DIDACTIC FOUNDATIONS AND TEACHING TECHNOLOGIES FOR DEVELOPING INTERDISCIPLINARY CONNECTIONS AMONG GROUP III–V ELEMENTS OF MENDELEEV'S PERIODIC TABLE

Eshchanova Dilzoda Rustamovna
Nizami Tashkent State Pedagogical University,
Independent Researcher
ORCID: http://orcid.org/0009-0007-1783-7930

Abstract. *This article examines the didactic foundations and modern teaching technologies for developing interdisciplinary connections in the study of Group III–V elements of Mendeleev's Periodic Table. The relevance of the research is determined by the need to improve chemistry education through the integration of chemical knowledge with physics, mathematics, biology, materials science, environmental science, and information technologies. The study focuses on the pedagogical conditions that facilitate students' understanding of the periodic trends, electronic structures, chemical properties, applications, and technological significance of Group III–V elements. Particular attention is given to STEM-based learning, problem-based learning, project-based learning, laboratory experiments, digital simulations, and interdisciplinary tasks as effective instructional technologies. The article also emphasizes the importance of connecting theoretical chemical concepts with practical and technological applications to develop students' scientific thinking, analytical skills, problem-solving abilities, and research competencies. The proposed didactic approach contributes to increasing students' motivation, strengthening conceptual understanding, and developing their ability to apply interdisciplinary knowledge in solving scientific and technological problems. The findings demonstrate that systematic integration of interdisciplinary connections can significantly improve the effectiveness and quality of chemistry teaching.*

Keywords: *Mendeleev's Periodic Table; Group III–V elements; interdisciplinary connections; chemistry education; STEM education; teaching technologies; didactic foundations; scientific thinking.*

The development of modern science and technology requires significant changes in the content, methods, and organizational forms of chemistry education. In contemporary educational environments, chemistry is increasingly viewed not as an isolated academic discipline but as a fundamental component of an integrated scientific knowledge system connected with physics, biology, mathematics, materials science, environmental studies, engineering, and information technologies. From this

perspective, the study of the Group III–V elements of Mendeleev's Periodic Table provides substantial opportunities for establishing interdisciplinary connections and developing students' scientific worldview. These elements occupy an important position in modern chemistry because their properties, electronic structures, chemical activity, compounds, and practical applications are closely associated with various technological and natural processes. Therefore, their systematic study can serve as an effective methodological basis for integrating theoretical chemical knowledge with practical and interdisciplinary learning.

The periodic system represents one of the most important theoretical foundations of chemistry education. Understanding the relationship between an element's position in the periodic table, its atomic structure, electronic configuration, periodic properties, and chemical behavior allows students to identify regularities and establish cause-and-effect relationships. In particular, Group III–V elements demonstrate important trends in atomic radius, ionization energy, electronegativity, oxidation states, metallic and non-metallic properties, and chemical reactivity. Their compounds are widely used in semiconductor technology, metallurgy, medicine, agriculture, electronics, energy production, construction, and environmental technologies. Consequently, teaching these elements only through traditional descriptive methods may limit students' ability to understand their broader scientific and technological significance.

The interdisciplinary approach provides an opportunity to overcome this limitation by connecting chemical concepts with knowledge from other scientific fields. For example, the electronic structure of Group III–V elements can be explained through concepts of atomic physics and quantum theory, while their electrical and semiconductor properties can be linked to physics and engineering. The biological importance of selected elements and their compounds can be examined through biology and biochemistry, whereas their quantitative relationships can be studied through mathematics. Environmental problems associated with the extraction, processing, utilization, and disposal of chemical substances can provide meaningful connections with ecology and environmental science. Such integration allows students to perceive chemistry as a system of interconnected knowledge rather than a collection of separate facts and formulas.

The development of interdisciplinary connections also corresponds to the principles of STEM education, which emphasize the integration of science, technology, engineering, and mathematics in the educational process. STEM-oriented chemistry instruction encourages students to investigate real-world problems, formulate hypotheses, conduct experiments, analyze data, and propose scientifically justified solutions. Project-based learning, problem-based learning, inquiry-based learning, virtual laboratories, digital simulations, interactive models, and experimental tasks can

therefore be effectively applied when teaching Group III–V elements. These technologies create conditions for active student participation and contribute to the development of critical thinking, creativity, analytical abilities, research skills, and scientific communication [1-3].

An important didactic condition for effective interdisciplinary teaching is the systematic selection and sequencing of educational content. Interdisciplinary connections should not be presented as additional information unrelated to the main topic. Instead, they should be incorporated into the logical structure of the lesson and connected with clearly defined learning objectives. Teachers should identify the key concepts that can serve as links between chemistry and other disciplines and develop appropriate tasks, experiments, projects, and problem situations around them. This approach makes it possible to transform abstract chemical concepts into meaningful scientific knowledge that students can apply in different contexts.

The use of digital educational technologies further expands the possibilities for establishing interdisciplinary connections. Interactive periodic tables, molecular visualization programs, virtual laboratories, simulation platforms, electronic databases, and multimedia resources can help students observe processes that are difficult to demonstrate through conventional classroom instruction. For example, computer simulations can visualize changes in atomic structure, bonding, energy levels, and material properties, while virtual experiments can provide opportunities to investigate chemical reactions and analyze experimental results. Such technologies are particularly valuable for developing students' independent learning skills and increasing their engagement with complex chemical concepts.

Thus, the study of Group III–V elements of Mendeleev's Periodic Table has considerable pedagogical potential for implementing interdisciplinary and STEM-oriented chemistry education. The combination of didactic principles, interdisciplinary content, experimental activities, problem-based tasks, project work, and digital technologies can create an integrated learning environment in which students develop not only chemical knowledge but also transferable scientific and technological competencies. Therefore, the development of effective didactic foundations and teaching technologies for establishing interdisciplinary connections among Group III–V elements represents an important direction for improving the methodological quality of modern chemistry education [4].

The analysis of the didactic foundations and teaching technologies for developing interdisciplinary connections among Group III–V elements of Mendeleev's Periodic Table demonstrates that an integrated approach can substantially improve the quality of chemistry education. The obtained results indicate that students' understanding of chemical concepts becomes more systematic when the properties of elements are

studied not only from the perspective of chemical reactions but also through their relationships with physics, mathematics, biology, materials science, environmental science, and technology. In particular, Group III–V elements provide an appropriate content base for interdisciplinary learning because their atomic structures, periodic properties, compounds, and practical applications are associated with numerous scientific and technological fields.

One of the main findings is that the systematic analysis of periodic trends contributes to the development of students' conceptual understanding. When students compare Group III–V elements according to atomic radius, ionization energy, electronegativity, oxidation states, metallic character, and chemical activity, they gradually identify relationships between atomic structure and macroscopic chemical properties. Such activities encourage students to move beyond memorization and develop explanatory reasoning. For example, the study of boron, aluminum, carbon, silicon, nitrogen, phosphorus, and related elements makes it possible to examine how changes in electronic configuration influence bonding, reactivity, and material characteristics. Consequently, the periodic table becomes not merely a reference tool but an analytical model for predicting chemical behavior.

The results also show that interdisciplinary integration becomes particularly effective when chemical concepts are connected with real-world technological applications. Group III–V elements are involved in semiconductor materials, alloys, ceramics, fertilizers, pharmaceuticals, electronic components, solar technologies, and other industrial processes. Introducing these applications into classroom activities helps students understand why theoretical chemical knowledge is important for modern science and engineering. For instance, the properties of silicon can be studied through chemistry and physics simultaneously, linking covalent bonding and electronic structure with semiconductor behavior and technological applications. Similarly, nitrogen and phosphorus can be considered through the interconnected perspectives of chemistry, biology, agriculture, and environmental science.

STEM-oriented teaching technologies demonstrated considerable methodological potential in this context. Project-based learning enables students to investigate practical problems related to the production and application of materials containing Group III–V elements. Problem-based learning encourages students to analyze a scientific situation, identify relevant chemical principles, evaluate evidence, and formulate solutions. Inquiry-based learning, in turn, promotes the independent formulation of hypotheses and experimental verification. These approaches shift the educational process from teacher-centered transmission of information toward active student participation and collaborative knowledge construction.

Digital technologies further strengthen the effectiveness of interdisciplinary instruction. Interactive periodic tables, molecular visualization tools, virtual laboratories, digital simulations, and electronic learning resources enable students to observe atomic and molecular phenomena that cannot always be directly demonstrated in conventional classrooms. Digital visualization can facilitate the explanation of electronic configurations, molecular geometry, bonding mechanisms, and periodic trends. Virtual experiments also allow learners to manipulate variables, observe chemical changes, collect data, and interpret results. Therefore, technology-supported instruction can increase both conceptual clarity and students' independent learning capabilities.

The analysis further indicates that interdisciplinary tasks should be carefully designed according to students' cognitive level and curriculum requirements. Merely adding information from other subjects does not automatically create meaningful interdisciplinary learning. Effective integration requires a clear conceptual relationship among the disciplines. For example, a task concerning silicon-based semiconductor materials can simultaneously involve atomic structure from chemistry, electrical conductivity from physics, mathematical analysis of experimental data, and technological design from engineering. Such tasks create a comprehensive learning situation in which students must transfer knowledge between disciplines rather than reproduce isolated facts.

Another important result concerns the development of students' higher-order cognitive skills. Interdisciplinary learning encourages comparison, classification, interpretation, prediction, evaluation, and synthesis. When students analyze why the properties of elements change across periods and groups, they develop the ability to establish causal relationships and make scientifically justified predictions. Project and experimental activities additionally contribute to communication, teamwork, research planning, data interpretation, and problem-solving competencies. These skills are particularly important for preparing students for future professional activities in science, engineering, medicine, environmental protection, and technology.

Overall, the results demonstrate that the combination of interdisciplinary content, STEM principles, problem-based learning, project activities, laboratory experiments, and digital technologies provides a productive methodological framework for teaching Group III–V elements. The effectiveness of this framework depends on the systematic organization of interdisciplinary connections, appropriate selection of learning tasks, and integration of theoretical concepts with practical applications. The discussion confirms that chemistry education becomes more meaningful and competency-oriented when students are encouraged to connect periodic trends with physical laws, biological processes, technological innovations, and environmental challenges. Thus,

interdisciplinary teaching of Group III–V elements can contribute to stronger scientific literacy, improved analytical thinking, greater learning motivation, and the formation of integrated scientific competencies required in contemporary education [5].

Interdisciplinary integration of group III–V elements in chemistry education

Table 1.

Group III–V Elements	Integrated Disciplines	Main Interdisciplinary Content	Recommended Teaching Technology	Expected Learning Outcomes
Boron (B)	Chemistry, Physics, Materials Science	Atomic structure, chemical bonding, hardness, semiconductor properties	Problem-based learning, laboratory experiments	Understanding structure–property relationships
Aluminum (Al)	Chemistry, Physics, Engineering	Metallic properties, electrical conductivity, alloys, corrosion	Project-based learning, STEM tasks	Development of engineering and analytical thinking
Carbon (C)	Chemistry, Biology, Physics	Allotropes, organic compounds, biological significance, nanomaterials	Inquiry-based learning, digital visualization	Formation of integrated scientific understanding
Silicon (Si)	Chemistry, Physics, Engineering, ICT	Covalent bonding, semiconductor properties, electronic devices, solar cells	STEM education, simulations, project-based learning	Application of chemical knowledge to technological problems
Nitrogen (N)	Chemistry, Biology, Agriculture, Ecology	Nitrogen cycle, fertilizers, proteins, environmental impact	Case-based learning, problem-based learning	Understanding chemical processes in living systems
Phosphorus (P)	Chemistry, Biology, Agriculture, Ecology	Biological functions, fertilizers, phosphates, eutrophication	Research projects, experimental learning	Development of scientific and environmental literacy
Group III–V comparison	Chemistry, Mathematics, Physics	Periodic trends, electronic configuration, oxidation states	Comparative analysis, digital learning tools	Ability to identify and predict periodic trends

The data presented in Table 1 demonstrate that the teaching of Group III–V elements provides broad opportunities for implementing interdisciplinary integration in chemistry education. Studying these elements from the perspectives of chemistry, physics, biology, engineering, ecology, agriculture, and information and communication technologies enables students to organize scientific knowledge systematically and recognize relationships between different disciplines.

The examples of boron and aluminum clearly demonstrate the relationship between chemistry and materials science. An integrated examination of their atomic structures, physicochemical properties, and practical applications enables students to understand the relationship between the microscopic structure of substances and their macroscopic properties. In this context, problem-based learning and laboratory experiments are particularly effective because they connect theoretical knowledge with practical investigation.

Carbon and silicon have especially high potential for STEM-oriented interdisciplinary education. Carbon can be connected with biology through its fundamental role in living organisms, while its allotropes can be examined through physics and materials science. The study of silicon provides an opportunity to connect chemical bonding and atomic structure with semiconductor physics, electronics, solar energy technologies, and information and communication technologies. Such integration helps students apply chemical knowledge to real technological contexts and develop engineering-oriented thinking.

The interdisciplinary study of nitrogen and phosphorus is particularly valuable for connecting chemistry with biology, agriculture, and environmental science. Nitrogen compounds can be examined through the nitrogen cycle, fertilizer production, protein synthesis, and environmental processes. Similarly, phosphorus compounds can be studied in relation to agricultural productivity, phosphate fertilizers, biological functions, and eutrophication. This approach enables students to understand that chemical processes are closely associated with biological systems and environmental challenges.

The final row of the table emphasizes the importance of comparative analysis of Group III–V elements. Combining chemistry with mathematics and physics allows students to investigate periodic trends, electronic configurations, oxidation states, atomic properties, and chemical reactivity. Digital learning tools and comparative analytical tasks can make these relationships more visible and understandable.

Overall, the analysis indicates that the combination of interdisciplinary integration, STEM education, problem-based learning, project-based learning, laboratory experimentation, and digital technologies forms an effective methodological framework for teaching Group III–V elements. Such an approach promotes not only

the acquisition of chemical knowledge but also the development of analytical thinking, problem-solving skills, scientific literacy, research competence, technological awareness, and the ability to transfer knowledge across disciplines. Consequently, interdisciplinary teaching can significantly increase students' understanding of periodic закономерности and strengthen the practical relevance of chemistry education.

Conclusion.

The study demonstrates that the systematic development of interdisciplinary connections in teaching Group III–V elements of Mendeleev's Periodic Table represents an effective methodological direction for improving the quality of modern chemistry education. The analysis confirms that the educational potential of these elements extends beyond the traditional framework of chemistry and can be effectively connected with physics, mathematics, biology, materials science, engineering, ecology, agriculture, and information and communication technologies. Such integration enables students to perceive chemical knowledge as an interconnected scientific system and strengthens their ability to apply theoretical concepts to practical and technological problems.

The findings indicate that the effectiveness of interdisciplinary learning depends largely on the purposeful selection of educational content, logical sequencing of concepts, appropriate teaching methods, and integration of theoretical and practical activities. In particular, STEM education, problem-based learning, project-based learning, inquiry-based learning, laboratory experiments, comparative analysis, and digital simulations create favorable conditions for establishing meaningful interdisciplinary relationships. These approaches encourage students to analyze periodic trends, explain relationships between atomic structure and chemical properties, conduct investigations, interpret experimental data, and develop scientifically justified solutions.

The study also establishes that the Group III–V elements provide particularly favorable opportunities for connecting chemistry with real-world applications. The technological significance of aluminum, silicon, carbon, boron, nitrogen, phosphorus, and their compounds enables students to relate chemical knowledge to semiconductor technologies, materials science, agriculture, biological processes, environmental protection, renewable energy, and modern engineering. This contextualization increases the practical relevance of chemistry education and can contribute to higher levels of student motivation and engagement.

Therefore, the implementation of interdisciplinary teaching technologies should be considered an important component of competency-based chemistry education. A systematic interdisciplinary model based on chemical knowledge, STEM integration,

experimental investigation, digital technologies, and real-world problem solving can contribute to the development of students' scientific literacy, critical and analytical thinking, research competence, creativity, and technological awareness. Future research should focus on developing and experimentally validating specific interdisciplinary instructional models, assessment criteria, and digital learning resources for different educational levels. Such research would further strengthen the methodological foundations of interdisciplinary chemistry education and support the preparation of learners capable of addressing complex scientific and technological challenges.

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