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THEORETICAL FOUNDATIONS OF INTEGRATING GREEN CHEMISTRY PRINCIPLES INTO HIGHER EDUCATION

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Abstarct: This article highlights the theoretical foundations of integrating green chemistry principles into the higher education system. It analyzes the essence of green chemistry, its integral connection with sustainable development, and its significance in fostering ecological responsibility and professional competencies among future chemistry specialists. Furthermore, the pedagogical and didactic aspects of implementing green chemistry education are revealed

Keywords: green chemistry, higher education, integration, sustainable development, ecological responsibility, professional competence, didactic principles.

INTRODUCTION: Today, as the negative impact of human activities on the environment continues to grow, issues of environmental safety and sustainable development are gaining critical importance. In particular, processes related to the chemical industry and chemical technologies are considered among the primary sources of environmental problems. From this perspective, the concept of Green Chemistry has emerged as a vital scientific direction aimed at developing environmentally safe, economically efficient, and resource-saving chemical processes. Teaching green chemistry principles in the higher education system is essential for developing the ecological thinking of future specialists and preparing them to solve modern scientific and technological challenges. Therefore, studying the theoretical foundations of integrating green chemistry into the educational process remains a highly relevant task.

LITERATURE REVIEW: The primary tasks facing chemical science can be divided into three groups: Filling the market with economically affordable and durable materials: polymers, fibers, composite materials, and fertilizers.

Developing products belonging to new classes: catalysts, chemical materials for electronics, composites, and new types of drugs—this is also referred to as "intellectual chemistry."

Maximizing the efficient use of fundamental natural processes, such as photosynthesis, and the economical utilization of biomass and water. This direction is known as Green Chemistry [2].

The scientific field of "Green Chemistry" was proposed in the 1990s and was quickly supported among chemists as a new methodological approach. First and foremost, 12 principles of green chemistry were developed, which consist of the following:

Prevention: It is better to prevent waste formation than to treat or clean up waste after it has been created.

Atom Economy: Synthetic methods should be designed to maximize the incorporation of all reagents used in the process into the final product.

Less Hazardous Chemical Syntheses: Synthetic methods should be designed to use and generate substances with little or no toxicity to human health and the environment.

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Designing Safer Chemicals: Chemical products should be designed to affect their desired function while minimizing their toxicity.

Safer Solvents and Auxiliaries: The use of auxiliary substances (e.g., toxic solvents, separation agents) should be made unnecessary wherever possible.

Design for Energy Efficiency: Energy requirements of chemical processes should be recognized for their environmental and economic impacts, and synthesis should be conducted at ambient temperature and pressure.

Use of Renewable Feedstocks: Raw materials or feedstocks should be renewable rather than depleting whenever technically and economically practicable.

Reduce Derivatives: Unnecessary derivatization (use of blocking groups, protection/deprotection) should be minimized or avoided if possible.

Catalysis: Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

Design for Degradation: Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment [3].

Real-time Analysis for Pollution Prevention: Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

Inherently Safer Chemistry for Accident Prevention: Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires. Thus, Green Chemistry defines its strategic goal as prioritizing the avoidance of hazardous substances in the selection of starting reagents and the execution of chemical processes. Currently, three main directions of Green Chemistry are highlighted: new synthetic pathways (via catalysis), the use of renewable feedstocks (moving away from petroleum products), and the elimination of traditional organic solvents. In essence, this approach aims to eliminate toxic emissions from chemical production, thereby improving the living environment and ensuring ecological purity. We believe that implementing the principles of Green Chemistry will serve as a foundation for achieving the priority tasks set by the Ecological Movement of Uzbekistan, which is a guarantee for raising a healthy generation [4].

By integrating Green Chemistry principles into the curriculum, educators can convey a positive message to students about how chemists fulfill their responsibilities toward environmental stewardship. This provides an opportunity to transform students' perceptions of chemistry's role in society and addresses the need to discover and develop sustainable chemistry for the future [5].

While Green Chemistry focuses on waste management, it specifically involves managing waste produced during a chemical process. In contrast, Environmental Chemistry is a "branch of knowledge" that studies the chemical aspects of the environment, including the analysis of pollutants in nature and soil [6]. Green Chemistry, often called sustainable chemistry, focuses on minimizing chemical usage and hazardous waste during synthesis [7]. Environmental Chemistry analyzes natural chemical processes and is crucial for determining pollution levels, focusing on the impact of using non-renewable raw materials. Green Chemistry differs from traditional chemistry by ensuring environmentally benign production, which serves as a catalyst for economic growth [8].

In recent years, universities and research centers in developed countries have increasingly adopted Green Chemistry principles. At international conferences, such as the 2nd International

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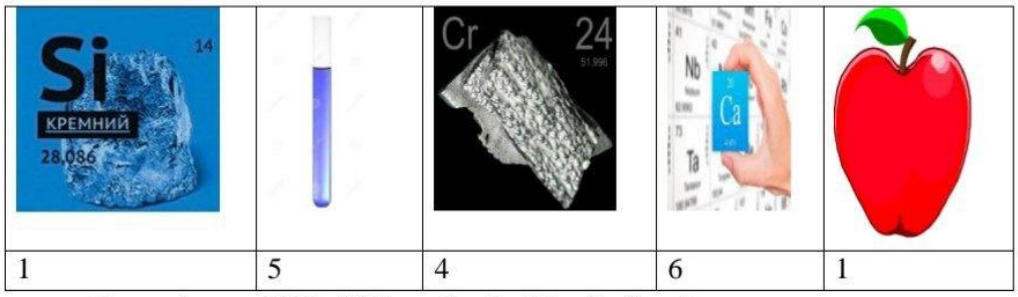
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Conference held in Moscow and St. Petersburg in 2008, the organization of Green Chemistry education was a key topic. That same year, the "Chemistry for Sustainable Development – Green Chemistry" center was established at Moscow State University, emphasizing the urgency of creating specialized educational programs [9].

Every technological process must account for energy consumption and its sources. Alongside economic indicators, atom efficiency and the E-factor must be determined. In chemistry lessons, students should learn about nature-friendly alternatives to organic solvents, catalytic processes, modern analytical methods, and elements of toxicology. Teaching the elements of green chemistry during chemistry lessons and practical sessions helps maintain environmental criteria and fosters the development of environmental education [10, 11]. In the process of chemistry lessons, we can utilize various methods to closely integrate a chemical and ecological approach for students, including the following.

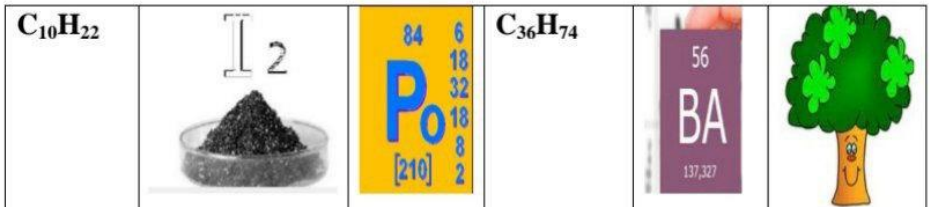
METHODS USED: The REBUS method is an approach used to enhance the effectiveness of teaching in chemistry lessons through visual aids and images. The word "Rebus" is translated from Latin as "by means of things." The Rebus originated in France in the 15th century, and the first collection was published in that country in 1582.



1	5	4	6	1

Bu usul oraqali biz “Kimyo” so’zni hosil qilamiz

Kremniy	**Probirka**	**Xrom**	**Kalsiy**	**Olma**
K	**I**	**M**	**Y**	**O**



2,3	2	3,4	1,8	5	4

Dekan Yod Poloniy geksatrikontan Bariy Daraxt

Natijada “Ekologiya”so’zi hosil bo’ldi.

Incorporating green chemistry principles into curricula involves several theoretical stages:Interdisciplinary integration: Analyzing waste-free technologies through the integral connection of chemistry with biology, ecology, and economics (for example, via the concept of "atom economy").Methodological approach: Replacing traditional laboratory practices with microscale chemistry methods and less toxic reagents.The role of the 12 Principles: Teaching the 12 principles developed by P. Anastas and J. Warner using real-world industrial case studies (Problem-Based Learning - PBL).

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CONCLUSION: In conclusion, several decisions have been made to integrate "Green Chemistry" elements into the curricula of secondary schools, lyceums, technical schools, and higher education institutions. Today, various measures are being implemented in our Republic based on these decisions. Currently, universities worldwide have adopted an innovative path, leading to the development of innovative educational programs. Education in the field of "Green Chemistry" fosters a new perspective in students, helping them visualize, understand, and develop skills in chemical and technological processes. This program requires an integrated approach to teaching disciplines such as biology, medicine, physics, mathematics, and chemical technology, demanding a shift in the conceptual understanding of chemistry. It ensures that the negative environmental impact at all stages of the process is minimized, creating opportunities to transition toward zero-waste technologies. Conducting education in this direction enhances the environmental and hydro-ecological literacy of the younger generation and strengthens their commitment to environmental protection.

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