Science for Sustainable Development (2021-2030), seeking to contribute to the achievement of SDG14 and to extend its scope to fill the gap from "*the ocean we have*" to "*the ocean we want*". The concept of OL is central to operationalising Challenge 10, which aims to "*ensure that the multiple values and services of the ocean for human well-being, culture, and sustainable development are widely understood, and identify and overcome barriers to behaviour change required for a step change in humanity's relationship with the ocean*" (UNESCO-IOC, 2021).

Towards this direction, assessment and enhancement of OL issues among university students, the youngest active citizens who should use ocean knowledge and skills of ocean issues to communicate about the ocean in a meaningful way and make informed and responsible decisions, is required. This study aims to assess the levels of specific OL dimensions, such as knowledge, attitudes, and behaviour of university students coming from different disciplines of Science and Humanities Departments, and to reveal the potential needs and gaps while giving proper recommendations for mainstreaming ocean science issues into formal higher education.

Materials And Methods

A cross-discipline study was conducted on students attending eight Departments from four Universities in two European countries, Greece and Italy (Figure 1). The Departments were grouped into two general discipline fields, Science and Humanities; the total sample comprised 495 students. Table 1 shows the distribution of students by country, discipline, and gender. Two main hypotheses were tested regarding ocean sciences issues: (a) students enrolled in Science disciplines prevail, regarding ocean content knowledge, over students enrolled in Humanities, and (b) content knowledge strongly affects pro-environmental attitudes and behaviour.

A structured questionnaire to investigate knowledge, attitudes, and behaviour toward ocean sciences issues was developed according to previous research (e.g., Mogias et al., 2015; 2019) following the OL Framework (NOAA, 2013) and administered to students in the spring semester of 2024. The research tool contained demographics, a knowledge scale with 32 close-ended questions, and an attitude and behaviour scale with 10 statements each, following a 5-point Likert scale, revealing the degree of participants' agreement. Descriptive (relative frequencies, mean values, and standard deviations) and inferential statistics (t-tests and One-Way ANOVAs) were implemented using SPSS v.29; a probability value of 0.05 or less was predetermined as the significance level.

Figure 1. Location of the University Departments per country.

Results

Of the 495 students comprising the total sample of the study (almost two-thirds females), 48.3% emerged from Greek and 51.7% from Italian University Departments; accordingly, 58.6% had enrolled in Science while the rest in Humanities disciplines. Table 1 reveals in detail the sample distribution of the study. All students seem to choose the Internet as their primary source of information regarding environmental issues (4.08±0.987 and 3.83±1.027 for Science and Humanities students, respectively), while the former group also seem to prioritise the university faculty (3.61±1.112), academic textbooks (2.77±1.219), and scientific papers (2.69±1.320); on the contrary, TV appears to be the Humanities students' next highest preference (2.85±1.152), followed by friends and family (2.64±1.059) (Figure 2).

Table 1. Sample distribution of the study.

Country	Department	Discipline	Number of students (N)	Gender (%)	
				males	females
Greece	Marine Science	Science	85	49.4	50.6
	Environment	Science	56	42.9	57.1
	Primary Education	Humanities	55	16.4	83.6
	Education Sciences in Early Childhood	Humanities	43	2.3	97.7
Italy	Natural Sciences	Science	52	52.9	47.1
	Geological Sciences	Science	97	50.5	49.5
	History & Culture	Humanities	24	35.4	64.6
	Classical Philology & Italian Studies	Humanities	83	21.1	78.9

Students coming from both fields were found to possess rather low to moderate levels of ocean sciences content knowledge (mean score 16.60±5.278 for Science and 11.57±4.389 for Humanities students) but, at the same time, very positive attitudes and behaviour towards relevant issues (Figure 3). A statistically significant difference between the two discipline groups was recorded only for the content knowledge dimension ($p \leq 0.001$) (Figure 3a), while this was not the case for the other two dimensions; on the contrary, a statistically significant difference is depicted between attitudes and behaviour for each group ($p \leq 0.05$ and $p \leq 0.001$, respectively), with the former scale clearly prevailing (Figure 3b). Figures 4 and 5 reveal that despite the existing differences between the two main categories of students, they present comparable depictions in terms of the questionnaire items; more specifically, focusing on the content knowledge items, we detect that almost the same questions were hard and, respectively, the same ones were easy to correctly answer (Figure 4).

Figure 2. Mean values of the preferred information sources. by Science and Humanities students

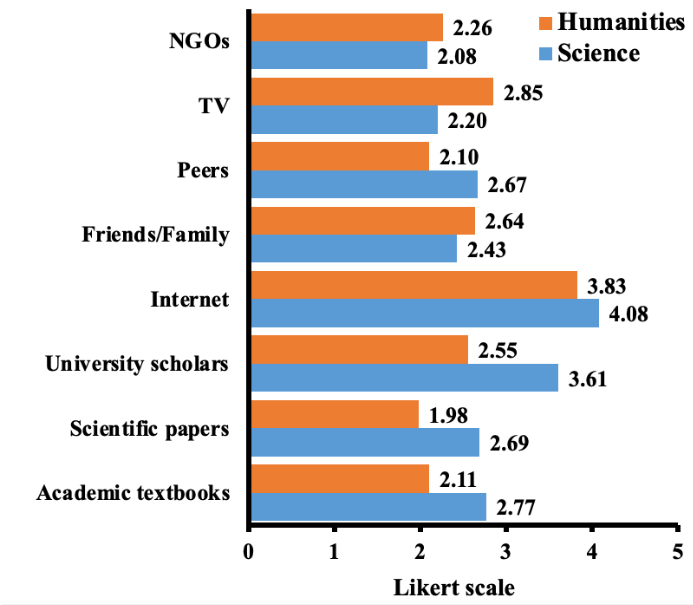
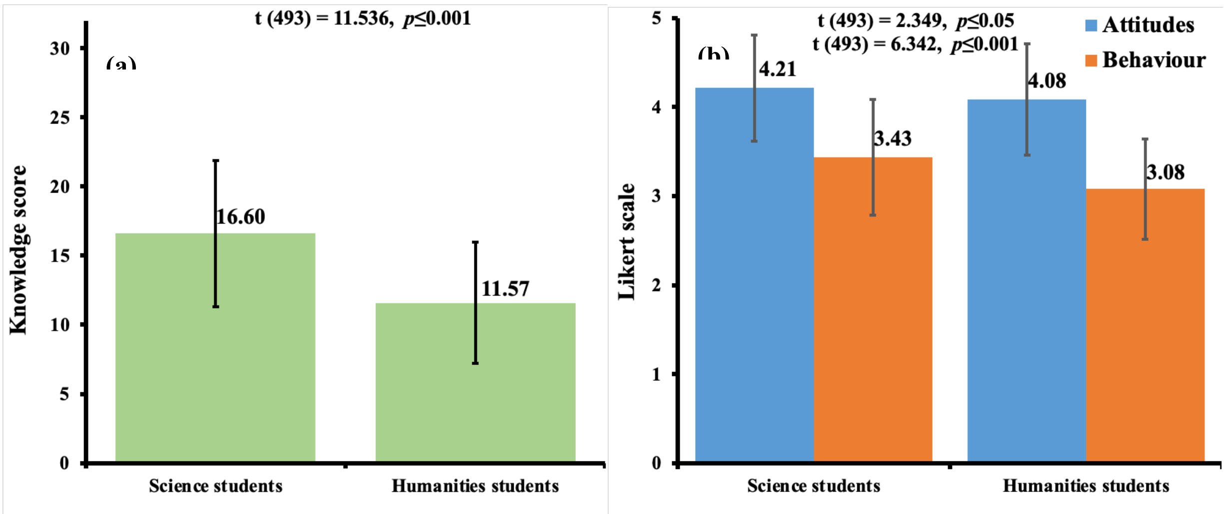


Figure 3. Mean knowledge (a), and attitudes and behaviour (b) values of Science and Humanities students



The common most difficult to answer items were questions 1, 16, 26, and 30, referring to the interconnection of all sea basins (mean value 3.4 and 4.9% for Science and Humanities students, respectively), the ocean's role in the global carbon cycle (22.1 and 19.0%), the vital role of estuaries (16.9 and 9.3%), and the basic sources of oil spills (8.0 and 7.8%); the common easiest questions to answer were 7, 8, and 29, referring to the transportation of several materials through rivers and watersheds to the ocean (mean value 84.1 and 82.9% for Science and Humanities students, respectively), the evidenced existence of seas and lakes million years ago in present-day terrestrial surfaces (87.9 and 81.0%), and the modern society's influence on the ocean (81.7 and 83.9%) (Figure 4). In terms of the other two scales, namely attitudes and behaviours, our findings portray amazing similarities between the two groups of students when depicting their level of agreement across all statements; more specifically, the attitude statements fluctuated between 3.72 (±1.054) and 4.48 (±0.768) (Figure 5a, Table 2), while the behaviour statements between 2.29 (±1.221) and 4.68 (±0.793) (Figure 5b, Table 3).

Figure 4. Fluctuation of correct answers provided by Science and Humanities students regarding the knowledge scale of the research tool.

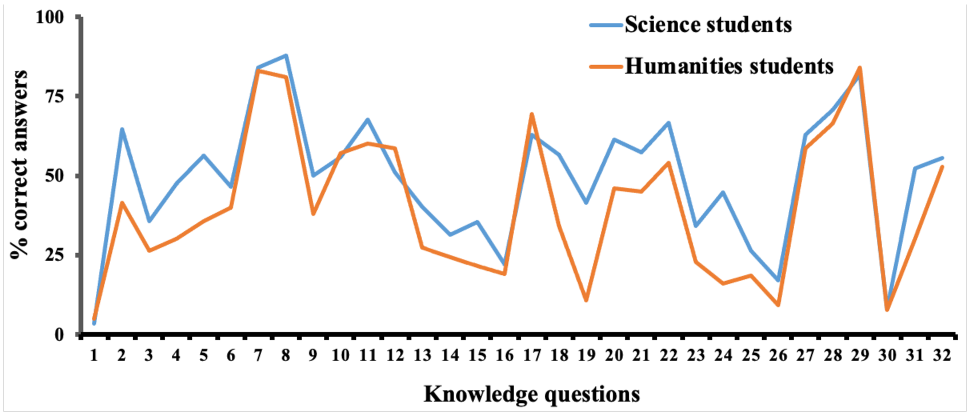
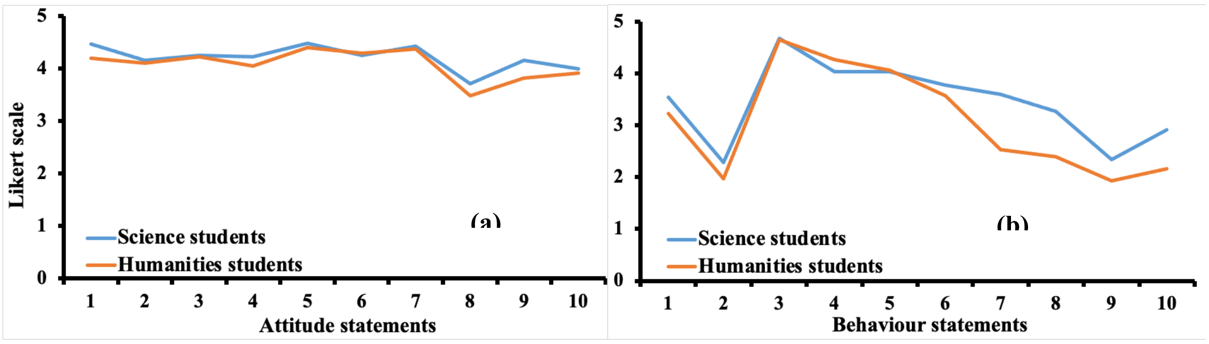


Figure 5. Fluctuation of values provided by Science and Humanities students regarding the attitudes (a) and behaviour (b) scales of the research tool.



Discussion

The aim of this study was not to compare students based on their nationality, nor among the Science and, respectively, the Humanities Departments. Our main interest focused on assessing the potential existing gaps between students attending these two scientific fields, primarily in ocean content knowledge, and whether these gaps could, and to what extent, influence their pro-environmental attitudes and behaviour. The results revealed low to moderate knowledge of ocean sciences issues in favour of Science students as expected, sharing the same misconceptions, while they exhibited positive attitudes and behaviours. These findings are in line with the existing literature (e.g., Koulouri et al., 2022; Mogias et al., 2019; 2022) targeting several populations, such as primary and secondary school students, and pre-service teachers, among others.

Our findings confirmed our first hypothesis regarding ocean content knowledge levels, based on the nature of the students' disciplines, but rejected the second one regarding knowledge impact on other OL dimensions such as attitudes and behaviour, as Humanities students with a comparatively decreased content knowledge exhibited almost equal positive attitudes and behaviours to their Science peers. Results of this study indicate that the involvement of other dimensions, such as emotional connections, access and experience, adaptive capacity, trust, and transparency, could promote pro-environmental attitudes and behaviour as these were portrayed by the work of McKinley et al. (2023). Moreover, modern teaching and learning require multi-perspective approaches (e.g., scientific, historical, geographic, among many others) that promote interdisciplinary, inclusive, and intercultural competencies (e.g., Santoro et al. 2017). Furthermore, the inter- and multi-disciplinarity that connects freshwater, marine, education, and social scientists is an acknowledged way of communicating complex ocean issues (Mokos et al., 2022).

The White Paper for Challenge 10 of the UN Ocean Decade, referring to "*Restoring Society's Relationship with the Ocean*", emphasises the major societal transformations needed to create a sustainable and equitable future (Glithero et al., 2024). Behaviour changes in personal, emotional, and cultural connections with the ocean are necessary beyond conventional scientific methods and proper science communication under the prism of Education for Sustainable Development (ESD), climate education, and global citizenship.

Table 2. Mean values and standard deviations (sd) portraying the sample's level of agreement in the attitude scale.

	Attitude statements	Science students		Humanities students	
		mean	sd	mean	sd
1	I believe that human life is inextricably linked to the ocean	4.47	0.773	4.20	0.819
2	I feel frustrated with the overexploitation of marine resources at risk of depletion (e.g., fish)	4.16	1.017	4.11	0.956
3	I am concerned that human activities carried out on land (e.g., industries, agriculture) significantly affect the health of the marine environment	4.25	0.851	4.22	0.874
4	I feel frustrated when the leaders of several countries postpone the necessary measures to protect the ocean	4.23	1.104	4.05	1.167
5	I feel frustrated that sensitive marine ecosystems will be lost if humans do not change their behaviour towards the marine environment	4.48	0.768	4.40	0.718
6	I believe that humans are responsible for the extinction of many marine species	4.25	0.840	4.29	0.901
7	I believe that all of us, regardless of whether we live near the ocean or far from it, are responsible for protecting it	4.42	0.752	4.38	0.860
8	I feel personally responsible for protecting the ocean	3.72	1.054	3.48	1.162
9	I would like to get to know the marine environment better so that I can protect it and contribute to its future conservation	4.17	0.997	3.82	0.999
10	I would like to contribute to the protection of the marine environment, although I feel that I cannot do much on my own	3.99	0.988	3.91	0.974

In conclusion, attempting to provide an answer to the dilemma already presented in the title of the present study, we should all agree that current environmental issues require multi-perspective and innovative approaches. The concept of OL aims to connect ocean science and ESD through behavioural change initiatives and the adaptation of a systems approach. Continuing to invest almost exclusively during the past decades in experts' education proved not to be the best practice; what we need is to create a universal culture for the general public, which will eventually guide us to active citizenship. Only in this way will we be able to understand that the vitality of the ocean is inextricably connected to our survival, and thus collaborate towards its conservation, protection, and sustainable management of its resources.

Table 3. Mean values and standard deviations (sd) portraying the sample's level of agreement in the behaviour scale.

	Behaviour statements	Science students		Humanities students	
		mean	sd	mean	sd
1	With my lifestyle I try to reduce the impact I have on the environment in order to protect the ocean	3.54	0.931	3.22	1.084
2	I participate in organized social actions for the protection of the marine environment (e.g., beach cleaning)	2.29	1.221	1.97	1.026
3	I collect my trash when I'm on the beach	4.68	0.793	4.65	0.750
4	I avoid playing with marine organisms, even for a few minutes when I am on the beach	4.04	1.241	4.27	0.998
5	I recycle and reuse plastic, as it has a significant negative impact on the marine environment	4.03	1.027	4.07	1.050
6	I am opposed to the construction of houses and hotels on the beach, as it negatively affects the coastal and marine environment	3.78	1.224	3.57	1.153
7	I explore the diversity of marine life when I get the chance to do so	3.60	1.242	2.54	1.190
8	I encourage my family and friends to learn more about the marine environment and how to protect it	3.27	1.317	2.40	1.136
9	I know enough about the ocean and the problems it faces, but I still don't change my daily habits to protect it	2.34	1.025	1.93	0.910
10	I motivate my friends to learn more about how to protect the ocean	2.91	1.198	2.17	1.067

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What Are Students' Learning Goal Orientations In The Analytical Chemistry Laboratory?

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This study explored students' learning goal orientations in the analytical chemistry laboratory to gain insights on students' motivational patterns and how these vary by gender and cohort. Using the SELLMO-ST scales, the study assessed 273 students across five different cohorts. Learning goals emerged as the most prominent orientation, indicating high intrinsic motivation, while performance-approach goals exerted moderate influence. Performance-avoidance and work-avoidance scores were relatively low, suggesting that most students actively engaged with laboratory tasks. Gender differences revealed slightly higher performance-avoidance tendencies in female students, reflecting a stronger fear of failure. Overall, all student cohorts showed high learning goals which may arise from a shared enjoyment of the practical aspects of the laboratory course. Three distinct student profile groups were identified: 49% students with a strong focus on learning (profile 1), 32% students which combined learning with a performance-approach (profile 2), and 19% students with a high tendency to performance-avoidance and work-avoidance (profile 3). These findings highlight the importance of fostering intrinsic motivation and tailoring laboratory experiences to address diverse motivational patterns in chemistry laboratory education.

Keywords: Undergraduate Teaching, Laboratory, Motivation

Introduction

Research in chemical education has explored how students feel when learning chemistry and how this may be influencing how they perform. (Flaherty, 2020) One aspect is students' learning goals orientation, which play a crucial role in shaping their motivation, emotional engagement, and academic success. Learning goals are rooted in achievement goal theory (Urdan & Kaplan, 2020) which is closely linked to self-determination theory (Ryan & Deci, 2000). Both theories emphasize the interplay between intrinsic and extrinsic motivations in shaping students' engagement and success. It categorizes goals into mastery goals, which focus on developing competence and understanding, and performance goals, which emphasize demonstrating competence relative to others (Elliot & McGregor, 2001). These goal orientations are closely tied to emotional experiences, as students' motivations influence their perceptions of success and failure. Intrinsic motivation, linked to mastery goals, fosters adaptive behaviours like persistence and deep learning, alongside positive emotions such as pride and enjoyment. Conversely, extrinsic motivation, often associated with performance goals, can lead to anxiety and surface-level learning, particularly when driven by performance-avoidance goals and fear of failure (Pekrun, 2006). Studies in students' learning goal orientation in chemistry lecture-based courses indicated students were motivated both intrinsically and extrinsically. (Lewis, 2018; Naibert et al., 2024) While these studies have explored motivational patterns in lecture-based chemistry courses, there is limited understanding of how these dynamics play out in laboratory settings.

Aim

Our observations in the analytical chemistry laboratory course indicate that while some students dedicate significant effort and aim for excellence in mastering the analytical chemistry laboratory course, others are primarily driven by grades or prioritize merely completing tasks with minimal effort. Therefore, this study explored students' learning goal orientation in the analytical chemistry laboratory, using the Scales for Assessment of Learning and Performance Goals

(SELLMO-ST; Spinath et al., 2002). Grounded in achievement goal theory, SELLMO-ST measures four distinct orientations: learning, performance-approach, performance-avoidance, and work-avoidance goals. Learning is one goal orientation and is associated with intrinsic motivation and a focus on personal growth and understanding. Performance-approach goals emphasize outperforming others and receiving recognition, while performance-avoidance goals are driven by a fear of failure and avoiding appearing. The following research-questions were explored: (1) What are student learning goal orientations in the analytical chemistry laboratory? (2) What is the influence of gender on motivation profiles? (3) What difference in motivational patterns do students show between cohorts?

Method

Participants

The practical laboratory course for analytical chemistry is part of different science curriculums at an Austrian university. Participant students included first-year Chemistry (n = 71), third-year Molecular Biology (n = 84), second-year Environmental System Sciences (n = 47), and second-year pre-service Teacher Education (n = 14). Additionally, fourth-year students (n = 57) of the advanced analytical chemistry course took part in this study. Altogether, 273 students (58% female, 41% male and 1% diverse) participated in the study. The study was conducted with the approval of the university ethics committee and in accordance with established ethical guidelines. Participation was voluntary, and written informed consent forms from the students were collected. SELLMO-ST questionnaire return was > 95%.

Learning Goal Orientation

The student version of the Scales for the Assessment of Learning and Performance Goals (SELLMO-ST; Spinath et al., 2002) was used to evaluate academic goal orientations in the analytical chemistry laboratory courses. The SELLMO-ST instrument consists of 31 items, categorized into four scales starting with "In the analytical chemistry laboratory course, it is important for me…" : Learning (8 items, e.g., '... to learn something interesting'), Performance-approach (7 items, e.g., '... to get better grades than others'), Performance-avoidance (8 items, e.g., '... to hide if I know less than others'), and Work-avoidance (8 items, e.g., '... to finish my studies with little effort'). Items are rated on 5-point Likert scales ranging from "totally disagree" (1) to "totally agree" (5). Cronbach's alpha was 0.85 for the learning goal orientation scale, 0.84 for the approach-achievement, 0.89 for the avoidance-achievement and 0.89 for the work-avoidance scale, indicating good reliability. The SELLMO-ST questionnaire was administered in the analytical chemistry laboratory on the first day of each practical course. Answering the SELLMO-ST questionnaire took approximately 10 minutes. Data were analysed using IBM SPSS Statistics (Version 28).

Results & Discussion

(1) What Are Student Learning Goal Orientations In The Analytical Chemistry Laboratory?

Table 1 shows the descriptive statistics for the SELLMO-ST scales, assessing the different learning orientation goals in the analytical chemistry laboratory. Overall, the results show a highly pronounced learning orientation and, in comparison, less pronounced values for performance-approach, performance-avoidance, and work-avoidance.

This suggests that most students prioritize developing competence and understanding in their laboratory work, reflecting high levels of intrinsic motivation. Some students are motivated by external validation and competition in the laboratory setting, though it is not the primary driver for most students. The low performance-avoidance goals score indicates that most students experience relatively low levels of anxiety-driven motivation. Further, the low work-avoidance score shows that most students are willing to engage actively in laboratory tasks. This is a positive outcome, as learning goals are typically associated with adaptive learning behaviours and deeper engagement (Ryan & Deci, 2000). Furthermore, recent research by Liu (Liu et al., 2025) underscores the intricate relationships between motivation, emotions, and academic success in chemistry education.

Table 1: Descriptive statistics SELLMO-ST Scales (1 low to 5 high).

SELLMO -ST Scale	Mean	SD	α
Learning Goals	4.32	.59	.85
Performance-Approach	2.76	.75	.84
Performance -Avoidance	2.22	.87	.89
Work-Avoidance	2.02	.86	.89

(n = 273). M (mean) and SD (standard deviation), Cronbach's α.

The relationship between the SELLMO-ST goal orientation scales is presented in Table 2. The learning goals scale strongly associated with positive motivational patterns, including a positive correlation with performance-approach goals, and a negative correlation with work-avoidance. This suggests that students focused on learning goals are less likely to avoid effort and may also seek some level of recognition. There was no significant relationship with performance-avoidance, indicating that fear of failure does not strongly align with intrinsic motivation. The performance-approach goals scale positively correlated with performance-avoidance goals, indicating that students driven by competition may also experience fear of failure. This could be interpreted as the risk of critic versus appreciation, which in turn could be met by the feedback-style from laboratory teachers. An expected weak positive correlation with work-avoidance, suggesting a minimal connection between competition-driven motivation and effort minimization. In contrary, fear-driven motivation is often linked to disengagement and reduced effort is reflected in the moderately correlation of performance-avoidance with work-avoidance.

Table 2: Bivariate correlation SELLMO-ST Scales of goal orientation.

SELLMO Scale	2.	3.	4.
1. Learning	.202 (<.001)	-.049 (.420)	-.388 (<.001)
2. Performance-Approach		.588 (<.001)	.091 (<.137)
3. Performance-Avoidance			.423 (<.001)
4. Work-Avoidance			-

Note: *r* (p)

(2) What Is The Influence Of Gender On Motivation Profiles?

Key findings from the descriptive statistics in Table 3 indicate that female and male students had comparable mean scores for learning goals. This similar motivation may arise from a shared enjoyment of the practical aspects of the laboratory course and the self-selection involved in university program enrollment. Additionally, no significant differences were observed between genders in performance-approach or work-avoidance scores, which may be attributed to the laboratory setting's emphasis on teamwork and collaboration, helping to minimize motivational variation. However, there was a significant difference on performance-avoidance goals between female and male students. This pattern may reflect a stronger fear of failure among female students. Addressing this issue could involve maintaining a supportive laboratory environment that fosters confidence and reduces anxiety, where students feel comfortable expressing ideas without fear of negative judgment, and emphasizing the learning process through meaningful feedback.

Table 3: Descriptive statistics SELLMO-ST Scales (1 low to 5 high) for genders .

	M (SD)			
	Learning	Performance-Approach	Performance-Avoidance	Work-Avoidance
Female (n = 158)	4.34 (.19)	2.81 (.81)	2.36 (.93)	2.02 (.93)
Male (n = 111)	4.28 (.52)	2.70 (.65)	2.01 (.71)	2.01 (.74)
$t(267) =$	.912 $p = .363$	1.15 $p = .253$	3.28 $p = .001$	.067 $p = .946$

M (mean) and SD (standard deviation), t = independent sample t-test.

(3) What Difference In Motivational Patterns Do Students Show Between Cohorts?

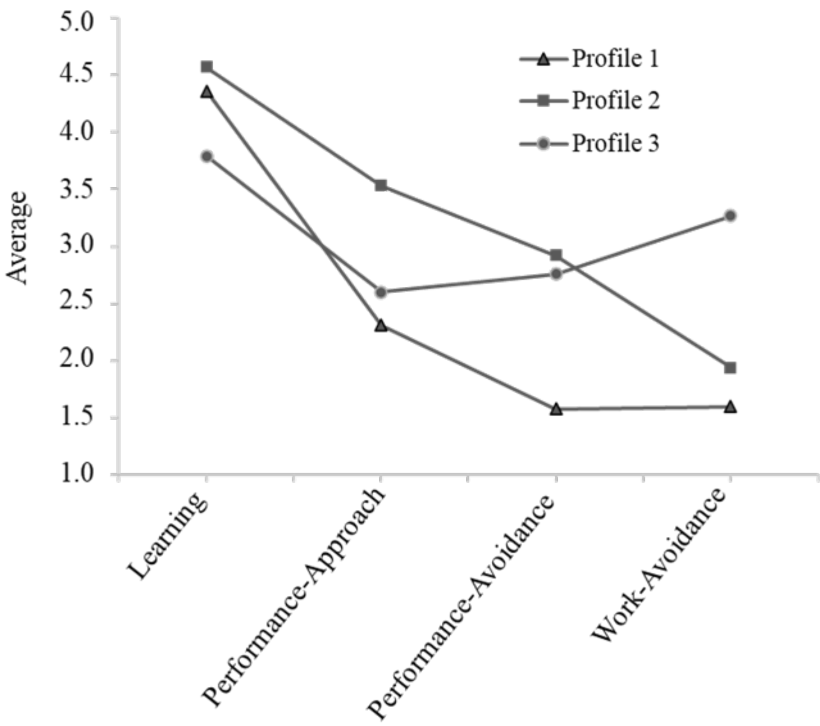
The motivational patterns from the five student cohorts are shown in Table 4. The key finding was between the Chemistry and Environmental Systems Sciences cohorts, where statistical differences were found for the mean scores for the learning scale ($t(116) = -2.73$, $p < .01$), performance-approach ($t(116) = -4.51$, $p < .001$), and performance-avoidance ($t(116) = -2.64$, $p = 0.009$), though not for work-avoidance ($t(116) = 1.68$, ($p = .096$). Suggesting less emphasis on competence and recognition in the analytical chemistry laboratory course, which may be influenced by the interdisciplinary focus of the Environmental Systems Sciences. These findings highlight the importance of tailoring laboratory experiences to student cohorts. Figure 1 shows three generated profiles (K-Means) from the student cohorts in the analytical chemistry laboratory. Profile 1 consist of 48,7% (n = 133), the second profile of 31,5% (n = 86), and the third profile of 19,7% (n = 54) students. The profile groups 1 and 2 show high learning goal orientation and low work-avoidance tendencies. Profile 1 demonstrates minimal influence from performance-oriented goals (either approach or avoidance) compared to profile 2, which shows moderate performance orientation. Profile 3 characterizes a high tendency to work-avoidance and performance-avoidance with a lower learning goal orientation compared to the other two profiles.

Table 4: Descriptive statistics SELLMO-ST Scales (1 low to 5 high) for student cohorts.

Student cohort	M (SD)			
	Learning	Performance-Approach	Performance-Avoidance	Work-Avoidance
Environ. System Sciences (n = 47)	4.03 (.62)	2.37 (.67)	1.90 (.70)	2.15 (.83)
Pre-Service Teacher (n = 14)	4.22 (.35)	2.60 (.76)	2.05 (.80)	2.70 (1.62)
Molecular Biology (n =84)	4.38 (.53)	2.79 (.79)	2.29 (.96)	1.84 (.77)
Chemistry (n = 71)	4.37 (.69)	2.95 (.68)	2.30 (.84)	1.89 (.83)
Advanced Analytical Chem. (4th year) (n = 57)	4.41 (.44)	2.80 (.72)	2.31 (.85)	2.13 (.69)

M (mean) and SD (standarddeviation)

Figure 1: Mean values of the learning goal orientation scales, learning, performance-approach, performance-avoidance and work-avoidance. Profile 1 (n = 133), Profile 2 (n = 86), Profile 3 (n = 54).



Conclusion

This study revealed that students in the analytical chemistry laboratory predominantly demonstrate intrinsic motivation, supported by strong learning goals, moderate performance-approach tendencies, and mostly low avoidance behaviors. This motivation may stem from the shared enjoyment of the practical aspects of laboratory course work and the students' self-directed choices in selecting their university programs. Gender differences revealed that female students experienced a stronger fear of failure, which could be addressed by maintaining a supportive laboratory environment and emphasizing the learning process through meaningful feedback. Additionally, the findings suggest that laboratory experiences for the interdisciplinary Environmental System Sciences cohort could be further refined to enhance meaningful learning by providing targeted feedback that emphasizes the relevance of laboratory tasks.

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Supporting First-Semester Chemistry Students: Development And Evaluation Of A Two-Phase Digital Learning Unit In Redox Chemistry

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STEM degree programs, such as chemistry, are associated with a range of challenges, with mathematical content areas posing particularly significant difficulties for students (e.g., Averbeck et al., 2018; Seymour & Hunter, 2019; Ye et al., 2024). However, in the context of redox chemistry, such content is fundamental to achieving a deeper understanding of chemical relationships.

This project aims to develop, implement and evaluate a two-phase digital learning unit designed to support first-semester chemistry students in understanding mathematical-chemical concepts and tackling related tasks in redox chemistry. In the first phase, students engage independently with interactive educational videos. In the second phase, they work on exercises and are provided with one of three different digital support measures.

The effectiveness of the intervention will be analysed primarily in terms of improvements in content knowledge. Additionally, student evaluations regarding the attractiveness and usability of the learning unit as well as cognitive load will be considered. Other aspects included in the evaluation are logfile analysis, students' written assignments, and video recordings of the training phase.

Keywords: Higher Education, Postsecondary Education, Undergraduate Teaching

Introduction

Chemistry is considered one of the most challenging subjects for students at university (e.g., Childs & Sheehan, 2009). This is evidenced by the high dropout rates reported internationally in STEM degree programmes such as chemistry, which show a rising trend. Academic performance issues disproportionately often lead to early dropouts (e.g., Heublein et al., 2022; Seymour & Hunter, 2019).

Students enter higher education with diverse initial conditions, such as varying levels of prior knowledge and mathematical skills. However, these factors are among the key determinants of subsequent learning success (Averbeck et al., 2018). The content covered during the first semester forms the foundation for learning as part of a cumulative acquisition of knowledge. Consequently, there is an acute need for targeted measures to support first-semester students in mastering subject-specific challenges.

Thematic areas with high mathematical components appear to present particular difficulties for first-year students (Hoban et al., 2013; Potgieter et al., 2008; Ye et al., 2024). These include redox chemistry, which is taught in the first semester. Topics such as balancing redox reaction equations and applications of the Nernst equation are especially challenging (Potgieter et al., 2008). This is emphasised by numerous misconceptions and difficulties documented in the literature (see overviews by Duit, 2009; Horton, 2007). These include, for example, the concept of oxidation in general, difficulties identifying reducing and oxidising agents (e.g., Brandriet & Bretz, 2014), misinterpretation of oxidation numbers, and general struggles with setting up and balancing redox reaction equations (e.g., Potgieter & Davidowitz, 2011). Although extensive research highlights learners' challenges in understanding redox chemistry, relatively few studies provide concrete suggestions for addressing these issues and evaluate their effectiveness (Goes et al., 2020).

Our objective is therefore to design, implement and evaluate a learning unit focused on redox chemistry that aims to help learners deal with their difficulties.

Research Design And Method

The developed two-week learning unit comprises two main phases. In the first phase, students engage with educational videos that have been designed according to research-based principles for maximising learning success (Kulgemeyer, 2020) and that have been enhanced with interactive *H5P* elements to promote active learning (e.g., Brame, 2016). They then attend two seminars, 135 minutes in total, where they work on exercises (training phase). During this time, the students are assigned to one of three different digital support measures. In a previously conducted qualitative study, the primary difficulties faced by first-semester students in redox chemistry were identified (Kneuper et al., 2025b). Based on these findings, worked examples (WE), flowcharts (FC) and brief solutions (BrS) were designed to help students deal with these difficulties in the training phase. It is important to emphasise that all students receive identical exercises in terms of content, and the allocated time for completing these tasks is consistent across all groups.

WEs present learners an experts' solution to a given problem, including the final answer. This allows students to understand and learn from this model approach (e.g., Atkinson et al., 2000). To encourage self-explanation (*self-explanation effect*) and promote the transition from learning with WEs to solving tasks independently, each thematic area includes a progression: an elaborated WE with self-explanation prompts, followed by a faded WE where learners complete specific solution steps independently, and finally open-ended tasks (e.g., Atkinson et al., 2000; Atkinson et al., 2003; Wittwer & Renkl, 2010).

FCs provide visual representations of workflows required to solve various problems or complete tasks and therefore serve as strategic tools (Işık, 2024; Yuriev et al., 2017). The FCs offered are structured around sub-goals and encourage procedural checks (Ye et al., 2024).

BrS show students the final answer, but do not provide any information or guidance on how to solve the problem/task. This enables them to check their solution, though they do not receive any process-related support. A more detailed description of the three support measures can be found in Kneuper et al. (2025a).

One focus of our research is to examine how the content knowledge of the students who take part in our study develops:

> Q1: To what extent do the educational videos affect the students' content knowledge?
>
> Q2: To what extent does the training affect the students' content knowledge, depending on the support measure offered?

Additional aspects investigated in this study, though not covered within this paper, include students' evaluations of the learning unit, the influence of personal variables on the development of content knowledge (e.g., gender or science motivation) and detailed analysis of students' interactions with WEs, FCs or BrSs.

To address Q1 and Q2, a knowledge test was developed that covers the conceptual basis of redox reactions as well as applications, such as reasoning with the Nernst equation. The test was validated through an ongoing exchange with the professor who gave the introductory chemistry lecture in the first semester. It consists of 27 multiple-choice single-select items (MC) and six open-ended items. The MC items are internally consistent (α = .810), while a scoring scheme for the open-ended items is under development.

The content knowledge test is administered at three different times: at the beginning of the learning unit (pre), after engaging with educational videos (mid), and upon completion of seminar exercises (post). To answer question Q2, participants are assigned to one of three statistically comparable intervention groups based on their prior knowledge levels (pre-test content knowledge, MC items) and gender.

First Results of Iteration 1

In the winter semester 2024/25, a first iteration was conducted with $N = 90$ first-semester students (chemistry, chemical-biology and chemistry teaching), of whom 79 students (44 females, 34 males, 1 not specified) participated completely in the intervention and where therefore included in our analysis. Table 1 provides an overview of the initial results from the content knowledge test, addressing research questions Q1 and Q2. It should be noted that this analysis only considers the MC items; the evaluation of open-ended items is still pending.

Table 1. Development of the students' content knowledge (MC items) based on the intervention group (*$p < .001$).**

Group	Time	*n*	*M*	Mean Difference	Effect Size (part. η^2)	95%-CI
Worked Examples	pre	26	.437	.164***	.702	[0.104, 0.224]
	mid		.601			
	mid	26	.601	.105***		[0.051, 0.160]
	post		.707			
Flowcharts	pre	27	.420	.148***	.629	[0.091, 0.205]
	mid		.568			
	mid	27	.568	.019		[-0.026, 0.064]
	post		.587			
Brief Solutions	pre	26	.466	.127***	.499	[0.051, 0.202]
	mid		.593			
	mid	26	.593	.048		[-0.004, 0.101]
	post		.641			
All	pre	79	.441	.146***	.593	[0.111, 0.182]
	mid		.587			
	mid	79	.587	.057***		[0.028, 0.087]
	post		.644			

To examine the development of content knowledge within each group, a one-way ANOVA and post-hoc tests with Bonferroni-correction were performed separately for each group (WE/FC/BrS). The results are summarised in Table 1: Significant increases in content knowledge from 'pre' to 'mid' were observed across all groups, with large effect sizes. From 'mid' to 'post', significant improvements were detected exclusively in the WE group, whereas no significant changes were found for the FC and BrS groups.

Interaction effects between intervention groups (WE/FC/BrS) and time (pre/mid/post) on content knowledge development were determined by a mixed ANOVA with Greenhouse-Geisser correction. A significant interaction effect between time and group was detected with a moderate effect size ($F(3.70, 140.43) = 3.32$, $p = .015$, partial $\eta^2 = .080$). Table 1 shows that the increase in content knowledge from mid to post is highest in the WE group and lowest in the FC group, suggesting that the WEs are more effective in facilitating learning than the FCs.

Discussion & Outlook

The preliminary findings of this study indicate that the learning unit is well-suited for first semester students (see also Kneuper et al., 2025a) and that the educational videos are effective in supporting learning. Moreover, among the support measures compared, worked examples appear to be the most effective. A more detailed analysis is currently being carried out, incorporating the remaining content knowledge data (open-ended items), task processing data, generated logfiles, and video recordings from the training phase. To this end, appropriate coding manuals are being developed. Combining these sources of information is expected to provide valuable insights into developing effective learning opportunities for complex content areas in higher education. Furthermore, a second iteration in the winter semester 2025/26 is planned to increase the sample size.

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Representational Competence In The Context Of Electric Fields: An Eye-Tracking Study

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Multiple visual representations can significantly enhance learning and understanding of scientific concepts. However, for visual representations to be effectively used in learning, learners need representational competences, i.e. abilities to interpret and fluently coordinate multiple representations. Therefore, to design effective multi-representational learning materials, it is essential to understand representational competence and how learners retrieve and process information from visual representations. In this article, we present a study that explores representational competence in the context of electric field representations. In the study, 38 university science students completed a test including two different visual representations of electric fields, namely equipotential line diagrams and field line diagrams. In each task, they were asked to evaluate characteristics of the electric field shown, with some tasks requiring inter-representational coherence formation and others not. During task completion, students' eye gaze was recorded. Analyses revealed that while students demonstrated strong visual understanding of individual representations, they struggled to integrate these representations as shown by low response accuracy and confidence while perceiving high item difficulty and indicating high cognitive invest. Moreover, initial conclusions about students' visual strategies for handling the representations could be revealed.

Keywords: Non-Verbal Representations, Eye-Tracking, Process Skills

Theoretical Background

Visual representations play a crucial role in science and science education. Being able to use and switch between different representations is essential for understanding scientific concepts (Rau, 2017). However, to truly benefit from visual representations in learning, students need representational competences—knowledge and skills required to use visual representations for reasoning and problem-solving (Klein et al., 2017). These competences consist of two aspects: visual and connectional understanding (Rau, 2017). Visual competences involve intra-representational coherence formation, i.e. knowing how individual representations work, what information they convey, and how they connect to scientific concepts (Seufert, 2003). Connectional competences involve inter-representational coherence formation which incorporates the ability to connect and flexibly switch between different visual representations (Seufert, 2003).

Because visual representations are important in scientific communication, many researchers highlight the need to develop representational competences to help students grasp complex scientific ideas (De Cock, 2012; Rau, 2017). Therefore, numerous studies geared towards characterizing students' representational competences in science learning (e.g., Kohl & Finkelstein, 2005; Rau, 2018).

From the perspective of cognitive psychology, it is important to understand how learners retrieve information from one or multiple visual representations to design effective learning materials. Since these retrieval processes are difficult to observe directly, eye tracking, i.e. analysis of eye movements, provides valuable insights into how learners handle visual representations (Ubben et al., 2018). For example, in previous studies from science education research, analyses of gaze behaviour revealed representation-specific visual strategies (Hahn & Klein, 2025) and processes of information extraction from different representations (Susac et al., 2023).

The Present Study

This study focuses on visual representations of electric fields, specifically equipotential line diagrams and field line diagrams. Equipotential line diagrams represent the electric potential, and field line diagrams depict the electric field, i.e. its magnitude and direction (Figure 1). Previous research identified numerous learning difficulties related to the interpretation of such electric field representations (Bollen et al., 2017; Campos et al., 2023, Küchemann et al., 2021). For instance, students confused characteristics of field lines and equipotential lines, and they failed to recognize field line density as an indicator of the field's magnitude (Bollen et al., 2017). Since electric field representations are crucial in undergraduate physics, understanding representational competences is key to developing multi-representational learning materials.

Research Aims

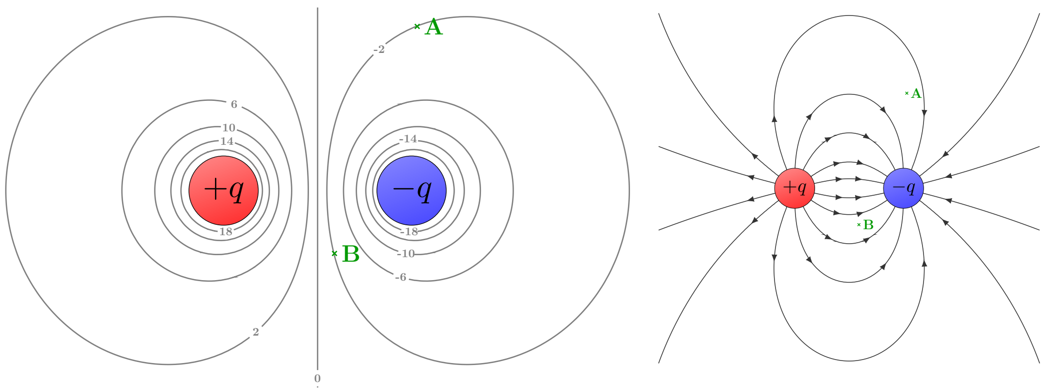
The current study takes an exploratory approach to investigate students' representational competences in using electric field representations. The following objectives are focused: (1) characterizing students' ability—their visual and connectional understanding—to handle electric field representations and (2) identifying visual strategies employed by students when processing electric field representations. To achieve these objectives, the study triangulates gaze data during representation processing and performance measures, i.e. students' response accuracy, response confidence, and perceived item difficulty.

Design And Methods

The study involved 38 university science students (20.9 ± 2.1 years, 68% male), most of whom were pursuing bachelor's or master's degrees in physics (3.5 ± 2.3 semester of study). Almost all participants were currently enrolled in or had taken a course on electrodynamics (95%). In the study, students completed a test on electric field representations, judging the magnitude, direction, and potential of fields shown as equipotential or field line diagrams. Some tasks required inter-representational coherence formation (e.g., judging electric potential using a field line diagram; in the following referred to as inter-representational coherence formation items), while others required interpretation within the same representation (intra-representational coherence formation items; Figure 1). The test included three scenarios commonly encountered in undergraduate electrodynamics courses, namely a point charge near an uncharged metallic plate, a symmetrical dipole (Figure 1), and an unsymmetrical dipole. After completing a task, participants moved to the solution page and provided their solution as well as a retrospective think-aloud explanation of their reasoning. Additionally, students rated their response confidence and the perceived difficulty of each item. During test assessment, students' gaze behavior was recorded using a Tobii Pro Fusion eye tracker (sampling frequency 120 Hz).

The following analyses focus on the symmetrical dipole scenario (Figure 1). To evaluate students' representational competences, response accuracy, response confidence, and perceived item difficulty were compared between intra- and inter-representational coherence formation items. These comparisons were conducted for tasks involving equipotential and field line diagrams of the symmetrical dipole, addressing the field's magnitude and potential. Moreover, gaze data during task processing was analysed by referring to the fixation count on the diagram. For analyses, performance measures and gaze metrics were subjected to non-parametric paired comparison analyses. Pearson correlation coefficient r and odds ratio OR are referred to as measures of effect size by following the interpretation of Cohen (1988).

Figure 1. Equipotential line diagram (left) and field line diagram (right) of a symmetric dipole (positive charge $+q$, negative charge $-q$). Two tasks were posed for each diagram: "Decide in which of the indicated points, A or B, (1) the electrical potential / (2) the magnitude of the electric field is higher". For the left diagram, the first question involves intra-representational coherence formation, while the second question requires imagining the corresponding field lines (inter-representational coherence formation item). For the right diagram, those task requirements apply vice versa. The points A and B are identically placed in all diagrams, ensuring isomorphic representations. While the electric field's magnitude is higher at point B (higher field line density), both points share the same electric potential.



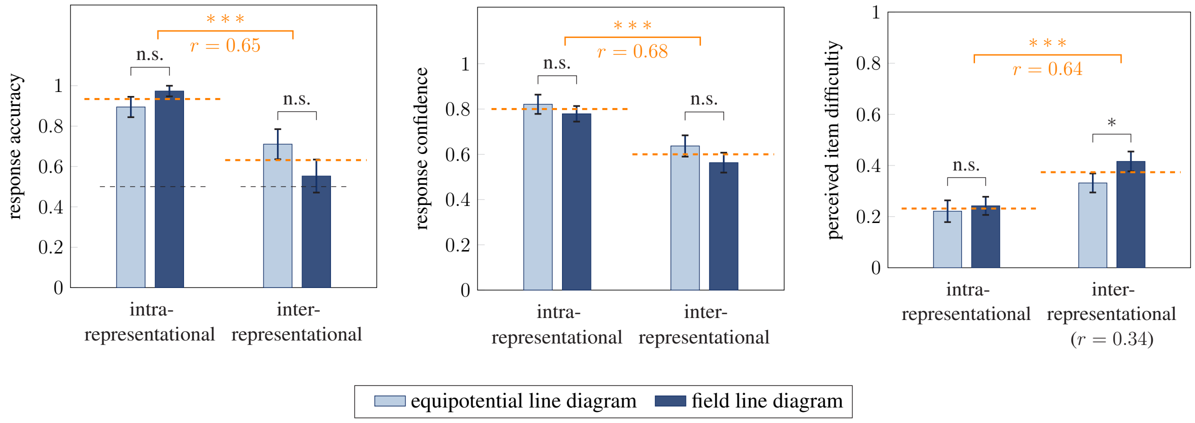
Results

When comparing students' response accuracy between intra- and inter-representational coherence formation items of the symmetrical dipole, a large-sized effect was observed ($z = -4.01, p < 0.001, r = 0.65$; Figure 2 left, orange). Students achieved lower scores on the inter-representational coherence formation items (0.63 ± 0.38) compared to the intra-representational coherence formation items (0.93 ± 0.17).

Regarding students' response confidence and perceived item difficulty of the symmetrical dipole scenario, similar effects were observed (Figure 2 middle and right, orange). For inter-representational coherence formation items compared to intra-representational coherence formation items, students were less confident in their answers ($z = -4.18, p < 0.001, r = 0.68$) and reported higher item difficulty ($z = 3.93$, $p < 0.001$, $r = 0.64$), with large effect size, respectively. Notably, students found it more challenging to judge the field's potential using the field line diagram than to determine the field's magnitude from the equipotential line diagram ($z = -2.07, p = 0.039, r = 0.34$), representing a medium-sized effect.

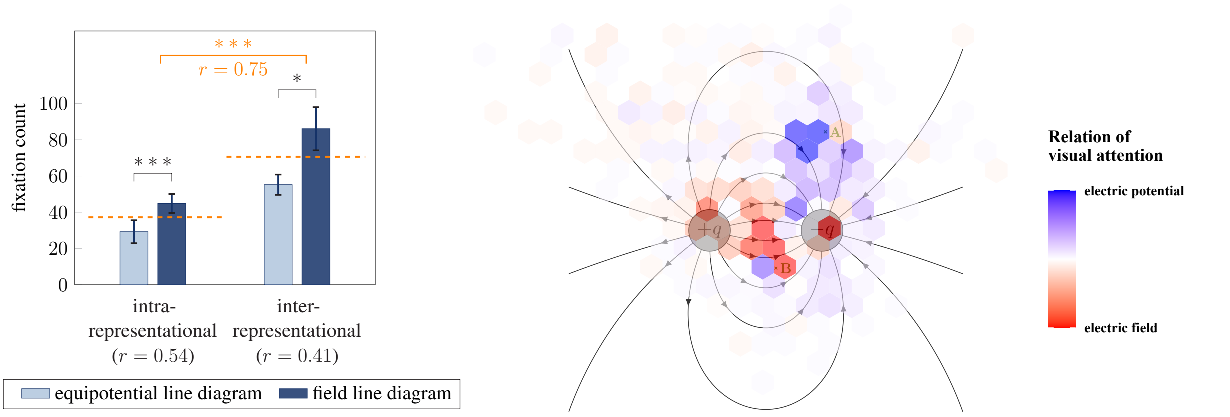
Gaze data analyses revealed that students fixated more often on the diagrams during inter-representational coherence formation items compared to intra-representational coherence formation items ($z = 4.63$, $p < 0.001$, $r = 0.75$), with large effect size (Figure 3 left, orange). Across both item categories, students showed significantly higher fixation counts for tasks involving the field line diagram than for those with the equipotential line diagram ($z = -3.29$, $p < 0.001$, $r = 0.54$ for intra-representational coherence formation items; $z = -2.52$, $p = 0.012$, $r = 0.41$ for inter-representational coherence formation items), with large and medium effect size, respectively.

Figure 2. Students' response accuracy (left), response confidence (middle), and perceived item difficulty (right) for symmetrical dipole items. Performance indicators are compared between intra-representational coherence formation items and inter-representational coherence formation items (means for both item categories in orange) using sign tests for response accuracy and Wilcoxon signed-rank tests for response confidence and perceived item difficulty. Comparisons between items involving equipotential line diagrams and field line diagrams are conducted using McNemar tests for response accuracy and Wilcoxon signed-rank tests for response confidence and perceived item difficulty (* / * / n.s. statistical significance $p < 0.05$ / $p < 0.001$ / not significant, effect size r, black dashed lines indicate guessing probability, error bars represent 1 SEM).**



When the equipotential line diagram of the symmetrical dipole was presented, response accuracy did not differ between the intra- and the inter-representational coherence formation task ($p = 0.07$). However, students allocated significantly more visual attention to the equipotential line diagram when evaluating the field's magnitude compared to its potential ($z = -3.87, p < 0.001, r = 0.64$).

Figure 3. Students' fixation counts on the diagrams for symmetrical dipole items (left) and visual attention difference pattern when processing the field line diagram (right). Left: Fixation counts are compared between intra-representational coherence formation items and inter-representational coherence formation items (means for both item categories in orange) and between items involving equipotential line diagrams and field line diagrams using Wilcoxon signed-rank tests (* / * statistical significance $p < 0.05$ / $p < 0.001$, effect size r, error bars represent 1 SEM). Right: Hexagons illustrate differences in students' visual attention when analysing electric potential (blue) versus field magnitude (red) in the field line diagram. Colour intensity represents the magnitude of attention difference between the two tasks.**



In contrast, when students were shown the field line diagram of the symmetrical dipole, students achieved significantly lower scores (0.97 ± 0.16 versus 0.55 ± 0.50; $\chi^2(1,38) = 12.50$, $p < 0.001$, $OR = 17$) and fixated significantly more often on the diagram ($z = -3.93$, $p < 0.001$, $r = 0.64$) when they judged the field's potential compared to its magnitude. Students' gaze patterns also revealed task-specific attention distribution within the field line diagram (Figure 3 right). When determining the field's magnitude, students predominantly focused on the charges and the field lines surrounding point B. Conversely, when assessing the field's potential, their attention was directed toward point A and the area around the negative charge.

Discussion And Outlook

When handling electric field representations, students demonstrated lower response accuracy, reported lower confidence, perceived higher item difficulty, and allocated more visual attention to the representations when inter-representational coherence formation was required compared to items that involve intra-representational information extraction. These findings align with frameworks from cognitive psychology that distinguish between two facets of representational competences: visual understanding of a single representation and connectional understanding of different representations (Rau, 2017; Seufert, 2003).

In the context of electric fields, these results suggest that students possess strong visual understanding of equipotential and field line diagrams. Contrary to prior studies, no difficulties in associating field line density with the field's magnitude were observed (Bollen et al., 2017). Instead, students exhibited targeted focus on the field lines around the point with higher field magnitude. Moreover, nearly all students correctly judged the field's magnitude from the field line diagram, which implies that their visual strategies were guided by top-down processes rather than by surface features of the diagram, indicative of advanced visual expertise.

However, consistent with earlier research on electric fields, students encountered significant challenges in connectional understanding (Campos et al., 2023). Specifically, when tasked with assessing the field's potential from a field line diagram, their performance was hardly above guessing probability, they reported high item difficulty and showed high cognitive invest. While students performed well in judging the field's magnitude from a field line diagram, these findings suggest a specific lack of representational competence in relating field lines to electric potential. To shed light on students' difficulties and reveal expertise characteristics, further analyses will focus on students' reasoning and comparisons between high- and low-achieving students.

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Improving Problem-Solving Skills Using Entrepreneurial STEM Intervention

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This study aims to provide an example for potential future interventions in the context of entrepreneurship and sustainability and enhance problem-solving skills with an entrepreneurial STEM intervention. Fourteen senior pre-service chemistry teachers (PTs) worked in five small groups, each developing a distinct STEM project (e.g., making soap from used cooking oil). For each project, the groups were required to identify relevant Sustainable Development Goals (SDGs) and prioritize social entrepreneurship. Data was collected using the Interpersonal Problem-Solving Inventory (pre and post) and PTs' reflection forms (post). The quantitative data indicated that the implemented STEM activity significantly impacted the sub-dimensions of negative approach to interpersonal problems, low self-confidence, and unwillingness to take responsibility in PTs' interpersonal problem-solving skills. The qualitative data pointed to the changes in participants' capability of making connections between chemistry and everyday life. PTs have stated that they have gained valuable experience in laboratory practice and project writing, both of which would contribute highly to their career. In addition, some of the PTs have stated that the intervention improved their entrepreneurial skills. Lastly, the study contributes to the field by bringing authenticity to STEM education by incorporating social and green entrepreneurship and supporting students' problem-solving skill development.

Keywords: *Entrepreneurial STEM, problem-solving, social entrepreneurship*

Introduction

Recently, STEM education has begun to focus on various topics, including sustainability and entrepreneurship. When the research on entrepreneurship is reviewed, it is commonly viewed as financial entrepreneurship in education rather than other types, such as social, innovative, and sustainable entrepreneurship. While financial entrepreneurship focuses on monetary expectations through performing different activities such as starting a business and selling a product or a service with profit (Hisrich & Peters, 2002), social entrepreneurship focuses on social change and cultural issues rather than monetary expectations (Barberá-Tomás et al. 2019), and green entrepreneurship focuses on solving environmental problems using sustainable processes (QAA, 2018). Currently, the integration and implementation of entrepreneurship in STEM education is a new area with a limited number of studies. The current study aims to integrate enterprise education and STEM education while promoting social and green entrepreneurship. Enhancing entrepreneurial STEM education is important because entrepreneurial thinking and practices are essential for fostering sustainable, collegial, and collaborative interactions that enable innovative STEM practices (Abd-El-Khalick et al., 2011). One of the common features of STEM education and entrepreneurship is their focus on generating solutions to real-life problems. In this regard, entrepreneurial skills such as problem solving and creativity play a crucial role in enhancing the understanding of the relationship between STEM and real-world contexts (Bicer et al., 2017; Sarı et al., 2022; Kaya-Capocci et al., 2024). Moreover, although there are studies indicating that entrepreneurial STEM activities positively affect students' problem-solving skills, there is a need for an increase in the number of such studies (Sarı et al., 2022; Kaya-Capocci et al., 2024). This study investigated the effects of Entrepreneurial STEM activities on students' problem-solving skills through the implementation of activities structured according to the nine-step Engineering Design Process proposed by Hynes et al. (2011). Previous research highlights Engineering Design

Process–based STEM practices as effective pedagogical tools for fostering 21st-century skills, including problem-solving abilities (Hacıoğlu et al., 2016), and for enhancing students' conceptual understanding (Tatlı, 2022).

Methodology

The research questions (RQs) of this study are:

1. How do PTs' problem-solving skills change following an entrepreneurial STEM intervention?

2. What do PTs think about the effectiveness of the intervention they've completed?

Participants

This study was conducted as part of a lesson titled "Service to Community" at a public university during the first semester of the 2024-2025 academic year. Fourteen PTs participated in the study.

Research Tools

While PTs' reflection form (post) was used to collect qualitative data, the Interpersonal Problem-Solving Inventory (pre and post) was used to collect quantitative data.

Interpersonal Problem-Solving Inventory (PSI)

The scale was developed by Çam and Tümkaya (2007) to assess interpersonal problem-solving skills. The scale consists of 50 items and yielded a five-factor solution: Negative approach to interpersonal problems, Constructive approach to interpersonal problems, Low self-confidence, Unwillingness to take responsibility, and an Insistent-persevering approach. It has been determined that the inventory applies to university students between the ages of 18 and 30. While the Cronbach's alpha internal consistency values of the subscales ranged from .67 to .91, the test-retest stability coefficients varied from .69 to .89.

Reflection Form

Following the completion of the intervention, the pre-service teachers (PTs) individually completed a reflection form. The form included two open-ended questions designed to explore their perceptions and experiences regarding the intervention (see Table 5). The questions were reviewed by two field experts to ensure their comprehensiveness and appropriateness.

Intervention

The intervention was conducted over 12 weeks during the first semester of the 2024–2025 academic year. After completing the PSI, the pre-service chemistry teachers (PTs) were organized into small groups and asked to identify problem situations related to the United Nations' Sustainable Development Goals (SDGs). The Sustainable Development Goals (SDGs) addressed by Group 1 are presented in Table 1. During the intervention, each group developed a distinct social entrepreneurship–oriented STEM project. The projects were: (1) Sustainable Soap Production from Used Cooking Oil, (2) Removal of Heavy Metals from Simulated Water Using Eggshell Powder, (3) Bioplastic Protective Face Masks from Banana Peels, (4) Eco-Friendly Soap Sheets, and (5) Smart Edible Films and Coatings with Natural Spoilage Indicators. The problem scenarios of the five social entrepreneurship projects are presented in Table 2. In addition, the learning objectives of the Group 1 project are provided as an illustrative example in Table 3.

Throughout the implementation of the STEM activities, students followed the nine-step Engineering Design Process proposed by Hynes et al. (2011), which includes: (1) problem identification, (2) problem research, (3) generation of possible solutions, (4) selection of the most appropriate solution, (5) prototype development, (6) testing and evaluation, (7) sharing and reflection, (8) redesign, and (9) finalization. After the intervention, all PTs completed the PSI again and submitted reflective forms.

The SDGs related to Group 1's project are presented in Table 1.

Table 1. SDGs of Group 1's Project.

No	Goal(s)
4	Quality Education (Target 4.7)
6	Clean Water and Sanitation (Target 6.3)
12	Responsible Consumption and Production (Target 12.4 & 12.5)
14	Life Below Water (Target 14.1)

Table 2. Groups' Social Entrepreneurship Interventions and Identified Problems.

Grup	Project Titles and Problem Statements
1	Sustainable Soap Production from Used Cooking Oil This project aims to produce an environmentally friendly cleaning product by recycling used cooking oil, thereby reducing water pollution and promoting sustainable waste management practices
2	Removal of Heavy Metals from Simulated Water Using Eggshell Powder The project focuses on mitigating the risks of heavy metal contamination in wastewater by employing waste eggshells as an eco-friendly, low-cost, and sustainable adsorption material.
3	Bioplastic Protective Face Masks from Banana Peels This project aims to reduce environmental pollution caused by disposable face masks by producing biodegradable bioplastic protective face masks from waste banana peels as a sustainable alternative.
4	Eco-Friendly Soap Sheets The project focuses on developing portable, biodegradable soap sheets as a sustainable alternative to conventional wet wipes, thereby reducing environmental pollution and promoting responsible consumption.
5	Smart Edible Films and Coatings with Natural Spoilage Indicators The project focuses on developing biodegradable edible films and coatings integrated with natural indicators to monitor the spoilage of meat and meat products, thereby enhancing food safety and reducing packaging-related environmental impacts.

Table 3. Learning Objectives of the Group 1 Project

Subject Disciplines	Learning Objectives
Chemistry	- Explain acid–base reactions.
Technology	- Provide examples of interdisciplinary applications of computational thinking.
Mathematics	- Determine an unknown quantity when the ratio of two quantities is given.
Engineering	- Develop and use sketch drawings to support idea generation and problem-solving during the engineering design process. - Gather qualitative and quantitative experimental data. - Document and analyse observations.
Social Entrepreneurship	- Recognize the role of interpersonal communication in social entrepreneurship. - Analyse the social responsibilities of entrepreneurs. - Propose strategies for spreading knowledge, products, and services for societal benefit.

Data Analysis

Quantitative data were analysed using the SPSS 22 package program. The Wilcoxon test was applied separately for each of the five sub-dimensions of the Interpersonal Problem-Solving Inventory. For a significant difference between the pre-test and post-test, the sigma value must be less than 0.005.

The qualitative data were analysed through content analysis. The codes were developed by two researchers. Each form was assigned a code by researchers individually, and these codes were compared to see whether there would be any disagreements. Through these discussions, the variance of 2% between the coders was resolved. The inter-rater reliability for the coding is 98%. The initial letters 'PT' and a number from 1–14 was given to each preservice teacher (i.e., PT-16).

Findings

The current study revealed the following findings related to the RQs, respectively.

RQ1—Investigating PTs' Problem-Solving Skills

In the inventory, which consists of five sub-dimensions, each sub-dimension was separately subjected to the Wilcoxon test, and sigma values were obtained (see Table 4). When examining the sigma values, it was found that the intervention created a significant difference in the sub-dimensions of the Negative approach to interpersonal problems, low self-confidence, and unwillingness to take responsibility. However, it did not create a significant difference in the sub-dimensions of constructive approach to interpersonal problems and insistent-persevering approach.

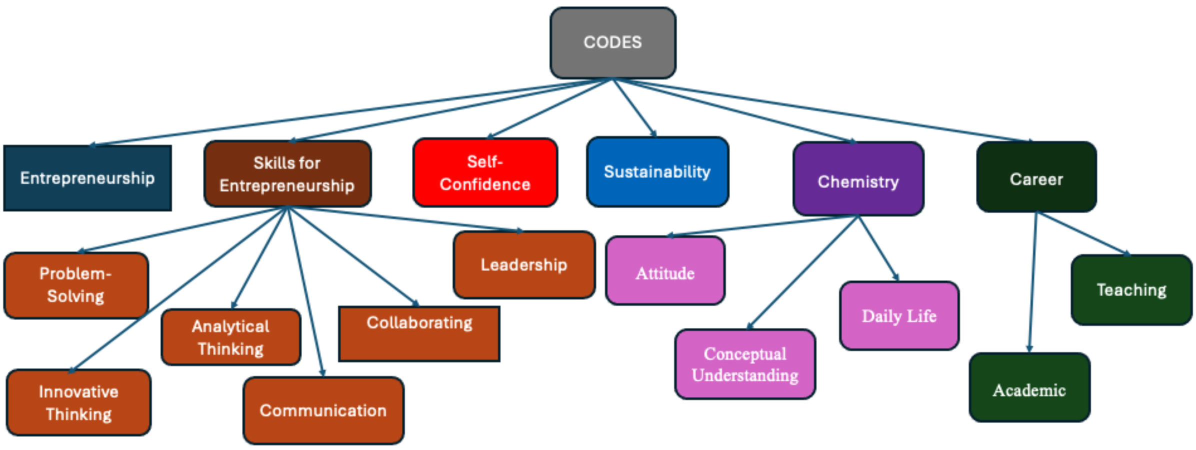
Table 4. The sub-dimensions and sigma values.

The Sub-dimensions	Asymp. Sig. (2-tailed)
Negative approach to interpersonal problems	0.001
Constructive approach to interpersonal problems	0.182
Low self-confidence	0.002
Unwillingness to take responsibility	0.004
Insistent-persevering approach	0.889

RQ2—Investigating Pts' Experiences And Feelings Of The Intervention

To respond to RQ2, PTs' opinions about the intervention were investigated through interview questions, and their opinions were classified under six major codes (see Figure 1 and Table 5).

Figure 1. Concept map for the codes of the study.



The results showed that the intervention strengthened PTs' entrepreneurship potential and the different skills necessary for Entrepreneurship. Besides, some PTs believed that the intervention helped improve their self-confidence. In addition, approximately 25% of PTs stated that the intervention improved their understanding of chemistry, attitudes toward chemistry, and their sustainability awareness by helping them to make connections with the world. Figure 3 shows that problem-solving is the most developed skill (see Figure 3). Furthermore, most of the PTs believed that this intervention was helpful to promote their future careers in both academic and teaching means (see Figure 4).

Table 5. Reflection forms' questions & example excerpts.

• **Interview Questions**
• What are your opinions about the effectiveness of the project you were involved in? • Do you think this project will be helpful later in your career?
Entrepreneurship *"These experiences have encouraged me in what I can achieve in Entrepreneurship. I will continue to take part in entrepreneurship interventions in the future that both generate financial and social benefits (PT-4)*
Skills for Entrepreneurship & Self-confidence • **Problem-Solving** *"The project improved my problem-solving skills, now I am more adept at using search engines and I am better at researching." (PT-1)* • **Collaboration** *"This project improved my teamwork and collaboration skills" (PT-10)* • **Innovative Thinking & Analytical Thinking** "*Trying to find solutions to environmental problems has improved my innovative and analytical thinking skills*" (PT-10) • **Communication & Leadership & Self-confidence** *"In this project, I was the team leader, in this way, I improved my communication and leadership skills and increased my self-confidence (PT-10)*
Sustainability "*Seeing that we can contribute to the environment by repurposing waste materials has increased my interest in and awareness of sustainability. In the future, I am to take part in interventions that focus on developing more sustainable solutions.*" (PT-9)
Chemistry • **Attitude & Conceptual Understanding & Daily Life Connection** "*Realizing the chemical properties of the eggshells makes chemistry more real and meaningful for me. I realized how effectively the eggshells we usually dispose of can be used in addressing the significant use of removing heavy metal accumulations, that pose a risk to human health. This allows me to use chemistry in my daily life, and this allows me to recognize I enjoy this subject. Once again, we learned new elimination methods for pollution, such as phytoremediation"*. (PT-9)
Career • **Academic Experience** "*This project provided me with the opportunity to conduct scientific research. In this regard, I believe it has contributed to my academic and career development." (PT-10)* • **Teaching Experience & Sustainability** *"The knowledge I've gained in this experience will be useful in my teaching life. For example, I can teach my students about making soap from used cooking oils, as well as about information on sustainability." (PT-8)*

Figure 2. Percentage of codes for the first question from the form.

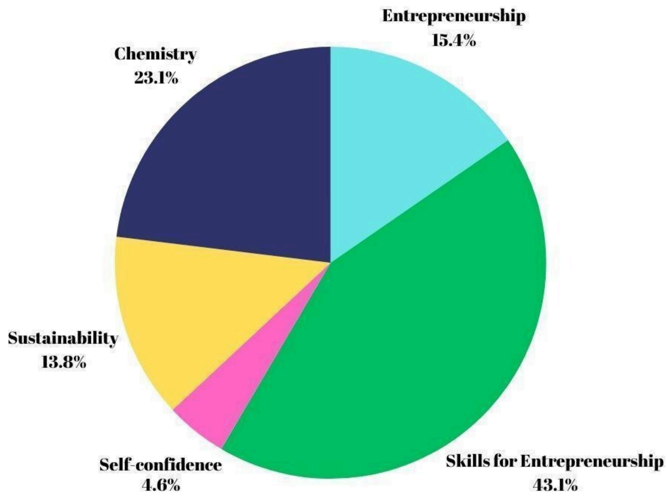


Figure 3. Percentage of sub-categories for "Skills for Entrepreneurship".

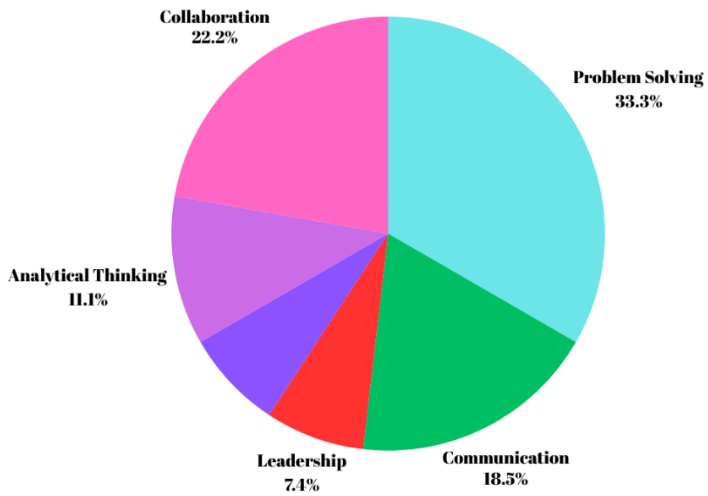


Figure 4. Percentage of codes for the second question from the form.

Discussion & Conclusion

The study aimed to increase PTs' problem-solving skills within the context of entrepreneurial STEM education. In the current study, qualitative data showed that 33.33% of PTs believed the effectiveness of the intervention to improve their problem-solving skills. A review of the literature on educational research reveals that studies examining problem-solving skills have generally focused on no more than three sub-dimensions (Kaya-Capocci et al., 2024). However, in the present study, the Interpersonal Problem Solving Inventory developed by Çam and Tümkaya (2007), which conceptualizes problem-solving skills across five sub-dimensions and considers three sub-dimensions insufficient for an in-depth analysis, was employed. This approach enabled a more comprehensive examination of the effects of Entrepreneurial STEM activities on problem-solving skills across five distinct sub-dimensions. Examining the results of the interpersonal problem-solving inventory, which constitutes the quantitative data, a significant difference was observed in three out of the five sub-dimensions, while no significant difference was found in the other two. The sub-dimensions with a significant difference were negative approach to interpersonal problems, low self-confidence, and unwillingness to take responsibility. The sub-dimensions without a significant difference were constructive approaches to interpersonal problems and an insistent-persevering approach. The negative approach to interpersonal problems dimension refers to intense negative emotions and cognitions, such as helplessness, pessimism, and sadness experienced when individuals encounter a problem (Çam & Tümkaya, 2007). The finding that STEM activities reduced PTs' negative perceptions toward problems supports the assertions of Topsakal et al. (2022). This positive shift may be attributed to students' learning how to systematically approach and solve problems by following the Engineering Design Process during STEM activities. The unwillingness to take responsibility reflects a reluctance to assume responsibility in problem-solving situations, while the low self-confidence dimension represents insecurity regarding one's ability to solve problems (Çam & Tümkaya, 2007). In the present study, positive changes were observed in both the unwillingness to take responsibility and low self-confidence sub-dimensions. These findings suggest that learning how to address a real-life problem within Entrepreneurial STEM activities may enhance PTs' self-confidence, enabling them to take greater responsibility in the problem-solving process.

The qualitative data also showed that some PTs believed that this intervention positively affected Entrepreneurship. Besides, they also stated the intervention was useful to improve some crucial skills (communication, leadership, innovative thinking, analytical thinking, and collaboration) and self-confidence, which are related to becoming and succeeding as an entrepreneur. In addition, it seems that the intervention presented here was effective in improving PTs' understanding of the chemistry topics and attitudes toward chemistry by helping them to make connections between real-world and chemistry knowledge. Lastly, we believe that the study is going to add a unique contribution to the related literature because it seems to be helpful to increase PTs' sustainability awareness.

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