FORMING STUDENTS' SCIENTIFIC-THEORETICAL HOLISTIC THINKING THROUGH TEACHING THE FUNDAMENTAL LAWS OF CHEMISTRY BASED ON AN AXIOMATIC-DEDUCTIVE APPROACH

Kamolova Nargiza Ibragimovna
Doctoral student, National Pedagogical University of Uzbekistan

Abstract. This article examines the theoretical and practical foundations for developing scientific thinking in chemistry education and analyzes both international and national educational experiences. It highlights the role of modern pedagogical technologies, the STEAM approach, inquiry-based learning, and innovative teaching methods in developing students' scientific worldview, critical and logical thinking, and problem-solving competencies. The article also discusses opportunities for adapting advanced international practices to the national education system and provides recommendations for their practical implementation.

Keywords: chemistry education, scientific thinking, STEAM, inquiry-based learning, innovative pedagogical technologies, critical thinking, competency-based approach, international experience, national experience, quality of education.

In the process of the formation and development of chemistry as a science, chemical laws, alongside fundamental theoretical concepts, have occupied a central position. They have not only established the foundations of chemistry but have also served as important tools for revealing general patterns in the scientific understanding of nature. Therefore, studying chemical laws in the educational process of general secondary schools is important not only for providing students with theoretical knowledge, but also for developing a scientific worldview, logical thinking, and a conscious approach to scientific inquiry. Through laws, students learn to understand cause-and-effect relationships in chemical processes.

Among the laws of chemistry, such fundamental theoretical principles as the law of conservation of mass, the law of definite proportions, the law of multiple proportions, the law of equivalents, and Avogadro's law occupy a special place as initial scientific principles that introduce students to a chemical worldview. Through these laws, students can understand the general logical mechanisms underlying chemical processes.

The law of conservation of mass, formulated by Lomonosov and Lavoisier, makes it possible to explain that the number and mass of atoms are conserved in every chemical reaction. This demonstrates to students the solid scientific foundations of chemistry based on the laws of nature. In general secondary schools, teaching these laws step by step and in logical sequence prepares students to comprehend complex theoretical concepts. At the initial stages, students can observe practical demonstrations of the law of conservation of mass through simple experiments and later understand its generality through mathematical calculations. As a result, they recognize that scientific truth can be experimentally verified.

Chemical laws strengthen students' confidence in scientific knowledge because they express the stability and universality of processes in nature. For example, through the law of definite proportions, students learn that the composition of the same chemical compound remains unchanged regardless of the conditions under which it is obtained. This forms an understanding in their worldview that the laws of nature possess strict consistency, which is essential for scientific thinking. In studying chemical laws, students also gain knowledge about scientific methods of understanding nature, because each law was discovered on the basis of experiments and observations. Studying the history of their formation gives students an understanding of the empirical and theoretical stages of scientific inquiry. Consequently, they realize that the development of science is closely connected with humanity's desire to study nature more deeply.

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The importance of chemical laws in scientific inquiry can also be seen in their role as a theoretical foundation for human production, engineering, and technological development. For example, based on the law of conservation of mass, the products and yields of reactions in various industrial processes can be calculated in advance. Based on the law of combining gas volumes, optimal ratios of different substances can be determined in the gas industry. Therefore, by mastering these laws in general secondary school, students acquire not only theoretical knowledge but also practical life skills. Chemical laws develop students' scientific thinking as well as their general logical and analytical thinking because each law teaches them to analyze causes and effects.

For example, based on the law of conservation of mass, students learn to correctly balance chemical equations and, in this process, develop the ability to maintain mathematical balance. This is useful not only in chemistry but also in studying other natural sciences, while helping students understand the scientific basis of many phenomena encountered in everyday life. Thus, teaching chemical laws in general secondary schools is of exceptional importance for developing students' scientific worldview, directing them toward the scientific understanding of nature, developing logical and analytical thinking skills, demonstrating the close relationship between theory and practice, and creating a theoretical foundation for deeper learning at subsequent educational stages. Paying close scientific and methodological attention to the teaching methodology of chemical laws is one of the most important conditions for improving educational effectiveness.

The concept of axiomatic deduction is regarded as an important method for strengthening theoretical foundations and systematizing knowledge in the educational process in various fields of science. It makes it possible to present fundamental principles to students in a logically consistent sequence. This approach has particular didactic significance in studying laws in chemistry. Axiomatic deduction refers to the process of logically substantiating other knowledge, conclusions, and laws on the basis of initially given axioms or propositions accepted as self-evident.

Applying the axiomatic-deductive method integrates theoretical concepts and practical skills in students' thinking because chemical laws serve not only as theoretical foundations but also provide a basis for laboratory work, solving calculation problems, and explaining processes in everyday life. After introducing students to a process inductively through experimental observations, the teacher can consolidate the principal law or rule as an axiom and then explain other conclusions derived from it deductively. This develops students' scientific thinking in two directions.

For example, when studying Avogadro's law, students first observe the relationships among the volume, pressure, and temperature of gases. Then the axiomatic meaning of Avogadro's idea is presented, from which gas laws can be derived deductively. This not only strengthens the theoretical concept but also develops logical thinking skills.

Although many laws and rules in textbooks and methodological manuals for general secondary schools are presented systematically, their mutual logical relationships are sometimes insufficiently highlighted. Therefore, teachers should use the principles of axiomatic deduction that connect them. Such an approach prevents knowledge from remaining fragmented and transforms it into an integrated system. When students study the structure of substances, chemical bonds, reactions, or the essence of the periodic law, their knowledge becomes deeper and more stable if they understand which fundamental principle each concept or phenomenon derives from.

For example, Mendeleev's periodic law is often presented as a discovery based on experimental observations. From the perspective of axiomatic deduction, however, it can be considered in terms of accepting the regularity of atomic masses and the properties of elements as a fundamental principle and explaining the resulting periodic patterns. Thus, students acquire knowledge not merely through memorization but through understanding fundamental principles, making them better prepared to apply this knowledge in practice.

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Another advantage of applying axiomatic deduction in chemistry lessons is that it develops students' critical thinking because they learn to analyze which fundamental principle a new concept derives from before accepting it. In this process, they strive for independent thinking. For example, when studying the laws of chemical kinetics, students observe that reaction rates depend on various factors. An important question for them is how these factors are governed by a general law. If the teacher presents the dependence of reaction rate on collision frequency and particle energy distribution as fundamental principles, all subsequent factors can be explained deductively from this perspective. As a result, students perceive the topic as a coherent logical system.

In general secondary school settings, it is also important to consider students' age characteristics because axiomatic deduction requires a relatively high level of abstract thinking. Therefore, at the initial stages, the teacher should rely on simple experiments and observations and subsequently generalize them by presenting fundamental laws as axioms. At the elementary stage, students learn the properties of substances through practical experiments; in middle grades, they understand regularities inductively; and in upper grades, they can master complex theoretical concepts consistently on the basis of axiomatic deduction because their logical thinking has developed sufficiently. Thus, axiomatic deduction is not limited to upper-grade students; through a gradual approach, it can be applied at all educational stages and can effectively systematize students' knowledge.

The development of chemistry is one of the clearest examples of the development of human thought. The need to explain substances in nature and the processes of their transformation has existed since ancient times. In this process, humanity used observation, experimentation, and logical conclusions to formulate general regularities on the basis of deduction. Therefore, chemical laws not only explain natural phenomena but also contribute to expanding students' scientific worldview.

First, the law of conservation of matter should be considered because it is one of the most fundamental and foundational ideas in chemistry. Although the law was formulated by Lomonosov and Lavoisier, humanity had in fact encountered its manifestations throughout thousands of years of experience. In everyday life, people observed that ash was produced when coal burned but could not see the gases released into the air, leading them to think that "matter had disappeared." Scientific research, however, demonstrated that no matter disappears and no matter is created from nothing; rather, matter changes from one form into another. Thus, when students understand this law, they can connect their everyday experiences with scientific reasoning.

For example, in general secondary schools, a teacher can demonstrate this law through simple experiments. A child may think that wax "has disappeared" when it gradually decreases while burning, but if the teacher explains that carbon dioxide and water vapor are formed in the air, the concept of "disappearance" is replaced by the concept of "transformation of matter into another form." Similarly, if an experiment is conducted in a closed glass container with a precisely measured mass, the law can be demonstrated by showing that the mass before and after the reaction remains the same.

The law of conservation of matter serves not only as a basis for writing chemical equations but also develops students' scientific thinking, logical analysis, and deductive reasoning skills. They first observe a simple experiment, then analyze it, and finally arrive at a general conclusion. At the next stage, it is necessary to explain the law of definite proportions. This law, developed through the research of Lavoisier and Proust, states that every pure chemical compound consists of elements in constant and definite mass ratios. For example, regardless of whether water is obtained from a river, a lake, or synthesized in a laboratory, its composition is always 88.9% oxygen and 11.1% hydrogen. Thus, this law serves as a universal criterion for determining the chemical nature of substances.

In teaching this law in general secondary school, teachers can use examples from everyday life because the fact that water has the same properties everywhere is an easily understandable example. Likewise, the constant ratio of sodium and chlorine in salt (NaCl) can stimulate students' scientific interest because they can see that table salt and sodium chloride in a chemistry laboratory have the

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same composition. In addition, the law of definite proportions develops students' ability to distinguish the qualitative and quantitative composition of substances. Through deduction, they can reach the conclusion that if a substance always consists of elements in the same ratio, it is a pure compound. This law also helps them clearly distinguish mixtures from pure substances.

Another fundamental law is the law of combining volumes, formulated by Gay-Lussac. According to this law, when gaseous substances react and are formed, their volumes are in simple whole-number ratios. For example, two volumes of hydrogen react with one volume of oxygen to produce two volumes of water vapor. These simple ratios demonstrate to students not only the mathematical basis of chemical processes but also that chemical processes obey precise quantitative regularities. The teacher can also use experiments because gas volumes are relatively easy to measure, allowing students to observe the result more clearly. For example, by demonstrating the explosive mixture of hydrogen and oxygen and relating their volumes to the appropriate ratio, the practical confirmation of the law can be demonstrated. Through this process, students integrate mathematical thinking with chemical knowledge.

The law of multiple proportions, formulated by Dalton, states that if two elements form several compounds, the masses of the elements in those compounds are in simple whole-number ratios. For example, when carbon and oxygen form CO and CO_2, the ratios are 12:16 and 12:32, respectively, meaning that the masses are in the simple ratio 1:2. Thus, this law is one of the pieces of evidence demonstrating the discrete and atomic nature of chemical processes. Understanding the law of multiple proportions may initially seem difficult for students, but if it is presented through simple examples and in deductive sequence, it becomes engaging. By calculating mathematical ratios, students themselves participate in confirming chemical regularities. This law also opens a path toward understanding atomic theory because the existence of such simple ratios can be explained through the existence of atoms.

The law of equivalents should also be considered because it is important for quantitatively explaining chemical processes. In a chemical reaction, the combination of one element with another or its replacement by another element depends on their equivalent weights. For example, 1 gram of hydrogen corresponds to 8 grams of oxygen and 35.5 grams of chlorine. Thus, the same amount of hydrogen reacts with different elements in precise mass ratios, demonstrating the existence of a general quantitative regularity for all elements. In general secondary school, simple calculations can be used to explain this law because students can understand its logical basis through arithmetic operations. The teacher should develop the concept of equivalence gradually through deduction: first demonstrating simple experiments and then leading students to a general conclusion.

Presenting the fundamental laws of chemistry on the basis of deduction is methodologically important for general secondary schools because students first observe phenomena through experiments and observations, then analyze them, and finally arrive at general regularities through logical reasoning. As a result, they not only master chemical knowledge but also develop scientific thinking, analytical skills, and deductive reasoning, creating a foundation for deeper study of subjects at subsequent educational stages.

The fundamental laws of chemistry serve as a foundation for the development of the science and have not only determined the direction of theoretical chemistry but also provided students with a logical basis for understanding matter and natural phenomena. Therefore, teaching these laws in general secondary schools should focus not merely on memorization but on developing scientific thinking. For example, the law of conservation of mass is essential for explaining the nature of chemical reactions; the law of definite proportions demonstrates the strict order present in the nature of substances; and the law of multiple proportions substantiates the combination of elements in simple whole-number ratios. The law of equivalents is used in quantitative analysis, while Avogadro's law

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opens the way to understanding the molecular structure of matter. Thus, all of these laws are closely interconnected and serve a common purpose.

Rather than explaining these laws separately, it is more effective to analyze their historical emergence, scientific foundations, interrelationships, and methodology of application in education because when abstract concepts are taught in logical sequence, a holistic scientific picture is formed in students' minds. The law of conservation of mass was formulated by Lomonosov and subsequently confirmed experimentally by Lavoisier: during chemical reactions, matter does not disappear or appear but changes from one form into another. Thus, it can be understood as the chemical expression of the general law of conservation in nature.

This law is used in chemistry lessons to introduce students to reliable evidence based on experimentation. For example, the constancy of mass during the reaction between sodium carbonate and hydrochloric acid in a closed container can be directly demonstrated. At the same time, this law is closely related to the law of conservation of energy in physics and to the cycling of matter and energy in the biosphere in biology, demonstrating the unity of general laws of nature and forming students' understanding of interdisciplinary connections.

The next fundamental law—the law of definite composition—was proposed by Proust and states that every pure chemical compound always consists of elements in the same mass ratio. In school, this law encourages students to develop confidence in the strict regularities between elements and compounds because they can experimentally observe that water or iron oxide obtained from different sources has a constant composition. This law follows from the Lomonosov–Lavoisier principle and further specifies it: if the mass of matter is conserved, the constituent masses in compounds are also maintained in definite ratios.

The law of multiple proportions, studied by Dalton, demonstrates that the same elements can form several compounds and that the mass ratios of the elements in these compounds can be expressed as simple whole numbers. This law shows school students that the combination of elements is not random but follows a strict mathematical order, thereby strengthening their logical thinking. The similarity between the laws of definite proportions and multiple proportions is that both demonstrate the constancy of composition; however, the former shows that one compound has a constant composition, whereas the latter shows that the same elements may combine in different ratios and that even in such cases definite quantitative relationships exist.

Another of the fundamental laws is the law of equivalents, according to which different substances react with the same amount of another substance in equivalent quantities. For example, the amount of hydrogen that combines with 8 g of oxygen is equivalent to the corresponding amount of chlorine or sodium. In other words, substances participating in chemical reactions do so in definite quantitative ratios. This law is widely used in quantitative calculations, titration methods, and industrial processes; in school, it is used to explain the nature of mass and molar ratios. In essence, this law strengthens Dalton's atomic-theoretical foundations and provides a broader explanation of the fixed ratios in which substances combine.

Avogadro's law played a decisive role in the development of molecular theory because Avogadro established that equal volumes of gases under the same conditions contain equal numbers of molecules. Thus, gas volume depends not on mass but on the number of molecules, creating a logical relationship between molecular masses and gas volumes. This law introduces students to the molecular concept in school lessons and encourages them to think more deeply about the structure of matter at the next stage. Avogadro's law is closely connected with the law of equivalents and Dalton's atomic theory and has contributed to the foundations of modern chemistry and quantum-mechanical theories in physics.

The interrelationship among these laws is that they together form a unified scientific system based on the constancy of composition, quantitative ratios, and molecular structure. The law of

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conservation of mass provides a general foundation; the law of definite proportions follows from it; the law of multiple proportions develops logically from the quantitative relationships among elements; the law of equivalents expresses quantitative ratios more broadly; and Avogadro's law completes the formation of the atomic-molecular conception. These laws logically complement one another and create a holistic body of knowledge for students. Their similarity lies in the fact that all of them demonstrate the existence of strict mathematical and logical regularities in transformations of matter, while their differences are reflected in their scope and mode of expression.

For example, the law of conservation of mass applies to all chemical reactions; the law of definite proportions is characteristic of an individual compound; the law of multiple proportions covers different compounds; the law of equivalents provides a convenient form for calculations; and Avogadro's law substantiates molecular structure. Explaining such comparative analysis to students teaches them not merely to remember facts but to compare, generalize, and analyze logically, which fully meets the requirements of modern education.

In school practice, experimental activities are particularly important for teaching these laws, such as observing reactions in closed containers, comparing the composition of substances obtained from different sources, determining the volume ratios of gases, and calculating equivalent quantities. Through these practical tasks, students see the empirical reliability of theoretical laws and develop deeper confidence in them. The overall analysis of these laws shows that they have consistent logical relationships and, together, form the main pillars of chemical knowledge and contribute to the formation of students' scientific worldview.

The process of teaching chemistry in general secondary schools is explained not only by the transmission of theoretical knowledge to students but also by the need to form a scientific worldview in their thinking and help them understand the laws of natural phenomena and the material world as an integrated whole. Scientific thinking enables students to understand phenomena not superficially but in terms of their essence.

The fundamental laws of chemistry have a special role in developing students' thinking on a scientific-theoretical basis because they form the foundation of all chemical phenomena and processes. Through these laws, interdisciplinary relationships and the unified regularity of the material unity of nature can be demonstrated. In teaching chemical laws, the teacher should explain them not merely at the level of memorization but through methods that develop students' independent thinking. If the essence of laws is not explained on a logical basis, students cannot fully understand their theoretical and practical significance.

For example, when teaching the law of conservation of matter, the teacher should not limit the explanation to the theoretical statement that matter neither disappears nor appears from nothing, but should demonstrate through a simple laboratory experiment that the mass of substances remains the same before and after a reaction. Knowledge reinforced by practical evidence is retained more consistently in students' minds and contributes to the development of their thinking.

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