FORMATION OF COMPETENCE VIA CHEMISTRY PRACTICAL CLASSES IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

Nataliia Tereshchenko[1]

DOI: https://doi.org/10.30525/978-9934-26-715-4-33

Abstract. The competence of sustainable development regarded as an integrative set of the aforementioned competencies, which together constitute the ability to act responsibly and effectively in the context of contemporary ecological, social, and economic challenges. Formation of students' competence is a crucial component of modern higher education, aimed at preparing specialists capable of addressing global environmental challenges. Chemistry, as a fundamental natural science, provides unique opportunities for integrating sustainable development principles into the educational process. In particular, chemical educational practices contribute to the achievement of several Sustainable Development Goals (SDGs): Goal 4 (Quality Education), promoting rational resource use (Goal 12), raising awareness of chemical processes influencing climate change (Goal 13), safeguarding of ecosystems essential for food security, alongside the mainstreaming of biodiversity into national development strategies (Goal 15). Thus, integrating sustainable development competence into chemistry education not only enhances professional training but also ensures alignment with the global agenda for sustainable development in an era of profound transformations. *The purpose of the paper* is to highlight the pedagogical potential of practical chemistry classes in fostering ecological awareness, value based orientations, and responsible professional behavior among students. Special attention given to the integration of sustainable development principles into laboratory work and project-based learning. The study seeks to demonstrate ecological-oriented chemistry tasks contribute to the formation of scientific reasoning, systems thinking, value-based orientations, and personal responsibility in

[1] Candidate of Chemical Sciences, Senior Researcher in Chemistry,
Associate Professor at the Department of General, Organic and Physical Chemistry,
National University of Life and Environmental Sciences of Ukraine, Ukraine

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solving professional and environmental challenges. *Methodology* of the study based on general research methods: analysis and synthesis, induction and deduction, observation and abstraction. The introductory diagnostic testing conducted on a voluntary basis. Students performed the tasks independently in accordance with the principles of academic integrity. A set of pedagogical analysis methods applied, including analytical review, interpretation, classification and generalization of experimental data obtained during the analysis of diagnostic testing results. *Results* of the study indicate that practical chemistry lessons designed with an emphasis on sustainable development significantly contribute to the formation of environmental competencies among students. The work carried out with students of the specialties «Landscape Design» and «Food Technologies». At the introductory stage, diagnostic testing conducted on a voluntary basis to identify educational needs, assess the initial level of knowledge, and determine the degree of ecological competence formation. Practical classes included pedagogical analysis and the selection of effective didactic methods aimed at fostering sustainable development thinking. Students performed tasks independently in accordance with the principles of academic integrity. The learning process emphasized the strengthening of theoretical knowledge and its application in practice, the development of analytical competencies. Participants demonstrated an enhanced ability to connect theoretical chemical knowledge with real environmental challenges, particularly in monitoring xenobiotics in environmental objects and food products. The integration of theoretical knowledge with laboratory practice and complex project-based tasks fostered the development of analytical skills, systems thinking, and a sense of social responsibility. The design of practice-oriented tasks further contributed to the consolidation of ecological competence as a key component of professional training in the context of sustainable development. Based on laboratory analyses, students were able to propose technological solutions for the prudent application of fertilizers, the regulation of soil pH, and the optimization of irrigation regimes, in particular highlighting drip irrigation and the method of fertilizer application through drip systems. During practical sessions focused on detecting xenobiotics in edible oils, students suggested refining processes and emphasized the importance of complying with sanitary and hygienic standards across food chains. Such compliance is possible through the

monitoring of critical control points in production. Since laboratory control methods are continuously evolving, lifelong learning becomes an essential skill-one that is formed at the university and further developed throughout professional life. At the final stage of the learning process, formative assessment conducted through tasks (tests, open-ended questions, essays) and applied to all participants of the educational process as a mandatory element of a methodologically designed class, aimed at obtaining feedback and evaluation. *Practical implications.* Integrating environmental principles into practical chemistry lessons enhances students' professional training by linking scientific knowledge with real-world environmental challenges. Such pedagogical approaches strengthen the capacity of future specialists to design technological solutions for pollution reduction, apply green chemistry practices, and comply with sanitary and hygienic standards in professional contexts. In addition to mastering subject-specific knowledge, students develop ecological awareness, analytical skills, and social responsibility. These competencies are essential for addressing global sustainable development challenges in sectors such as food production, agriculture, environmental management, and landscape design. *Value/ originality.* The originality of this study lies in its pedagogical focus on integrating ecological principles into practical chemistry education. Unlike traditional laboratory training that emphasizes only technical proficiency, this approach combines scientific knowledge with practical skills in real and near-real professional tasks. These tasks embody sustainable development values and foster systems thinking, ethical awareness, and interdisciplinary problem solving.

INTRODUCTION

In examining the role of the United Nations Sustainable Development Goals (SDGs) in education, international scholarship underscores that SDG 4 (Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all) – functions as a pivotal driver for the realization of the remaining sixteen goals [1, p. 40]. Recent systematic reviews and bibliometric analyses published in Scopus-indexed journals confirm that quality education underpins lifelong learning and inclusive practices, while simultaneously providing the foundation for evidence-based strategies aimed at building equitable, inclusive, and

sustainable education systems. These findings reinforce the pivotal role of SDG 4 in shaping educational policies and pedagogical frameworks aligned with sustainable development [1; 2]. These results reinforce the pivotal role of Sustainable Development Goals in shaping educational policies and pedagogical frameworks aligned with sustainable development, underscoring the necessity of didactic design. Among the natural science disciplines that provide subject-specific knowledge essential for achieving the SDGs, chemistry holds one of the central positions. Practical chemistry classes, through practice-oriented learning, serve as a means of cultivating sustainability-oriented competencies, while teachers, in line with global aims, implement multifactorial pedagogical strategies that address students' educational requests and integrate sustainable development values into the learning process [3; 4]. This process is relevant across different countries, since the formation of professional competencies is multi-stage and depends on a complex set of factors: from systemic and socio-economic conditions to individual cognitive characteristics manifested in motivation, learning activity, and the use of digital platforms. The pedagogical design of practical chemistry classes has a thematic foundation that enables educators to address issues directly related to the Sustainable Development Goals. Goal 4 (Quality Education) is realized through the consideration of students' educational requests and the application of diagnostic methods, which foster individualized learning and the development of competencies for lifelong education. Goal 6 (Clean Water and Sanitation) is advanced by integrating laboratory activities focused on water analysis, cultivating responsibility for the quality of natural resources. Goal 12 (Responsible Consumption and Production) is achieved through embedding the principles of green chemistry and environmentally oriented tasks, thereby shaping a culture of rational resource use. Goal 13 (Climate Action) is supported by research assignments that highlight chemical processes influencing climate change, encouraging ecological thinking and readiness for mitigation actions. Finally, Goal 15 (Life on Land) is addressed through interdisciplinary approaches, particularly in environmental sciences and landscape management, which foster responsibility for soil conservation, biodiversity protection, and sustainable ecosystem management. In this way, practical chemistry classes, through practice-oriented learning, become a means of

cultivating sustainability-oriented competencies, while teachers implement multifactorial pedagogical strategies that respond to students' educational requests and integrate sustainable development values into the learning process in accordance with the national legislative framework [5; 6; 7].

In Ukraine, alongside global challenges related to the transformation of educational content and approaches, additional unpredictable factors emerge as a direct consequence of the ongoing war. These circumstances intensify the complexity of the educational process, creating gaps in students' knowledge, disrupting learning continuity, and affecting students' psychological resilience. Understanding these processes and conducting a detailed analysis of educational losses substantiate the necessity of additional pedagogical work by university instructors, aimed at compensating war-induced learning gaps, restoring academic motivation, and supporting students' adaptation to new educational environments [8; 9]. Practical chemistry classes, designed with sensitivity to these conditions, become a crucial tool for restoring learning motivation, strengthening ecological competence, and aligning professional training with the principles of sustainable development. Practical chemistry lessons serve as a pedagogical space for the integration of theoretical knowledge and applied research activities. Students' educational requests become the starting point for designing the content of these lessons, ensuring their relevance to the level of preparation and professional interests of participants. As noted by Martyniuk [10] and León [11], the formation of professional competencies has a multidimensional character and requires an interdisciplinary approach, particularly in the fields of natural sciences, food technologies, and landscape design. In this context, the use of diagnostic and statistical methods, such as clustering of students' professional competencies, is highly relevant, as it allows the identification of groups of educational needs and directs didactic work toward their fulfillment. Generalized ecological, analytical, and social competencies formed through tasks of different content, designed in accordance with the subject matter and the specificity of each specialty. For instance, the formation of eco-analytical competence based on knowledge of pollutant compounds such as heavy metals and polycyclic aromatic hydrocarbons. Students of Landscape Design offered practical tasks with environmental objects such as water, soil, and plants,

while students of Food Technologies work with food chains and products. Both groups acquire knowledge of sanitary and hygienic standards and the impact of chemical compounds on human health, but their practical skills shaped through distinct case studies. In this way, the clustering of competencies enables the differentiation of educational trajectories, where students of «Landscape Design» develop ecological responsibility and analytical competence through environmental monitoring tasks. Students of «Food Technologies» strengthen eco-analytical and social competence through food safety and xenobiotic detection tasks, and cross-disciplinary clusters foster communicative and social competence through teamwork, presentation of results, and participation in discussions. Such an educational process is directly aligned with the Sustainable Development Goals. Particularly Goal 4 (Quality Education), Goal 3 (Good Health and Well-Being), Goal 12 (Responsible Consumption and Production), and Goal 15 (Life on Land), as it promotes inclusive and equitable learning, enhances awareness of health impacts of pollutants, encourages responsible use of resources, and cultivates ecological responsibility in relation to environmental protection.

1. Quality Education and Lifelong Learning

Quality education (Goal 4) is implemented through practical chemistry classes that are designed to meet students' educational requests, take into account their level of preparation, and ensure academic integrity. This approach allows not only the assimilation of learning material but also the development of competencies necessary for lifelong learning. It is well known that first-year students largely organize their educational activities based on their prior school experience. However, several researchers [12; 13], emphasize that this experience is often insufficient for effective entry into a new academic environment, since university education increases demands for independence, responsibility, and self-regulation. D. Martino [14], Analyzing the responses of students in natural science majors, particularly in a non-chemical discipline that is also grounded in the knowledge of laws, the ability to apply symbolic language, and the properties of objects, demonstrates that the transition from school to university learning is accompanied not only by increased cognitive load and larger volumes of information but also by significant emotional challenges. This dual burden

highlights the necessity of pedagogical strategies that address both the intellectual and affective dimensions of learning, ensuring that students can adapt to the heightened demands of academic study while maintaining motivation and resilience. Such an approach is directly connected to the Sustainable Development Goals, especially Goal 4 (Quality Education), which emphasizes inclusive and equitable access to learning opportunities. In the pedagogical context, the above-examined and acknowledged results can be interpreted as manifestations of a crisis of learning motivation, which requires targeted support from instructors. Lifelong learning involves the development of skills that remain relevant beyond the university setting: critical thinking, ecological thinking, and analytical competencies. These skills enable students to adapt to new challenges, integrate knowledge from different fields, and make scientifically grounded decisions. In this context, lifelong learning also encompasses digital literacy, interdisciplinarity, and social responsibility, as modern chemistry classes integrate analytical software, online resources, and environmentally oriented tasks that prepare students for professional transformations and global challenges (Table 1).

Individualization of learning is achieved through the use of diagnostic methods and pedagogical analysis, which allow practical tasks to be adapted to different specialties, such as «Landscape design» and «Food technologies». This conceptualization is further exemplified in Table 1, which summarizes the formation of competencies through chemistry education for sustainable development. The pedagogical aspects described in the table demonstrate that the formation of competencies in chemistry education is multidimensional and extends far beyond purely professional training. It contributes to the development of professional competencies aligned with students' future career paths. The connection between theory and practice is ensured through the integration of laboratory research, analytical tasks, and project work, enabling students to apply theoretical knowledge to solving real environmental problems. Such an approach fosters not only professional competence but also social responsibility, which is a key factor in achieving Goal 4 (Quality Education).

Table 1

Competency formation through chemistry education for Sustainable Development

Competency	Implementation in Chemistry Practical Classes	Contribution to SDGs
Self-regulation & self-direction	Students are familiar with lists of analyte compounds that have ecological impact and require professional attention; they perform laboratory tasks; maintain laboratory journals; and develop individual strategies for independent work as well as collaborative activities	Development of responsibility and the ability for self-regulation
Learning beliefs & strategies	Adaptation of practical tasks to specific specialties, personalized learning trajectories; design of practical assignments based on real professional problems that shape knowledge and understanding of the chemical composition of objects; effective strategies for acquiring skills in searching and using theoretical information; students compare their results with literature data and construct a scientific system of subject-specific knowledge	Improvement of learning quality and adaptability
Analytical competencies	Environmentally oriented studies and their results are openly discussed by students during classes and seminars; discussions and presentations enhance motivation for learning and highlight the purpose of implementing eco-technologies	Formation of intrinsic motivation and ecological responsibility
Critical & ecological thinking	Analysis of experimental results; ecological tasks involving monitoring of quality and safety indicators (chemical composition of mineral fertilizers, content of xenobiotics in food products, analysis of industrial wastewater, and emissions of pollutants into the air)	Deepening of professional skills for ecological monitoring
Information literacy	Use of analytical software, databases, and digital resources; engagement with international scientific databases (Scopus, PubChem); evaluation of source reliability and correct citation; development of academic integrity and social responsibility skills	Advancement of digital literacy and critical thinking for achievement

Each competency in Table 1 carries its own pedagogical significance. «Self-regulation and self-direction» form autonomy and metacognitive awareness, preparing students for professional contexts where self-management is indispensable. «Learning beliefs and strategies»

are formed and reinforced through the adaptation of tasks to specific specialties and the use of real professional problems, which contributes to the establishment of a coherent system of subject-specific knowledge and critical engagement with sources. «Analytical competencies» are formed and developed through open discussions and seminar presentations of environmentally oriented studies, which strengthen motivation and establish scientific communication skills. «Critical and ecological thinking» is formed and advanced by analyzing fertilizers, food products, wastewater, and industrial emissions, training students to evaluate risks and anticipate ecological consequences. «Information literacy» is formed and established through the use of analytical software, international databases, and the evaluation of source reliability, which reinforces academic integrity and social responsibility. Taken together, these pedagogical dimensions demonstrate how chemistry education functions as a structured platform for lifelong learning, combining technical expertise, ecological awareness, and social values [10; 14]. This integrated approach ensures that students are systematically prepared to meet global challenges and underscores the transformative role of education in achieving sustainable development.

2. Resource Efficiency and Rational Use

Global challenges articulated in the United Nations Sustainable Development Goals remain central benchmarks for state policy and increasingly embedded in contemporary pedagogical practice. According to the *Sustainable Development Report 2025* prepared by the Sustainable Development Solutions Network under the leadership of Jeffrey D. Sachs, Ukraine ranks 42nd out of 167 countries with an overall score of 75.7 [15, p. 12]. This position reflects a relatively high level of national engagement in the implementation of the Sustainable Development Goals. At the same time, the UN Report for 2025 emphasizes that the world is at a critical juncture in advancing the 2030 Agenda. Despite notable progress in health, education, and access to infrastructure, the pace of achievement remains insufficient [16]. This situation underscores the urgent need to intensify the dissemination of information about the Sustainable Development Goals, many of which directly related to ecological issues. Such efforts enhance public awareness and foster the capacity to act in pursuit of these objectives,

integrating environmentally responsible solutions across diverse sectors of human activity.

Within this framework, the field of landscape design plays a particularly significant role, as it directly contributes to the creation of favorable ecological environments and serves as a crucial factor in ensuring environmental security in the context of climate change. During chemistry classes, the study of system objects and their chemical properties, as well as their biological impact, can be delivered through effective practical tasks that foster applied understanding. The ability to make scientifically grounded and rational decisions is essential for contributing to urban and rural greening and for creating resilient ecosystems. Such professional activity based on the integration of disciplinary expertise with ecological principles of sustainable development. Within this framework, pedagogical analysis suggests that the educational process should be oriented toward the development of specific skills through clearly defined didactic methods. Analytical thinking formed through laboratory work, where students investigate chemical properties and evaluate biological impacts in applied contexts. Information literacy strengthened through the study of scientific literature, including the use of international databases and critical evaluation of sources. Reflective thinking and argumentation advanced through essay writing, which enables students to articulate ecological challenges and propose scientifically grounded solutions. Scientific communication skills are developed through oral reports and seminar presentations, fostering the ability to present findings clearly and to engage in academic discussion. Finally, interdisciplinary integration and teamwork are cultivated through project-based learning, where chemistry, ecology, and design knowledge combined to create practical solutions for sustainable urban and rural environments. This structured orientation provides the pedagogical space for the formation of essential skills and works toward shaping future professionals who acquire competencies necessary for ecological responsibility and resilience in the context of sustainable development. Scholarly publications by Ukrainian authors emphasize the importance of ecological education as the foundation for cultivating ecological culture and responsible attitudes toward the environment [17; 18].

An extended exploration of «Resource Efficiency and Rational Use» in the pedagogical context of natural sciences is logically connected with

the «Science-Technology-Society-Environment» (STSE) approach [19]. The application of STSE in chemistry teaching contributes to the development of ecological awareness, as students recognize the consequences of chemical use for both the environment and society. It also fosters the cultivation of critical thinking, enabling learners to analyze real problems such as water, soil, and air pollution and to propose scientifically grounded solutions. Moreover, it supports the integration of knowledge with social and environmental issues, as students link chemical properties of substances with their biological effects and broader societal implications. This orientation ensures that chemistry education not only builds disciplinary expertise but also prepares future professionals to act responsibly within the framework of sustainable development [19].

In schools and higher education institutions, thematic activities and ecological science clubs play an important role in shaping sustainable development competencies. These initiatives create an additional educational space that enhances motivation, strengthens ecological responsibility, and provides opportunities for students to engage in collaborative learning and research aimed at addressing pressing environmental challenges. Over the past decade, research and practice in the field of higher education for sustainable development have expanded considerably. In the curricula of Ukrainian higher education institutions, the competency-based approach has already been widely implemented. The quality of professional training is determined by the level of competence formation, which involves not only the acquisition of theoretical knowledge but also the development of skills and abilities applicable in professional practice [20; 21]. For example, in the preparation of landscape design students, practical tasks should be structured to include the study, analysis, and justification of indicators related to ecological and technological processes. Such tasks may encompass the evaluation of chemical properties of materials, the assessment of their biological impact, and the exploration of sustainable approaches to resource efficiency and rational use. In this context, students are encouraged to engage in scientific inquiry aimed at identifying eco-technological solutions, thereby integrating disciplinary expertise with ecological principles of sustainable development.

First and foremost, it deepens the understanding of fundamental chemical concepts such as concentration, molarity, mass fraction, and the ratio of

«concentration-solvent». Mastery of these principles requires precise calculations, attention to detail, and verification of the correctness of one's actions, which directly fosters the development of analytical competence. The practical preparation of working solutions for plant nutrition and the dilution of concentrated substances serves a pedagogical purpose: students not only follow an algorithm but also comprehend its meaning and the consequences it has for plant organisms and soil systems. This process cultivates research skills and the ability to apply theoretical knowledge in real-world contexts. Furthermore, the comprehension of both quantitative and qualitative characteristics of solutions develops the skill of rational resource use, safe handling of chemical substances, and ecological responsibility. Students learn to recognize that improper dosing or careless use of reagents can lead to environmental harm, thereby reinforcing the importance of sustainable practices. The preparation of solutions during laboratory work in subgroups stimulates communicative competencies, encouraging collaboration, negotiation, and the articulation of reasoning. It fosters the ability to justify methodological choices, explain individual decisions, and coordinate collective actions. In this way, the pedagogical integration of solution preparation tasks contributes simultaneously to the advancement of analytical, research, ecological, and communicative competencies. It transforms routine laboratory exercises into a comprehensive educational tool that prepares students for professional practice in chemistry and related fields, while instilling values of responsibility, sustainability, and cooperative learning. This holistic approach ensures that students acquire not only technical proficiency but also the broader set of skills and attitudes necessary for addressing contemporary environmental and societal challenges.

The consideration of the optimal chemical composition and physical parameters of soil, which ensure the availability of nutrients and the stability of the water–aeration regime, fosters in students an understanding of the causal relationships between substrate properties and agronomic outcomes. This enables them to explain why parameters such as bulk density, porosity, acidity, and electrical conductivity determine the intensity of plant growth, ornamental quality, and productivity. In the developed practical work, research materials and model chemical systems were applied, allowing students to investigate the influence of substrate composition on plant

development and to substantiate agronomic conclusions with empirical data. In the study, the results of ten soil samples were examined and analyzed in detail: a soil without additives (control sample, CS) and nine substrate mixtures created by combining three components in different proportions - decomposed corn stalks, decomposed shiitake mushroom substrate, and perlite [22].

This approach not only provided a comparative analysis of physicochemical parameters but also served as a pedagogical tool for cultivating ecological awareness, analytical competence, and the ability to integrate chemical knowledge with practical agricultural applications. The control soil was characterized by high bulk density (1.28 g/cm³) and low porosity (47.38%), which restricted root system development and led to poorer agronomic indicators, including reduced plant height, thinner stems, smaller leaf area, and fewer flowers. In contrast, the substrate mixtures provided an optimal range of bulk density (0.57-0.74 g/cm³) and porosity (54.33-71.48%), which facilitated better root penetration, more active gas exchange, and enhanced water-holding capacity. These findings illustrate the pedagogical value of integrating soil chemistry and physics into the educational process, as students not only acquire theoretical knowledge but also learn to interpret experimental data in terms of practical agronomic outcomes. This approach strengthens analytical skills, ecological awareness, and the ability to apply chemical principles to real-world environmental and agricultural challenges. The acidity of the substrates (pH 6.51-7.10) ensured optimal availability of macro- and microelements, while electrical conductivity (≥0.27) indicated a higher nutritional value of the mixtures compared to the control soil.

Pedagogical support in processing and comprehending such a broad set of theoretical and practical data can be provided through the introduction of new didactic tools at this stage of learning: associative cards, associative schemes, and homework assignments focused on their preparation (Table 2). The specific features of the teacher's pedagogical work in using informative cards lie in the multifunctionality of this tool and the differentiated approach to the formation of sustainable development competencies. Cards prepared by the teacher serve as normative guidelines: they demonstrate examples of correct structuring of information, ensure scientific reliability and methodological clarity. In this way, students learn

to work with verified sources, critically interpret material, and adhere to the principles of academic integrity. At the same time, student-created cards stimulate independent inquiry, foster creativity, and encourage ecological responsibility, thereby integrating disciplinary knowledge with real social and environmental issues. This dual orientation highlights the role of informative cards as both a methodological scaffold and a means of cultivating active, research-oriented learning in the context of sustainable development.

Table 2

Examples of informative cards for developing ecological competence

Card Type	Example Content	Pedagogical Function
Teacher-developed card	The acidity of substrates (pH 6.51 - 7.10) ensures optimal availability of macro- and microelements. Electrical conductivity (≥0.27) indicates higher nutritional value compared to control soil. These parameters determine nutrient accessibility, plant growth intensity, and ecological stability.	Provides normative clarity and structured information; teaches students to work with reliable sources, critically interpret data, and understand causal links between soil properties and agronomic outcomes.
Student-created card	In our experiment, substrate mixtures with pH 6.8 and electrical conductivity supported better rose growth compared to control soil. This shows that balanced acidity and conductivity improve nutrient uptake and ecological sustainability.	Stimulates independent search and interpretation; develops research skills, creativity, and ecological responsibility by encouraging students to connect theoretical knowledge with practical observations.

As can be seen from the content of the card, the inclusion of basic information serves as an entry point into the theoretical justification of the system under study. It stimulates independent inquiry, supports the recall of other parameters investigated during practical work, and encourages creativity. In preparing such cards, students integrate knowledge from different disciplines, present results with reasoned arguments, and connect them to practical tasks. This process contributes to the development of research, communicative, and integrative competencies, while simultaneously strengthening ecological responsibility. In this way,

the use of informative cards becomes not only a methodological aid but also a pedagogical strategy that supports active learning, interdisciplinary synthesis, and the cultivation of sustainable development competencies.

By working with quantitative indicators such as pH, electrical conductivity, and nutrient content, students not only acquire technical knowledge but also develop the ability to interpret how these parameters influence plant physiology and agronomic outcomes. The preparation and evaluation of substrate mixtures thus serve as a practical exercise in ecological responsibility, rational resource use, and the application of chemical principles to real agricultural challenges. In this way, the laboratory work fosters analytical competence, research skills, and critical ecological thinking, while simultaneously reinforcing the connection between chemistry education and sustainable development practices. The acquired knowledge about soil acidity, electrical conductivity, and nutrient composition plays a decisive role in shaping students' ecological competence. By learning to interpret how physicochemical parameters influence plant growth, productivity, and ecosystem stability, students develop the ability to connect chemical data with environmental outcomes. This fosters ecological awareness, analytical thinking, and responsibility for the consequences of professional decisions. The capacity to evaluate soil quality, optimize nutrient supply, and ensure safe handling of chemical inputs strengthens their understanding of sustainable practices and rational resource use. Such competencies are directly aligned with the United Nations Sustainable Development Goals. They contribute to Goal 4 (Quality Education) by integrating theoretical knowledge with practical training and preparing students for real environmental challenges. They advance Goal 12 (Responsible Consumption and Production) through the rational use of resources and environmentally safe technologies. They support Goal 13 (Climate Action) by equipping future professionals to design soil systems that mitigate the impacts of climate change. Finally, they reinforce Goal 15 (Life on Land) by promoting soil health, biodiversity, and ecological resilience.

At this stage of the study, the next block for student work focuses on the chemical composition of fertilizers and the processes by which plants are supplied with essential nutrients. The analysis of nitrogen (110-155 mg/kg), phosphorus (50-85 mg/kg), and potassium (250-450 mg/kg)

in the substrates allowed modeling of different scenarios of plant nutrition.

The role of soil and soil mixtures is directly linked to the broader questions of sustainable development, since their chemical and physical properties determine both ecological stability and agronomic productivity. In this context, eco-substrates and their economic effects were also analyzed by the students, who compared the efficiency of different mixtures not only in terms of plant growth and ornamental quality but also in relation to resource use, cost-effectiveness, and long-term ecological impact. The most effective mixtures for rose cultivation were those containing 70% corn stalks, 15% mushroom substrate, and 15% perlite, which provided intensive growth, robust development, and high productivity of the plants. The summarized results of the comparison between the control soil and the substrate mixtures are presented in Table 3, which demonstrates the key physicochemical soil parameters processed and analyzed by the students. These results require verification, and if the verification is carried out during the lesson, a test can be applied. However, for formative assessment it is more effective to use control methods that provide opportunities for extended feedback from the teacher, such as essays or open-ended questions (Table 3).

At the stage when all previous methods of knowledge formation have been applied and students have prepared themselves by acquiring both theoretical and practical knowledge in this area of professional activity, discussions and debates can be introduced. This progression ensures that students not only consolidate their understanding of soil chemistry and substrate mixtures but also develop critical thinking, communicative competence, and the ability to substantiate eco-technological solutions in the context of sustainable development.

The proposed and analyzed approach to competence formation and the use of formative assessment tools plays a crucial role not only in evaluating ecological competence but also in cultivating the broader skill of lifelong learning. Their effectiveness lies in the way they progressively engage students in diverse modes of thinking and application. Multiple-choice items foster the ability to quickly identify key parameters and make informed decisions, which is essential for adaptability in professional contexts. Short-answer questions develop precision in recalling and applying quantitative data, reinforcing the importance of evidence-based reasoning - a cornerstone

of continuous learning and responsible practice. Open-ended questions require analytical explanation and justification, nurturing critical thinking, reflection, and the capacity to integrate knowledge across disciplines.

Table 3

Examples of Test questions for assessing ecological competence

Question Type	Example Question/ Correct Answer	Pedagogical Explanation
Multiple Choice	Which soil parameter most directly influences the availability of macro- and microelements for plants? a) Bulk density b) Acidity (pH) c) Porosity d) Moisture Correct Answer *b)* Acidity (pH)	Acidity determines nutrient solubility and availability.
Short Answer	Write the minimum electrical conductivity value that indicates higher nutritional value of substrate mixtures compared to control soil. Correct Answer : ≥0.27	Show improved nutrient supply, teaching students to interpret quantitative indicators and connect them to ecological responsibility.
Open-ended	Explain why substrate mixtures with lower bulk density (0.57–0.74 g/cm³) and higher porosity (54.33–71.48%) are more favorable for plant growth compared to control soil. Correct Answer: Lower density and higher porosity improve root penetration, gas exchange, and water retention, supporting intensive growth and productivity	This develops analytical and ecological competence by requiring students to link physical soil parameters with biological outcomes, emphasizing rational resource use and sustainable agronomic practices.

Together, these pedagogical methods create a trajectory: and finally to reflective analysis. In this way, formative assessment becomes not only a tool for measuring ecological competence but also a mechanism for embedding the meta skill of lifelong learning within the framework of sustainable development.

The effectiveness of this trajectory is evidenced by the tangible learning outcomes achieved by students. Based on the results of laboratory analyses, they demonstrated the ability to propose scientifically grounded technological solutions aimed at ensuring resource efficiency and rational use in agrochemical practice. In particular, strategies were identified for the

prudent application of fertilizers, with emphasis on minimizing excessive nutrient input and preventing environmental contamination. The regulation of soil pH was highlighted as a critical factor for maintaining soil fertility and optimizing plant growth, and students suggested methods of balanced amendment application.

Furthermore, the optimization of irrigation regimes was addressed through the integration of drip irrigation systems, which conserve water resources while enhancing nutrient delivery efficiency. Special attention was given to fertigation techniques, whereby fertilizers are applied directly through drip systems, ensuring targeted nutrient supply, reducing losses, and supporting sustainable agricultural practices. Collectively, these achievements illustrate not only the acquisition of analytical and technological skills but also the formation of an integrative competence of sustainable development. This competence unites ecological responsibility, rational resource management, and the ability to translate chemical knowledge into environmentally sound decisions, thereby confirming the pedagogical effectiveness of the designed methodology.

3. Laboratory Control and Pollution Prevention

Laboratory control is not limited to the verification of chemical parameters it becomes a pedagogical instrument for cultivating ecological awareness and professional responsibility. By integrating safety protocols, structured instructional cards, and qualitative analyses of agrochemicals, students are guided to perceive laboratory work as a system of preventive measures against environmental risks. For the preparation of specialists in the field of Food Technologies, the emphasis on Laboratory Control and Pollution Prevention acquires takes on a central professional role. To reveal the essence and importance of scientifically grounded adherence to ecological standards, it is necessary to emphasize both the economic data and the biochemical evidence that underpin sustainable agricultural practices and food production. For the preparation of specialists in Food Technologies, such integration is not only a matter of technical accuracy but also of pedagogical significance, since students must learn to interpret laboratory results as indicators of ecological safety, resource efficiency, and pollution prevention. The interdisciplinary connection between chemistry, ecology, and food technology realized through laboratory control,

which demonstrates how compliance with ecological standards directly influences product quality, consumer trust, and market competitiveness. Analyses conducted in 2024-2025 show that one of the key opportunities for strengthening the competitiveness of Ukrainian agricultural exports to the European Union lies in closer alignment of national legislation with EU law [24, p. 2; 25, p. 17]. From a pedagogical perspective, the inclusion of such structured informational messages into real practical case studies during laboratory training enables students to grasp not only the chemical transformations and analytical procedures but also the broader ecological and economic consequences of non-compliance. In this way, laboratory practice becomes a multidimensional learning environment: students acquire factual knowledge, apply it in authentic contexts, and reflect on the systemic implications of their actions. This progression fosters the development of analytical skills, ecological responsibility, and resource-oriented thinking, ultimately contributing to the formation of integrative sustainable development competence. By situating chemical analysis within real ecological and economic frameworks, the methodology ensures that students' learning outcomes extend beyond technical proficiency to encompass the capacity for responsible decision-making and lifelong learning. They learn to recognize that laboratory control is a preventive measure against pollution, a guarantee of ecological responsibility, and a tool for achieving Sustainable Development Goals.

The formation of a system of knowledge and skills of critical interdisciplinary thinking among students of food technology is constructed with due consideration of careful familiarization with, and mastery of, information regarding a range of indicators. In particular, the Codex Alimentarius establishes a comprehensive multi-level control system that defines threshold values for xenobiotic substances in food products [26]. For students of food technology, the study of polycyclic aromatic hydrocarbons (PAHs) in food products carries both pedagogical and professional significance. PAHs are xenobiotic compounds that may arise during thermal processing or through contamination of raw materials and their presence in vegetable oils (Table 4) or nuts poses a recognized carcinogenic risk.

Table 4

Theoretical preparation for the analysis of PAHs in vegetable oils

Aspect	Content and normative threshold values (μg/kg)
Vegetable oil (DSTU)	DSTU 9127:2021 "High-oleic sunflower oil. Technical specifications" establishes permissible levels of benzo[a]pyrene (BaP ≤ 2 μg/kg) and the sum of four PAHs (PAH4 ≤ 10 μg/kg), harmonized with EU standards.
Export products of Ukraine	Safety requirements for oil products intended for export are based on compliance with European regulations (EU Regulation No. 835/2011; Codex Alimentarius). Norms: BaP ≤ 2 μg/kg; PAH4 ≤ 10 μg/kg.
Codex Alimentarius (standards)	The Codex Alimentarius Commission defines threshold values for BaP and PAH4 in food products, including nuts and vegetable oils, as part of a multi-level control system. Norms: BaP ≤ 2 μg/kg; PAH4 ≤ 10 μg/kg.
BaP – health impact	Benzo[a]pyrene (BaP) is a marker carcinogen with high toxicity; excessive intake is associated with cancer risk, liver dysfunction, and immune system impairment.
Laboratory control methods	High-performance liquid chromatography (HPLC)

National standards, in particular DSTU 9127:2021, establish requirements for controlling the maximum levels of polycyclic aromatic hydrocarbons (PAHs), with benzo[a]pyrene designated as a marker contaminant. However, for the educational process it is important to emphasize that not only marker pollutants pose a danger. Students' awareness of the need to monitor the entire group of PAHs within the "from field to fork" chain fosters an understanding of agrobiocenosis resilience and ecological responsibility. As can be seen from the preparatory theoretical stage summarized in Table 4, international regulatory frameworks such as the Codex Alimentarius and EU legislation establish strict threshold values (BaP ≤ 2 μg/kg; PAH4 ≤ 10 μg/kg), making compliance essential for Ukraine's export products. Engagement with these standards enables students to connect chemical knowledge with ecological and economic dimensions, thereby fostering critical interdisciplinary thinking. From a methodological perspective, the analysis of polycyclic aromatic hydrocarbons (PAHs) is conducted using advanced analytical techniques. High-performance liquid chromatography (HPLC) with fluorescence detection is widely applied for quantitative determination. Validation of these methods according to

ISO, Codex, and DSTU ensures accuracy, reproducibility, and international comparability of results. In practice, each export position is governed by its own set of regulatory frameworks, which define the potential pathways of contaminant accumulation and the requirements for laboratory monitoring. Full compliance of Ukrainian products with EU food safety standards today ensures food security both for Ukraine and contributes to the integration of Ukrainian producers into the international food safety system. For instance, sunflower oil is a leader among exported products of Ukraine's agro-industrial complex, providing a significant share of foreign currency revenues to the state budget. In the first half of 2025, exports exceeded 2 million tons, with total revenue surpassing 2 billion USD, confirming the important role of this product in the structure of Ukraine's agricultural sector.

The next stage of practical work involves highlighting the properties of analytes and preparing for laboratory analysis using chromatography. This step bridges theoretical knowledge with applied laboratory practice, ensuring that students not only understand the toxicological and structural features of PAHs but also learn how to translate them into analytical procedures.

In chromatographic analysis and toxicology, polycyclic aromatic hydrocarbons (PAHs) exhibit diverse properties determined by their structural configuration, physicochemical characteristics, and biological activity. Although many compounds share the same molecular formula, the topology of condensed benzene rings defines differences in polarity, solubility, fluorescence capacity, and interactions with biological systems. This structural variability explains why PAHs can be separated under different chromatographic conditions, using specialized columns and detectors that allow the identification of individual isomers and structural analogues. PAHs are classified according to the number and configuration of fused rings. For instance, four-ring compounds such as chrysene and benzo[a]anthracene possess relatively stable frameworks but differ in ring orientation, which influences their toxicological potential. Five-ring PAHs, including benzo[a]pyrene, benzo[b]fluoranthene, and benzo[k] fluoranthene, are characterized by greater planarity and an enhanced ability to intercalate into biomolecules, thereby increasing their carcinogenic potency. The specific arrangement of condensed nuclei determines electron

density, reactivity, and spectral properties, all of which are exploited in analytical identification. From a toxicological perspective, different PAH groups exert varying degrees of carcinogenic impact. Benzo[a]pyrene is regarded as a marker carcinogen with the highest activity, whereas chrysene and benzo[a]anthracene display lower but still significant hazardous effects. Within the human body, these compounds undergo metabolic activation to epoxides and diol-epoxides, which bind to DNA and induce mutations, ultimately disrupting cellular processes. Thus, the structural features of condensed aromatic nuclei directly shape both the analytical behavior of PAHs in chromatography and their toxicological profiles in biological systems (Table 5).

Table 5

Structural features of PAHs and analytical behavior, toxicological impact.

Compound	Structure	Chromatographic behavior	Toxicological profile
Chrysene ($C_{18}H_{12}$)	Four-ring PAHs (linear type)	Moderate polarity, stable retention, fluorescence detectable	Lower carcinogenic activity, but still hazardous
Benzo[a]anthracene ($C_{18}H_{12}$)	Four-ring PAHs (angular type)	Different elution vs chrysene due to ring orientation	Higher carcinogenic potential than chrysene
Benzo[a]pyrene ($C_{20}H_{12}$)	Five-ring PAHs (pyrene type)	Strong fluorescence, distinct retention in HPLC	Marker carcinogen, highest activity
Benzo[b]fluoranthene ($C_{20}H_{12}$)	Five-ring PAHs (fluoranthene type)	Similar chromatographic profile to BaP, but distinct isomer separation	Potent carcinogen, though less than BaP
Benzo[k]fluoranthene ($C_{20}H_{12}$)	Five-ring PAHs (fluoranthene type, alternative topology)	Separation requires optimized column conditions	Carcinogenic, intermediate potency

Experimental tasks of practical chemistry classes were developed on the basis of materials obtained through high-performance liquid chromatography (HPLC). These tasks are designed to bridge theoretical

preparation with applied laboratory practice. Students first become familiar with the physicochemical properties of analytes and the regulatory thresholds established by Codex Alimentarius and EU legislation.

On this foundation, they proceed to laboratory exercises that involve sample preparation, chromatographic separation, and data interpretation [26; 27]. A thoroughly elaborated theoretical basis is a necessary condition for understanding the practical significance of laboratory control methods and for building a system of the knowledge that enables the interpretation of analytical results and the scientific substantiation of conclusions. It is also essential for making professional decisions regarding the safety of food products at the relevant stages of the technological process of production and refining of edible oil (Table 6).

Table 6

Chromatographic determination of BaP in vegetable oils

Benzo[a] pyrene, Result	Compliance	Technological Actions
1.5 µg/kg	*Meets safety standards	Product complies with norms; maintain preventive monitoring
2.05 µg/kg	*Not compliant	Additional refining required; verify production stage of refining
5.7 µg/kg	*Not compliant	Initiate re-inspection of production chain; determine cause of elevated content

**Regulatory Limit (EU/Codex) ≤ 2.0 µg/kg*

The materials of chromatographic analysis of polycyclic aromatic hydrocarbons in samples of edible oil, obtained in an accredited laboratory, integrated into the practical tasks. Their use enables students to work with real data, to correlate the results with normative indicators of food safety, and to develop the ability for critical interpretation of experimental findings.

The application of real sample models ensures that educational activities brought closer to professional production conditions. A distinctive feature of practical work with materials of real samples is the use of interactive libraries created in the accredited laboratory. These libraries provide students with access to reliable data and calibration models, thereby allowing the reproduction of conditions of actual laboratory control. The Cromeleon 6.0 software environment used for the processing of chromatographic

signals, the construction of calibration curves, and the creation of databases that simulate the processes of analytical determination of food quality indicators. Subsequent visualization of the results in Microsoft Excel contributes to the development of skills in statistical evaluation, the analysis of statistically significant errors, and the estimation of measurement uncertainty, thereby enabling the formulation of substantiated laboratory control results and conclusions.

The integration of the aforementioned software tools and interactive libraries into the educational process ensures the combination of theoretical knowledge with practical skills, fosters analytical competencies, and enhances the level of professional readiness of food technology specialists. In this context, students not only master technical techniques of data processing but also learn to interpret results in accordance with normative requirements, which underscores the professional and social significance of analytical research and laboratory control in the activities of future food technologists. Overall, the developed content and methodology of practical tasks create conditions for the formation of competencies of a productive character. The reproduction of knowledge gradually transforms into its practical application, critical analysis, and the making of substantiated decisions, which is consistent with the findings of contemporary research emphasizing the necessity of transition from the reproductive level of learning to the productive one, oriented toward the development of analytical thinking and interdisciplinary skills [28, p. 67; 29, p. 1235]. In addition to the content and conclusions of the practical block, the final part of the class provides students with space for the presentation of obtained results, their reflection, and evaluation.

This stage is of particular importance in terms of generalizing the learning experience, engaging in discussion, and formulating professional conclusions. Students not only demonstrate the acquired skills of working with chromatographic methods but also analyze their own achievements and difficulties, correlating them with laboratory control of samples during food production. The activities conducted in the format of team interaction culminate in the discussion of conclusions in the form of a “production meeting,” thereby modeling the conditions of the industrial process.

The pedagogical modeling of production practices in food technology fosters in students a holistic understanding of the chain: «theoretical

knowledge – practical skills – result analysis – scientific justification of decisions – implementation of solutions» aimed at preserving human health and achieving the Sustainable Development Goals [30]. The relevance of the proposed content and pedagogical approach lies in its orientation toward the formation of competencies that meet the contemporary requirements of sustainable development. These include analytical accuracy, ecological responsibility, technological literacy, and critical thinking, which are essential components of professional training for food technology specialists. As illustrated by the described section of the practicum, students learn not only to identify xenobiotics in food products but also to propose technological solutions for reducing their levels, to evaluate compliance with international standards, and to recognize the importance of monitoring critical control points in production. This approach integrates chemical education into the broader context of food chain safety and sustainable societal development, ensuring a balance between scientific rigor, practical orientation, and social responsibility.

CONCLUSIONS

Quality Education, as one of the Sustainable Development Goals, possesses subject-specific components that directly or indirectly influence other sustainability objectives. As demonstrated in the study, chemistry disciplines and laboratory practice become central didactic tools, enabling students to connect abstract principles with measurable outcomes. Through the interpretation of laboratory data, evaluation of ecological risks, and comprehension of the economic implications of compliance with international standards, learners acquire the capacity for reflective practice and continuous professional growth.

«Resource Efficiency and Rational Use» highlights the necessity of teaching students to balance productivity with ecological responsibility. Rational resource management is not limited to economic optimization; it is fundamentally linked to ecological stability and the preservation of biodiversity. Pedagogically, this requires that students learn to quantify resource use, evaluate efficiency, and propose solutions that minimize waste and pollution. Laboratory experiments provide concrete examples of how rational use is achieved in practice, whether through monitoring contaminants, assessing energy efficiency, or evaluating the sustainability

of agrobiocenoses. By integrating chemistry, ecology, and economics into a unified teaching framework, resource efficiency becomes a formative principle that strengthens interdisciplinary thinking and prepares students to act as responsible professionals in the agri food sector.

«Laboratory Control and Pollution Prevention» serves as the nexus where theoretical knowledge, ecological awareness, and professional responsibility converge. Its role extends beyond technical certification to functioning as a preventive mechanism against pollution and ecological risks. For students, laboratory practice demonstrates that analytical procedures are not isolated exercises but formative activities that integrate chemistry, ecology into a coherent system of ecological responsibility. In the context of «Laboratory Control and Pollution Prevention», it is important to emphasize that student training in laboratory control builds a knowledge base that is actively applied to pollution prevention, optimization of technological processes, and ensuring compliance with international product standards. This has not only educational but also economic significance, since adherence to safety norms determines the competitiveness of food export batches. Rational resource management in this framework is closely linked to ecological stability and the preservation of human health. Pedagogically, this means that students must learn to quantify resource use, analyze the efficiency of technological processes, and propose solutions that minimize waste and pollution. Laboratory experiments provide tangible examples of how rational resource use is implemented in practice: through monitoring contaminants, assessing energy efficiency, and analyzing production stages.

Thus, the study of chemistry and practice-oriented tasks such as laboratory control, careful application of fertilizers, efficient use of irrigation water, urban greening, and pollution prevention serve as didactic instruments that foster sustainable development competencies in students. These competencies combine analytical accuracy with ecological responsibility and technological literacy. In this way, chemical education is integrated into the broader context of food chain safety, ecological stability, and social responsibility, ensuring that professional training contributes to both environmental protection and societal well-being.

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