



DEVELOPMENT OF METHODOLOGICAL LESSON DESIGNS FOR INORGANIC CHEMISTRY BASED ON HISTORICAL MATERIALS

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Abstract. *The article examines the theoretical and methodological foundations for developing inorganic chemistry lessons through the systematic integration of historical scientific materials. Particular attention is paid to transforming the history of chemical discoveries from supplementary biographical information into an active didactic resource that supports conceptual understanding, scientific reasoning, problem solving, and the formation of students' ideas about the nature and development of scientific knowledge. A methodological model based on the sequence “historical problem – scientific contradiction – hypothesis – experiment – discovery – modern interpretation – educational reflection” is proposed. The model is illustrated through historical episodes associated with the development of the periodic law, the prediction of undiscovered elements, the discovery of noble gases, and the evolution of ideas about chemical periodicity. The article also presents a pedagogical experiment design for comparing conventional inorganic chemistry instruction with historically contextualized instruction. Criteria for evaluating cognitive achievement, conceptual understanding, scientific reasoning, learning motivation, and historical-scientific thinking are described. The proposed methodology demonstrates that historical material can function not merely as an illustrative component of a chemistry lesson but as a mechanism for organizing inquiry, reconstructing the logic of scientific discovery, identifying contradictions, and encouraging students to establish relationships between empirical evidence and theoretical generalization. The methodological approach may be applied in higher education institutions preparing future chemistry teachers as well as in general secondary chemistry education.*

Keywords: *inorganic chemistry, history of chemistry, historical-scientific material, chemistry education, methodological lesson design, periodic law, problem-based learning, scientific reasoning, pedagogical experiment, professional competence.*

Introduction

The modernization of chemistry education requires a transition from the transmission of ready-made scientific information to instructional environments in which students understand how chemical knowledge is generated, verified, revised, and transformed into scientific theories. In traditional inorganic chemistry courses, scientific laws, classifications, formulas, and theories are frequently presented in their final and logically organized form. Although such an approach makes it possible to communicate a considerable volume of subject matter within a limited period, it can unintentionally create an impression that scientific knowledge develops linearly and that fundamental laws arise as finished intellectual constructions rather than as results of prolonged observation, experimentation, controversy, revision, and theoretical generalization.

The history of chemistry provides a methodological opportunity to overcome this limitation. When historical material is appropriately integrated into subject instruction, students encounter not only the final scientific conclusion but also the intellectual pathway leading to it. Historical reconstruction therefore allows learners to understand why a scientific problem emerged, what evidence was available at a particular stage of scientific development, what competing explanations existed, why some hypotheses were rejected, and how new experimental facts changed scientific thinking.

Matthews emphasizes that the interaction between history, philosophy, and science education helps students understand both scientific concepts and the nature of scientific knowledge [1]. A historical approach consequently should not be interpreted simply as the inclusion of dates, biographies, portraits, or isolated

anecdotes in chemistry lessons. Its methodological value lies in reconstructing the epistemic structure of scientific discovery and transforming it into an educational problem.

Research in chemistry education provides empirical support for this position. Lin demonstrated that chemistry teaching organized through the history of science improved students' conceptual problem-solving performance, while the greatest educational benefits were observed among learners with initially lower achievement [2]. This finding is particularly important for inorganic chemistry, because many concepts in this discipline, including periodicity, oxidation states, chemical bonding, acid-base behavior, coordination chemistry, and patterns of element reactivity, require students to move beyond memorization toward theoretical explanation.

Historical material can therefore perform several interconnected educational functions. It contextualizes abstract concepts, reveals the developmental nature of scientific theories, introduces cognitive conflict, creates inquiry situations, encourages evidence-based reasoning, and humanizes scientific activity. Olsson argues that historical perspectives can help students understand how earlier findings informed later chemical experiments and can contribute to more adequate ideas about the nature of science [3]. Thus, the effectiveness of historical material depends less on the quantity of historical facts than on the pedagogical architecture through which those facts are transformed into learning activity.

The purpose of the present study is to develop a methodological framework for designing inorganic chemistry lessons based on historical-scientific material and to establish a pedagogically justified model for evaluating the effectiveness of such instruction.

Historical Material as a Didactic Resource in Inorganic Chemistry

The methodological use of historical material in inorganic chemistry should begin with a distinction between descriptive historical information and didactically transformed historical content. A statement such as "Dmitri Mendeleev formulated

the periodic law in 1869” represents historical information. By itself, however, it does not necessarily generate learning activity. A methodological situation emerges when students are provided with the information available to chemists before Mendeleev and are asked to identify the problem of classification, compare competing classification systems, analyze irregularities in atomic masses, and explain why leaving gaps in a table could represent a scientifically rational decision.

Historical information becomes educationally productive when it contains an intellectual contradiction that corresponds to the conceptual objective of the lesson. The teacher's task is therefore not simply to reproduce the chronological history of a discovery, but to identify an episode in which the historical logic of scientific development can be transformed into a cognitive problem accessible to learners.

The periodic law provides one of the most productive examples. Prior to the emergence of the mature periodic system, chemists had accumulated information about a rapidly increasing number of elements and compounds. The educational problem may therefore be formulated from the perspective of a nineteenth-century scientist: how can chemically different elements be classified so that similarities in their properties are not treated as accidental?

Rather than showing the modern periodic table immediately, the teacher can provide students with selected data concerning atomic masses, valencies, oxide formulas, hydride formulas, metallic character, and reactivity. Students can then attempt to organize the data themselves. Such activity reproduces, in a pedagogically simplified form, an important element of scientific classification.

This approach is consistent with the broader historical role of the periodic table in chemistry education. The periodic system not only organizes chemical knowledge but also provides a conceptual framework through which relationships between substances become intelligible. Historical analysis shows that its educational role has been closely connected with the organization of chemical knowledge from the period of Mendeleev onward [4].

The most important methodological transition occurs when learners encounter anomalies. Historical scientific progress frequently begins where existing explanations become insufficient. The teacher can therefore deliberately present data that cannot be completely explained by the students' first classification. This transforms an ordinary classification exercise into an epistemic problem.

The same principle can be used in teaching noble gases. A modern student already knows that helium, neon, argon, krypton, xenon, and radon form a separate group. From a historical perspective, however, the existence of chemically inactive atmospheric components created an intellectual problem. Giunta's analysis of the discovery of argon demonstrates that historical episodes can be used to teach scientific method because they show how unexpected experimental evidence can lead to the revision of accepted scientific assumptions [5].

The pedagogical value of this episode is particularly high because the discovery can be presented not as a finished fact but as an unresolved contradiction. Students may be introduced to the discrepancy between nitrogen obtained from air and nitrogen obtained from chemical compounds. They can be asked whether such a difference should be interpreted as experimental error, impurity, methodological failure, or evidence for an unknown substance. By reconstructing possible interpretations, students learn an important principle of scientific reasoning: anomalous data should be evaluated rather than automatically discarded.

Methodological Model for Developing Historically Based Inorganic Chemistry Lessons. On the basis of theoretical analysis, a historically contextualized inorganic chemistry lesson can be organized according to the conceptual sequence:

Tarixiy muammo → Ilmiy ziddiyat → Gipoteza → Tajriba va dalillar → Kashfiyot → Zamonaviy ilmiy talqin → Ta'limiy refleksiya

In this model, the historical problem initiates learning. It should correspond to a genuine problem that existed in the development of chemistry, but it must be adapted to the students' level of preparation. The scientific contradiction represents

the inadequacy of available explanations. At this stage, students identify conflicting evidence or limitations of an existing classification.

The hypothesis stage gives students an opportunity to formulate explanatory assumptions. Their hypotheses do not have to reproduce the historical scientist's reasoning exactly. The pedagogical goal is to engage students in model construction and evidence-based prediction.

At the experimental evidence stage, learners compare their assumptions with observations, chemical data, reconstructed historical experiments, tables, graphs, or laboratory results. The discovery stage introduces the historically accepted interpretation only after students have attempted their own solution. Such sequencing prevents history from becoming merely declarative information.

The modern scientific interpretation stage is essential because historical models should not replace contemporary scientific explanations. For example, Mendeleev's original periodicity was primarily connected with atomic weights, whereas modern periodicity is interpreted through atomic number and electronic structure. Historical reconstruction therefore needs to culminate in a modern explanation based on nuclear charge, electronic configuration, effective nuclear charge, and periodic variation in atomic properties.

The final component is educational reflection. Students answer not only "What did we learn?" but also "What evidence changed the scientific interpretation?", "Why was the earlier model reasonable in its historical context?", "What made the new model scientifically stronger?" and "How did prediction contribute to acceptance of the theory?" Through such reflection, learners understand science as a dynamic system of evidence-based knowledge.

Methodological Design of a Lesson on the Periodic Law

A lesson devoted to the periodic law can begin without displaying the complete modern periodic table. Students receive selected information concerning approximately fifteen to twenty elements known in the nineteenth century. The

information may include relative atomic mass, typical valency, formulas of highest oxides, metallic or non-metallic character, and selected chemical properties.

Students are instructed to arrange the elements according to a principle that maximizes regularity. During this process, they may discover repeating chemical properties. The teacher then introduces historical attempts at classification and encourages comparison between students' arrangements and early scientific classifications.

The central cognitive conflict is introduced through missing positions. Students are asked whether a scientifically valid classification may contain gaps. In a purely memorization-based lesson, an empty cell appears as incomplete information. In a historically reconstructed lesson, however, it becomes evidence of the predictive function of a theory.

The historical prediction of the properties of eka-aluminium, later identified with gallium, can be transformed into an analytical task. Students compare predicted and experimentally determined properties and evaluate whether the correspondence supports the periodic system. The objective is not simply to admire the accuracy of a famous scientist but to understand how scientific theories gain explanatory and predictive power.

At the next stage, the problem becomes more sophisticated. Students are asked whether the periodic law remained unchanged after Mendeleev. The discoveries of noble gases and subsequent development of atomic theory demonstrate that scientifically productive theories can be extended and reinterpreted without losing their central explanatory significance.

This methodological construction enables students to see a law not as a sentence to memorize but as an intellectual tool for organizing experimental evidence and generating predictions.

Integration of Historical Experiment and Modern Laboratory Instruction

Historical materials are especially effective when combined with laboratory work. However, a historical experiment should not necessarily be reproduced literally. Some historical procedures involve hazardous reagents, obsolete apparatus, excessive concentrations, or conditions unsuitable for contemporary education. The methodological task is therefore to reconstruct the scientific logic while modernizing the experimental procedure in accordance with safety standards.

For example, when teaching the chemical activity of halogens, students can first examine the historical development of ideas concerning chlorine. Early interpretations treated chlorine-containing gases differently from the modern elemental interpretation. Rather than reproducing hazardous historical experiments, students can conduct safe microscale displacement reactions and analyze evidence for the relative oxidizing ability of halogens.

Likewise, the development of acid-base concepts can be introduced historically but experimentally investigated through modern pH measurement, indicators, conductivity, and digital sensors. Historical context explains why definitions changed; the modern experiment demonstrates the empirical basis for contemporary interpretation.

This relationship between historical narrative and laboratory inquiry is essential. Historical content without experimental or analytical activity can become anecdotal. Experimental activity without intellectual context can become mechanical. Their integration enables students to understand both what occurs chemically and why the corresponding question became scientifically important.

Pedagogical Experiment Model

The effectiveness of the proposed methodology can be evaluated through a pedagogical experiment involving control and experimental groups studying the same inorganic chemistry topics under comparable educational conditions. The control group follows the conventional curriculum, whereas the experimental group

studies selected topics through historically contextualized methodological lesson designs.

The experimental instruction should preserve equivalent curriculum content, instructional time, assessment requirements, and expected subject outcomes. The independent methodological variable is the systematic integration of historical problems, reconstructed scientific contradictions, evidence-based historical cases, predictive tasks, and reflective questions.

The pedagogical experiment may be organized in diagnostic, formative, and final stages. During the diagnostic stage, both groups complete equivalent assessments of prior knowledge, conceptual understanding, learning motivation, and scientific reasoning. The formative stage includes a sequence of historically structured inorganic chemistry lessons. The final stage uses parallel assessment instruments designed to measure changes in knowledge quality, ability to explain concepts, transfer of knowledge, reasoning with evidence, and learning motivation.

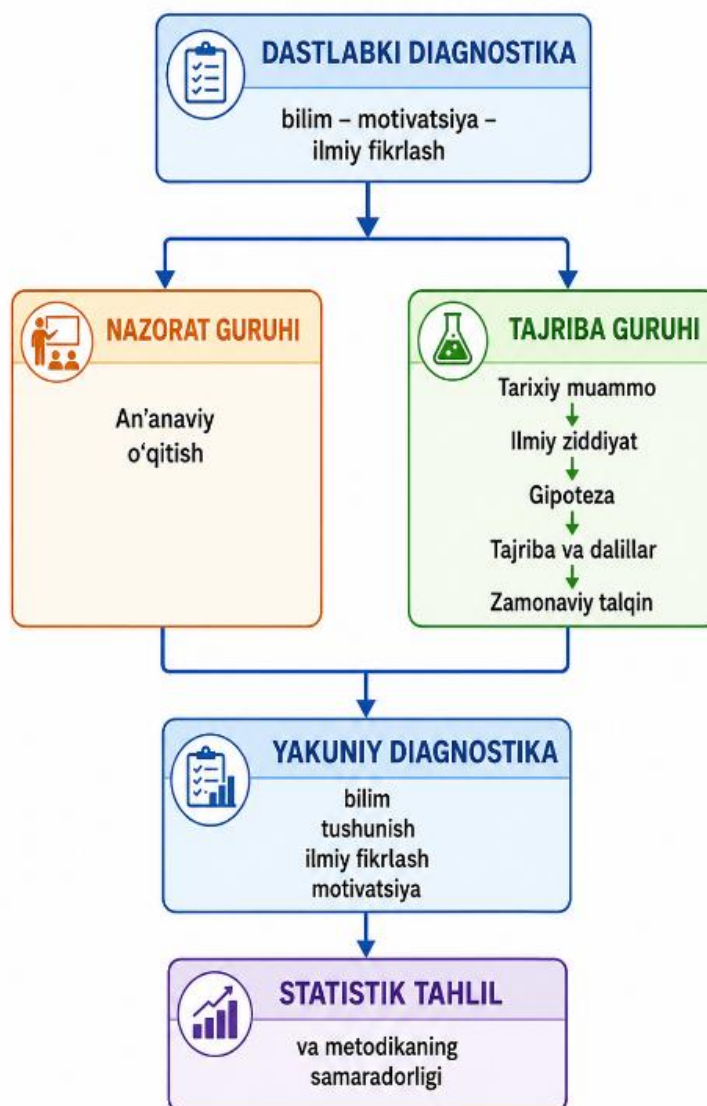


Figure 1. Pedagogical experiment model for teaching inorganic chemistry through historical-scientific materials.

The figure illustrates the logic of comparing conventional instruction with the proposed historically contextualized methodology. The experimental group does not simply receive additional historical information. Historical material determines the structure of the cognitive activity: students encounter a scientific problem, identify a contradiction, construct a hypothesis, analyze experimental or documentary evidence, and connect the historical conclusion with the modern chemical interpretation. Therefore, the difference between the two groups concerns instructional methodology rather than the total amount of chemistry content.

The assessment system should distinguish factual achievement from conceptual achievement. A student may correctly identify the position of an element in the periodic table without being able to explain why its chemical properties vary periodically. For this reason, tasks requiring explanation, prediction, comparison, interpretation of unfamiliar evidence, and justification of conclusions should accompany standard achievement tests.

Scientific reasoning may be evaluated through historical situations containing incomplete or contradictory evidence. Students can be asked to choose between alternative hypotheses and justify their selection. Historical-scientific thinking can be evaluated through the learner's ability to explain why an older scientific interpretation was reasonable under the evidence available at that time and why subsequent data required its modification.

Learning motivation can be measured with a validated questionnaire or an instrument adapted and psychometrically checked for the target sample. In addition to quantitative assessment, interviews, reflective writing, lesson observation, and analysis of student responses may be employed to understand how historical contexts influence learning behavior.

When real experimental data are obtained, statistical analysis should begin by checking the comparability of the groups at the diagnostic stage. Depending on data distribution and sample characteristics, the researcher may use independent-samples t-tests, paired-samples tests, analysis of covariance, or appropriate non-parametric alternatives. Reporting effect size in addition to statistical significance is recommended because pedagogical significance cannot be adequately represented by a p-value alone.

Expected Educational Effects and Interpretation

The major expected effect of the methodology concerns the quality rather than merely the quantity of knowledge. Historical reconstruction requires students to establish relationships between observation, interpretation, hypothesis, and theory.

Consequently, the learner moves from recognition of chemical facts toward an understanding of how those facts support generalizations.

Previous chemistry education research provides a basis for this expectation. Lin's quasi-experimental study involving 220 eighth-grade students reported stronger conceptual problem-solving performance among learners taught chemistry through historical materials [2]. The result supports the proposition that history becomes pedagogically effective when it is integrated into conceptual learning rather than taught independently from chemistry content.

Another expected outcome concerns misconceptions. Students frequently construct intuitive explanatory models that resemble earlier historical conceptions. Historical cases allow teachers to make such reasoning visible without presenting student errors as meaningless failures. A misconception can be compared with an earlier scientific interpretation and then examined against evidence. This approach helps create an intellectually respectful environment in which conceptual change is achieved through analysis rather than simple correction.

The methodology is also expected to influence perceptions of scientific knowledge. If textbooks present only successful theories and final definitions, students may conclude that science develops through isolated acts of genius. Historically contextualized lessons demonstrate that chemistry develops collectively, experimentally, and sometimes controversially. Discoveries may depend on new instruments, improved measurement, revision of terminology, reinterpretation of anomalies, or communication between different scientific communities.

The history of argon provides a particularly valuable case because the discovery emerged from careful attention to a small quantitative discrepancy. The educational message is therefore deeper than the historical fact itself: precise measurement and respect for anomalous evidence can become sources of major scientific discovery [5].

Teacher preparation is another significant issue. Research on the teaching of history of chemistry has indicated that while historical elements are present in many chemistry programs, systematic specialist preparation in this area remains limited. This creates a need for methodological resources that provide teachers not merely with historical facts but with ready-to-adapt educational scenarios, questions, primary-source fragments, data sets, laboratory tasks, and assessment instruments.

Digital Transformation of Historical Materials

Modern digital technologies substantially expand the possibilities for integrating history into inorganic chemistry. Historical material can be presented through interactive timelines, digitized laboratory notebooks, virtual museum collections, annotated historical periodic tables, animated reconstructions of experiments, QR-linked source materials, and interactive comparison tools.

However, digitalization alone does not create pedagogical effectiveness. A scanned historical document remains passive information unless the student is given an intellectual task. Digital resources should therefore be incorporated within the same methodological sequence of problem identification, evidence analysis, hypothesis construction, comparison, and reflection.

For example, an interactive timeline of periodic table development can allow students to compare the number of known elements at different historical stages. A dynamic periodic table can then connect the historical arrangement with modern electronic configuration. Such a transition visually demonstrates that the periodic law has both historical continuity and theoretical development.

Discussion

The proposed methodological framework differs from approaches in which historical information appears only at the beginning or end of a chemistry lesson as motivational background. In the present model, history determines the logical architecture of learning.

This distinction is important. The educational potential of historical materials does not automatically follow from their presence in a textbook. An additional paragraph about a scientist may increase cultural knowledge but may have little influence on conceptual understanding. To become a teaching technology, historical material must be transformed into an educational problem.

The most productive historical episodes are therefore those containing a meaningful discrepancy, prediction, competition between explanatory models, experimental uncertainty, or revision of a scientific concept. Such episodes naturally correspond to problem-based and inquiry-oriented instruction.

The approach also prevents an artificial separation between the history of chemistry and contemporary inorganic chemistry. Historical knowledge is not treated as a separate humanities component attached to science. Instead, it becomes a pathway toward understanding modern chemical ideas.

An additional advantage lies in its potential for teacher education. Future chemistry teachers need to understand both subject content and the epistemology of the discipline they will teach. Reconstructing the history of scientific concepts can help future educators identify conceptual difficulties, anticipate students' alternative ideas, and design learning situations in which explanations emerge from evidence.

At the same time, historical approaches should not be romanticized. They require additional preparation, reliable sources, careful adaptation, and appropriate time management. Excessive historical detail may distract from learning objectives. Historical narratives may also reproduce myths if teachers rely on popular sources instead of scholarly research. The methodological principle should therefore be selective integration rather than comprehensive chronology.

Conclusion

The use of historical-scientific materials in inorganic chemistry teaching represents an effective methodological direction for transforming factual instruction into conceptually oriented scientific learning. The history of chemistry is

pedagogically valuable not because it increases the number of facts included in a lesson, but because it reveals the process through which chemical knowledge is generated, tested, revised, and systematized.

The proposed sequence “historical problem – scientific contradiction – hypothesis – experiment and evidence – discovery – modern interpretation – educational reflection” provides a methodological basis for constructing inorganic chemistry lessons in which historical material performs an active cognitive function.

The history of the periodic law, prediction of undiscovered elements, discovery of noble gases, development of atomic theory, evolution of acid-base concepts, electrochemical theories, and coordination chemistry can all be transformed into educational cases based on this model.

Historically contextualized instruction can promote deeper conceptual understanding by allowing students to reconstruct relationships between experimental evidence and theoretical generalization. It can also contribute to scientific reasoning, evidence-based argumentation, motivation, and understanding of the nature of science.

The proposed pedagogical experiment model makes it possible to evaluate these effects through comparison of control and experimental groups using diagnostic and final assessments. For publication of empirical results, future research should report actual sample characteristics, validated assessment instruments, descriptive statistics, inferential statistics, effect sizes, and qualitative evidence from student responses.

Consequently, the development of methodological lesson designs based on historical materials should be regarded as an important component of contemporary inorganic chemistry education and professional preparation of future chemistry teachers.

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