ISSN: 2181-3337 | SCIENTISTS.UZ VOLUME 5 ISSUE 9 | SEPTEMBER 2026

THEORETICAL AND PEDAGOGICAL FOUNDATIONS FOR DEVELOPING STUDENTS' AESTHETIC-CULTURAL COMPETENCE

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DOI: 10.67620/sai.59b0013

ABSTRACT

This article proposes a strengthened methodological framework for developing students' intellectual and prognostic potential in chemistry education. Intellectual-prognostic potential is defined as an integrated capacity to analyze chemical phenomena, identify causal and periodic patterns, formulate evidence-based predictions, justify assumptions, and revise forecasts in response to experimental or theoretical evidence. The framework builds on competency-based chemistry teaching and combines problem-based learning, inquiry, laboratory work, modeling, scientific argumentation, and structured forecasting tasks. Particular attention is given to the transition among macroscopic observations, submicroscopic explanations, and symbolic representations, because meaningful prediction in chemistry depends on coordinating these levels. A classroom application based on halogen chemistry illustrates how students can predict trends in reactivity, anticipate consequences of chemical use, and explain the exothermic formation of hydrogen chloride using bond-energy reasoning. The paper also proposes assessment indicators for evaluating the quality of students' predictions, including conceptual accuracy, use of evidence, causal reasoning, and reflection on uncertainty. The approach is intended to move learners beyond reproduction of factual knowledge toward scientifically justified anticipation and decision-making. It can be integrated into introductory, reinforcement, laboratory, and assessment stages of chemistry lessons and provides a basis for future empirical evaluation in secondary and pre-university chemistry education.

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05.10.26

Keywords: *chemistry education; prognostic thinking; intellectual potential; inquiry-based learning; problem-based learning; scientific reasoning.*

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1. Introduction

Contemporary chemistry education is expected to develop more than knowledge of facts, formulas, and reaction equations. Students must learn to interpret evidence, recognize relationships, solve unfamiliar problems, and make reasoned judgments about what may occur under specified conditions. The original methodological position of this paper is that pedagogical forecasting should be treated not only as a teacher's activity for anticipating educational outcomes, but also as a student competence that can be intentionally developed through chemistry learning (Atabayeva, 2024; Baydulloev, 2010). In this sense, prediction becomes an intellectual operation through which learners connect prior knowledge with observable conditions and justify an expected result.

Chemistry is particularly suitable for developing such competence. Chemical reasoning requires students to move between observable phenomena, particle-level mechanisms, and symbolic

representations. The chemistry triplet framework helps explain why students often struggle when macroscopic, submicroscopic, and symbolic levels are presented without explicit connections (Taber, 2013). Predictive tasks can provide those connections: a learner observes or is given a chemical situation, identifies relevant structural or periodic principles, represents the process symbolically, and predicts a plausible outcome.

This orientation is consistent with broader science-education frameworks that emphasize scientific practices, explanation, modeling, argument from evidence, and the integration of knowledge with practice (National Research Council, 2012). It is also compatible with research on problem-based and inductive teaching, which positions learners as active interpreters and problem solvers rather than passive recipients of information (Hmelo-Silver, 2004; Prince & Felder, 2006). Accordingly, the purpose of this paper is to refine a methodological framework for developing students' intellectual-prognostic potential in chemistry lessons, clarify the competencies involved, and demonstrate how the framework can be applied through forecasting questions, laboratory reasoning, and the topic of halogens.

2. Conceptual Basis of Intellectual-Prognostic Potential

In this paper, intellectual potential refers to the learner's capacity to perform purposeful mental activity: to compare, classify, analyze, generalize, solve problems, create explanations, and understand relationships. Prognostic potential is the capacity to anticipate future states or outcomes on the basis of available evidence, established regularities, and scientifically defensible assumptions. Their integration produces intellectual-prognostic potential: the ability to construct a justified forecast rather than merely guess what will happen.

Four interrelated processes are central to this construct. First, students must diagnose the present situation by identifying relevant variables and chemical conditions. Second, they must select a principle or model capable of explaining those variables. Third, they must project the likely direction of change and formulate a prediction. Fourth, they must evaluate the prediction against evidence, alternative explanations, or experimental results. Prediction and explanation therefore should not be treated as identical. As Gil and Paiva (2010) note, a successful prediction is not by itself a complete explanation; students should also understand why a model supports the predicted outcome.

This distinction has important pedagogical consequences. A question such as 'What happens to halogen reactivity down Group 17?' assesses more than recall when students are required to connect atomic radius, electron shielding, attraction for an incoming electron, and oxidizing ability. Similarly, asking students to predict the thermal effect of a reaction becomes intellectually productive only when the forecast is linked to bond breaking and bond formation. Such tasks integrate chemical content with causal reasoning.

The development of this potential should be continuous rather than episodic. It requires instructional programs that repeatedly expose learners to situations in which they must anticipate, justify, test, and revise ideas. The original article identified improvement of teaching technologies, systematic attention to students' interests, development of independent learning, and interactive methods as important factors (Atabayeva, 2024; Baydulloev, 2010; Rogozhin, 2006; Tolipov & Usmonboeva, 2006). These factors can be strengthened by current research emphasizing inquiry cycles, problem solving, laboratory reasoning, modeling, and scientific argumentation (Hmelo-Silver, 2004; Hofstein & Lunetta, 2004; Osborne, 2010; Pedaste et al., 2015).

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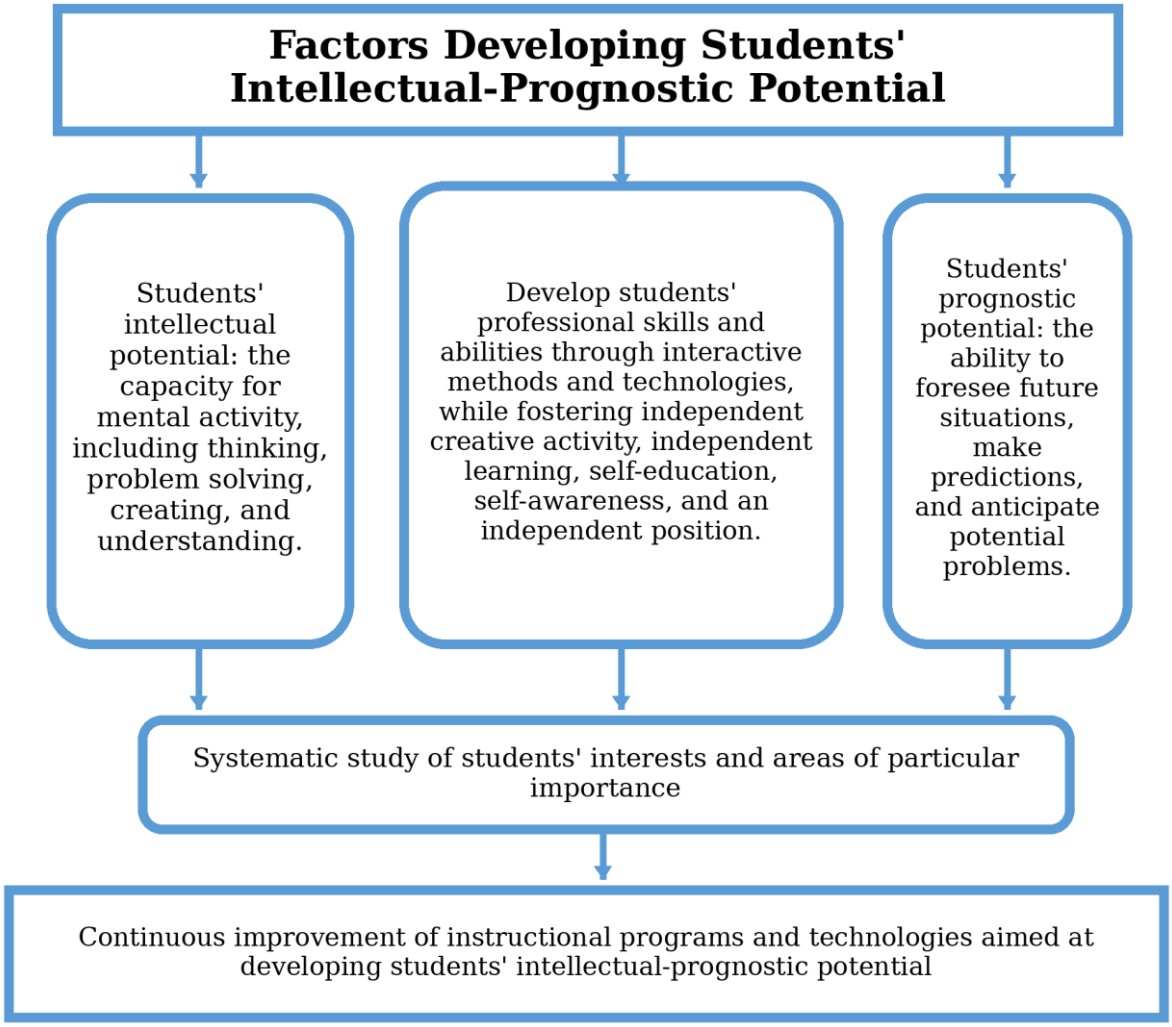


Figure 1. Factors developing students' intellectual-prognostic potential

3. Methodological Framework and Target Competencies

The proposed framework organizes chemistry learning around five competency domains derived from the original paper: observing chemical processes and phenomena; understanding and explaining them; expressing elements, formulas, and processes in chemical language; working with substances and equipment and conducting experiments; and applying chemical knowledge in practical contexts. Each domain can be redesigned to include a prognostic component.

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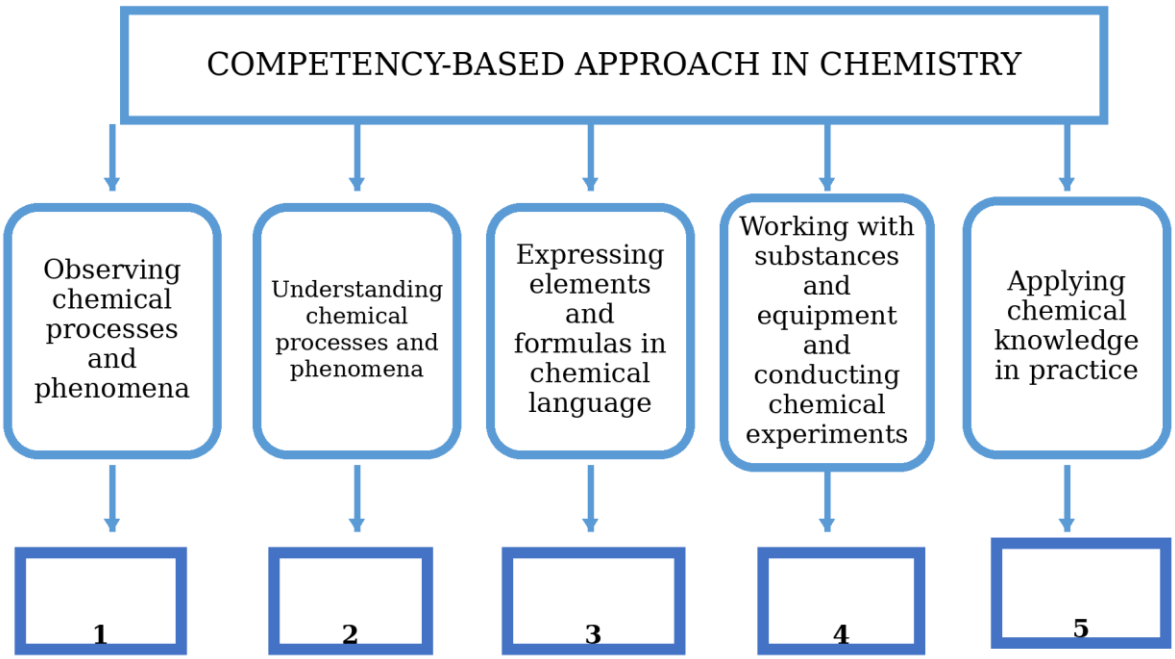


Figure 2. Competencies developed through the study of chemistry topics

Observation should move from description to anticipation. Before a demonstration, students may predict changes in color, state, temperature, gas evolution, or precipitate formation and identify the evidence that would confirm or challenge the forecast. Explanation should require students to state causal links and distinguish observation from inference. Symbolic competence should include predicting formulas, products, stoichiometric relationships, or trends before completing calculations. Experimental competence should include planning, selecting appropriate evidence, anticipating sources of error, and comparing expected and observed results. Practical application should require learners to evaluate likely consequences of chemical processes in health, environmental, industrial, and everyday contexts.

Table 1. Competency-based framework for developing prognostic reasoning

Competency domain	Prognostic expression	Illustrative prompt
Observation	Anticipates observable evidence before a process or demonstration	What change should be observed, and which observation would contradict your prediction?
Explanation	Uses causal relationships and chemical models to justify an expected outcome	Why should the predicted change occur at the particle level?
Chemical language	Uses formulas, equations, symbols, and quantities to project an outcome	Which product, coefficient, trend, or quantitative result is expected?
Experimentation	Plans evidence collection and compares expected with observed results	What should the data show if the hypothesis is correct?
Practical application	Evaluates likely consequences in realistic contexts	What chemical consequences may follow if this condition or practice changes?

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This framework is consistent with inquiry-based learning, in which orientation and conceptualization lead to investigation, conclusion, and discussion (Pedaste et al., 2015). It also reflects the value of laboratory work when practical activity is connected to conceptual questions rather than reduced to following procedures (Hofstein & Lunetta, 2004). Because chemistry knowledge is represented at several levels, forecasting tasks should deliberately connect the macroscopic, submicroscopic, and symbolic domains (Taber, 2013). For example, students may predict a visible change, explain it through particle interactions, and represent it with an equation.

The content of these competencies may be operationalized through the kinds of tasks identified in the original paper. Observation can include changes of state, combustion, dissolution, diffusion, evaporation, recrystallization, sublimation, boiling, solidification, separation, purification, and filtration. Conceptual understanding includes the law of conservation of mass, constant composition, equivalents, periodicity, and dissociation. Symbolic work includes reaction equations, coefficients, valency, molecular and structural formulas, units, and quantitative problem solving. Practical competence includes purposeful selection and use of laboratory glassware and measuring instruments, recording observations, and drawing conclusions. Everyday application includes interpreting chemical knowledge in water treatment, cleaning, food-related contexts, and safe handling of substances. When these familiar curriculum elements are paired with 'what do you expect and why?' questions, routine content becomes a vehicle for higher-order reasoning. The learner is required to move from recognition to projection: from identifying a law to using it to anticipate an outcome, from naming equipment to justifying its selection, and from performing a procedure to predicting the consequences of changing a variable.

The approach is methodological rather than experimental. It synthesizes the conceptual positions and teaching examples of the original article with established literature on active, inquiry-oriented chemistry education. No new student sample, intervention data, or statistical results are claimed. Consequently, the framework should be regarded as a theoretically grounded instructional model that requires subsequent classroom validation through pre/post measures, observation, student work, and teacher reflection.

4. Instructional Strategies for Developing Prognostic Thinking

Several teaching strategies can make prediction a routine part of chemistry learning. Problem-based learning is useful because it begins with a meaningful problem that cannot be solved by simple reproduction of a memorized statement. Students identify what they know, determine what additional information is required, propose solutions, and reflect on the reasoning used (Hmelo-Silver, 2004). In chemistry, a problem may ask students to anticipate which conditions will increase reaction rate, how a change in equilibrium conditions will affect composition, or what chemical risks may follow from an inappropriate use of a substance.

Inquiry-based instruction strengthens this process by placing predictions before investigation. Students formulate a hypothesis or expected result, collect evidence, and then compare the observation with the original forecast. The value of the laboratory is therefore not merely manipulative; it lies in coordinating action, evidence, interpretation, and explanation (Hofstein & Lunetta, 2004). Research on guided inquiry with writing and reflection also indicates that structured inquiry can support critical-thinking performance in chemistry students (Gupta et al., 2015).

Modeling is equally important. Students should be encouraged to use particle diagrams, energy profiles, structural formulas, periodic trends, and mathematical relationships as tools for forecasting. A model is educationally productive when students can state what it predicts, identify the assumptions on which the prediction depends, and recognize conditions under which the model may be insufficient. This approach reduces the risk of treating formulas as isolated symbols and helps create coherence across chemistry topics (Taber, 2013).

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Scientific argumentation adds a further quality criterion. A forecast should be presented as a claim supported by evidence and reasoning. Collaborative discussion allows students to compare alternative forecasts and evaluate which is better supported. Osborne (2010) emphasizes the role of critical discourse in learning science, while Walker and Sampson (2013) show that sustained engagement with claims and evidence in argument-driven chemistry inquiry can improve the quality of students' written and oral arguments.

The 'Mass Brainstorming' method described in the original article can be retained as a structured collaborative technique. Small groups receive a problem or forecasting task, generate possible outcomes within a limited period, select the most defensible forecast, and present their justification. The teacher then guides comparison among groups. Used at the beginning of a lesson, the method reveals prior conceptions; used during transition to a new topic, it activates transfer; used after instruction, it supports consolidation and application. Its educational value increases when students are required not only to produce many ideas but also to rank them according to chemical evidence and explain uncertainty.

Digital tools can support the same objective when they are used to make reasoning visible rather than to replace it. Interactive simulations, molecular visualizations, and graphing environments allow students to vary one condition, record a forecast, observe the modeled response, and explain discrepancies. A useful sequence is predict-observe-explain-revise: students commit to an initial expectation, encounter evidence, construct an explanation, and then refine the original model. This sequence is especially valuable for processes that are too rapid, microscopic, hazardous, or experimentally inaccessible in an ordinary classroom. The teacher's role is to ensure that technological visualization remains connected to chemical principles and that students distinguish a model-generated result from direct empirical observation.

5. Application to Halogen Chemistry

The halogens provide a productive context for intellectual-prognostic tasks because their properties display recognizable periodic trends and their compounds have important practical consequences. Instead of presenting fluorine, chlorine, bromine, iodine, and astatine as a list of facts, the teacher can organize learning around questions that require students to infer trends and anticipate outcomes.

A first task may ask: 'As atomic radius increases down Group 17, how should the chemical reactivity of the halogens change, and why?' Students can be guided to connect increasing electron-shell number and shielding with a weaker attraction for an incoming electron. From this reasoning, they predict that the oxidizing reactivity of the elemental halogens generally decreases down the group. A second task may ask learners to anticipate the consequences of omitting a disinfection step in drinking-water treatment. The purpose is not to memorize a single response but to identify a chain of cause and effect: altered control of microorganisms may change public-health risk, while treatment decisions must also consider chemical dose, by-products, and local standards. Similar questions can address prolonged iodine deficiency, environmental consequences of misuse of halogen-containing substances, or changes in physical state and color down the group. In each case, the teacher should require students to identify the evidence or principle underlying the forecast.

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Figure 3. Selected nonmetals in different physical forms (adapted from the original manuscript).

A second example concerns the reaction shown below. The original article uses this reaction to teach students to predict an exothermic outcome. Using approximate bond energies, breaking H-H and Cl-Cl bonds requires about 436 + 243 = 679 kJ mol-1, whereas forming two H-Cl bonds releases about 862 kJ mol-1. The estimated enthalpy change is therefore approximately -183 kJ mol-1.

$$Cl_2 + H_2 \rightarrow 2HCl$$

Estimated enthalpy change: $\Delta H \approx 679 - 862 = -183$ kJ mol^{-1}

The negative value supports the prediction that the reaction releases heat. The intellectual objective is not the numerical result alone. Students should articulate the causal structure: energy is required to break reactant bonds; energy is released when product bonds form; because the energy released is greater than the energy absorbed, the overall reaction is exothermic. This example also illustrates the difference between prediction and explanation emphasized in chemistry-education literature (Gil & Paiva, 2010).

For classroom use, the reaction should be treated through calculation, simulation, teacher-managed demonstration, or appropriately controlled resources rather than unsupervised mixing of reactive gases. Students can then extend the reasoning by asking how bond energies, light initiation, concentration, or reaction conditions might affect what is observed. Such extensions turn a familiar equation into a platform for forecasting, evidence-based explanation, and transfer.

6. Assessment and Pedagogical Implications

Assessment should measure the quality of reasoning, not only whether a forecast happens to be correct. Four indicators are especially useful: conceptual accuracy, relevance of evidence, explicit causal reasoning, and reflective evaluation of uncertainty. A high-quality response identifies the governing chemical principle, uses appropriate data or representations, explains the mechanism linking cause to outcome, and states the limits of the prediction. This approach prevents lucky guesses from being rewarded as equivalent to scientific reasoning.

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Table 2. Suggested criteria for assessing prognostic reasoning

Criterion	What to look for	High-quality performance
Conceptual accuracy	Correct chemistry principle or model	Uses the appropriate law, trend, structure, or energy concept without contradiction.
Evidence	Relevant observations, data, or representations	Selects evidence that directly supports the forecast and distinguishes evidence from assertion.
Causal reasoning	Explicit link from condition to outcome	Explains how and why the identified factor produces the predicted change.
Uncertainty and revision	Awareness of assumptions and alternatives	States limits, considers competing outcomes, and revises the forecast when evidence requires it.

Teachers can collect evidence through short prediction prompts, laboratory pre-questions, concept maps, written claim-evidence-reasoning responses, group discussions, and reflective comparisons between predicted and observed results. Inductive teaching research suggests that students benefit when problems or observations create a need for the concepts that follow (Prince & Felder, 2006). The National Research Council (2012) similarly emphasizes integrating disciplinary knowledge with scientific practices rather than teaching them separately.

For implementation, forecasting tasks should increase gradually in complexity. Early tasks may involve a single trend or variable; later tasks can involve competing factors, incomplete evidence, or several plausible outcomes. Feedback should address not only the final answer but also the reasoning path. In this way, prognostic competence becomes part of normal chemistry learning rather than an occasional enrichment activity.

7. Conclusion

Developing intellectual-prognostic potential gives chemistry education a forward-looking and reasoning-centered orientation. Students learn not only to state what is known, but also to use chemical principles to anticipate what is likely to occur, justify that anticipation, test it against evidence, and revise it when necessary. Problem-based learning, inquiry, laboratory activity, modeling, brainstorming, and scientific argumentation can all contribute when prediction is explicitly built into the task structure.

The proposed framework preserves the competency-based emphasis of the original study while strengthening its theoretical grounding and assessment logic. Its principal limitation is that it remains a methodological model rather than a tested intervention. Future research should examine its effects on students' prediction accuracy, causal reasoning, argument quality, transfer of knowledge, and independent decision-making across different chemistry topics and educational levels.

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