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Design and Implementation of Unit-Based Instruction in Senior High School Chemistry Guided by Big Ideas

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Abstract: Big ideas can organise chemistry curricula around explanatory relationships rather than disconnected topics, but their instructional value depends on how they shape tasks, representations and assessment across a complete unit. This article develops an evidence-informed architecture for big-idea-guided unit-based instruction in senior high school chemistry. A purposive conceptual synthesis connects research on core-idea-centred chemistry, curriculum coherence, documented misapplications of Le Chatelier's principle, representational reasoning, formative assessment and systems thinking. The synthesis is translated into an original ten-lesson unit on chemical equilibrium and ammonia synthesis, together with a traceability matrix, diagnostic contrast cases, an analytic assessment rubric and a prospective evaluation protocol. The central design output is an alignment chain linking an explanatory proposition to an essential question, an observable student performance, a task sequence and a responsive instructional decision. A worked comparison of compression, inert-gas addition and catalysis illustrates why naming a big idea or predicting an equilibrium shift is insufficient evidence of understanding. The framework distinguishes equilibrium composition from reaction rate, requires coordination of observable, particle-level and symbolic accounts, and limits systems-level discussion to claims supported by the unit's chemistry. Implementation is specified as a proposed classroom pathway rather than a completed intervention. No participants were recruited and no learning gains are reported. The article contributes a testable design specification for developing and investigating coherent chemistry units, while identifying the curricular, representational and assessment conditions on which its usefulness depends.

Keywords: big ideas, unit-based instruction, chemical equilibrium, formative assessment, chemistry education

1. Introduction

A chemistry unit may cover every required topic while leaving students unable to explain how its ideas belong together. A sequence on reversible reactions, equilibrium constants, changes in conditions and industrial synthesis is particularly vulnerable to this problem. Students can meet the content as several rules rather than as a connected account of a dynamic system. The educational case for big ideas therefore rests less on having fewer headings than on the claim that a small set of explanatory relationships should organise the selection, sequencing and reuse of knowledge (Harlen, 2015). For chemistry, this requires attention to what students can explain and predict, not only to the vocabulary they can reproduce (Cooper & Stowe, 2018). The question is also a practical one for Chinese senior high schools. The 2020 revision of the general senior high school curriculum programme asks that subject content be structured around disciplinary big ideas and situated within themes to support core competencies (Ministry of Education of the People's Republic of China, 2020). Meanwhile, the intellectual demands of the senior high school chemistry curriculum have risen across successive editions (Wei, 2020).

Core-idea-centred chemistry is not an untested aspiration in every setting. Stowe, Herrington, McKay, and Cooper (2019a, 2019b) describe adaptation of an undergraduate curriculum for high school and investigate high-school students' structure–property reasoning. Those studies provide a relevant precedent for curriculum coherence, but their topic and instructional setting do not establish the effectiveness of the equilibrium unit proposed here. Larger design programmes make a similar point about coherence. He, Krajcik and Schneider (2023) report the iterative development and testing of a coherent, standards-aligned project-based learning system for high school chemistry. Its units were deliberately linked through shared core ideas, practices and crosscutting concepts, and post-unit performances predicted later achievement (He, Chen, et al., 2023). Storyline units pursue coherence from the students' perspective, so that each activity answers a

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question the class has committed to (Reiser, Novak, McGill, & Penuel, 2021). The distinction matters: evidence for an educational orientation cannot be treated as evidence for every lesson sequence developed under its name.

The practical design problem addressed in this article is narrower than whole-curriculum reform. How can a teacher make a big idea consequential at the level of a teachable unit? A label such as "equilibrium and change" does not by itself specify which misconception to diagnose, which representations to juxtapose, or what to do when a student gives the right prediction for the wrong reason. Conversely, an attractive industrial context can become an introductory story that disappears once symbolic exercises begin. A useful design must connect the intended explanation, the evidence elicited from students and the teacher's subsequent action.

This article asks three design questions. First, what criteria distinguish an explanatory big idea from a topic heading in senior high school chemistry? Second, how can those criteria organise a coherent sequence of tasks and formative decisions? Third, what evidence would be needed to judge the feasibility and educational value of the resulting unit? The response is a conceptual framework with a worked ten-lesson design. Its contribution is an evidence-traceable architecture, not a claim to a new general theory of learning or to demonstrated classroom effectiveness.

The intended setting is an upper-secondary chemistry course in which students have encountered chemical equations, amounts of substance, gases and introductory reaction rates. Approximately ten periods of 45 minutes are proposed; this is a planning assumption, not an empirically established optimum. "Implementation" in the title refers to an operational pathway for future classroom enactment. No school intervention, interviews or achievement testing were conducted for this article. The proposed tasks, rubric and evaluation procedures are original design outputs requiring contextual review and empirical investigation.

2. Theoretical Foundations

2.1 Big ideas as explanatory commitments

For the purposes of this design, a big idea is an explanatory proposition that connects multiple phenomena, constrains acceptable accounts and remains useful when surface features change. "Chemical equilibrium" is a topic; "a system can maintain stable macroscopic composition while opposing transformations continue" is a proposition with explanatory consequences. The latter rules out the claim that a constant concentration necessarily means that reaction has stopped. It also generates a question about how stability can coexist with molecular change. This operational definition is a design interpretation of the emphasis on coherent scientific understanding in Harlen (2015), rather than a quotation or a universally agreed classification.

Three tests guide selection. An idea must have explanatory reach beyond one worked example, identify a relationship rather than a collection of terms, and admit a performance through which its use can be examined. An additional economy test asks whether adding the idea changes the planned tasks or assessment. If it changes neither, it is probably functioning as decoration. These are proposed design tests, not a validated measurement instrument. They respond to a documented risk. In a study of Chilean science teachers working with big ideas, Bravo González and Reiss (2023) found that teachers valued big ideas as an organising framework but often understood them as disciplinary content rather than as cross-cutting explanatory ideas. They keep the unit focused without suggesting that students can understand complex chemistry without substantial domain knowledge.

Sevian and Talanquer (2014) position chemical thinking around the use of chemical knowledge to address explanatory and practical questions. Their perspective supports organising a unit around what chemical accounts enable students to do. Research on the big ideas that students perceive in introductory chemistry and biology also treats learners' interpretations as an object of inquiry (Roche Allred et al., 2022). An intended curricular connection is not assumed to be visible to them. In the present unit, students therefore periodically state which earlier idea they used and why it applies to the new case.

2.2 Representations, mechanisms and bounded systems thinking

Equilibrium explanations require movement between different forms of chemical knowledge. A concentration–time graph records a macroscopic pattern; a particle model proposes what may be happening beyond direct observation; an equilibrium expression states a quantitative relationship under specified conditions. Taber (2013) cautions against treating the chemistry triplet as a simple, unproblematic taxonomy. Accordingly, this design does not assume that showing three representations creates understanding. Students must explain the correspondence between them and identify what each representation leaves unspecified. Design research that uses authentic chemical practices as contexts supports a related "need-to-know" principle: each concept is introduced when the task requires it, not in advance (Bulte, Westbroek, de Jong, & Pilot, 2006).

Systems thinking adds questions about boundaries, interactions and consequences. Recent chemistry education work includes a teaching framework (Talanquer & Szozda, 2024), investigation of educators' perspectives (Szozda, Bruyere, Lee, Mahaffy, & Flynn, 2022), first-year chemistry teaching and assessment (Reynders, Pilcher, & Potgieter, 2023), and a design-based model developed in a sustainable chemistry course (Vuorio, Pernaa, & Aksela, 2025). These contributions

differ in setting and evidential purpose. They motivate careful attention to systems boundaries, but do not validate a particular senior high school intervention.

The present design uses bounded systems thinking. Students first explain the reacting gas mixture, then connect that explanation to a simplified production decision involving rate, equilibrium composition and resource demands. Broader questions are introduced only when they change the chemical explanation or expose a limit of the available evidence. A complete life-cycle assessment, detailed reactor engineering and quantitative process optimisation are outside the unit's scope. This boundary is intended to protect chemical depth rather than to deny the wider significance of ammonia production.

2.3 Alignment and the instructional use of evidence

Backward design begins with intended understanding and acceptable evidence before selecting activities (Wiggins & McTighe, 2005). The present framework adds an explicit response requirement: every major diagnostic task should identify an instructional decision that its evidence could change. Black and Wiliam (2009) treat assessment as formative through the use of evidence to inform learning and teaching. A quiz is therefore not formative merely because it is frequent, and a lesson is not aligned merely because its objective and worksheet contain the same words.

The alignment chain used here is proposition → question → performance → task → evidence → response → transfer. Its value is practical traceability. A teacher should be able to work backwards from an assessment item to the intended idea, and forwards from a plausible response to an instructional move. The chain also reveals overclaiming: a correct substitution into an equilibrium expression cannot, by itself, establish mechanistic understanding or the ability to judge industrial trade-offs. The performance focus is also compatible with distinguishing scientific practices from content recall in the National Research Council (2012) framework; that compatibility is not a claim of alignment with every national syllabus.

3. Conceptual Design Method

3.1 Evidence base and scope of the synthesis

The article uses purposive conceptual synthesis and a worked design case, rather than a systematic review or an empirical design-based research study. Jaakkola (2020) provides a methodological rationale for making the theoretical role and contribution of a conceptual article explicit. Literature was selected to perform four functions: define the curricular problem, inform representational and assessment choices, supply chemistry-specific design precedents, and identify conditions that a future evaluation must examine. Foundational texts were retained alongside recent chemistry education studies because recency alone does not determine their conceptual relevance.

Targeted online searches were conducted during manuscript preparation, with the final search check on 15 October 2026. A supplementary benchmark search of Elsevier, Wiley, Springer Nature, Sage and Taylor & Francis journals on 22 November 2026 added nine publications on equilibrium misconceptions and curriculum coherence. All bibliographic records were re-resolved against Crossref. Search combinations included "big ideas" and "high school chemistry", "chemical equilibrium" and "sensemaking", "systems thinking" and "chemistry education", and "conceptual articles" or "conjecture mapping". Publisher records, official publications and author-affiliated repositories were used to check bibliographic details and the accessible basis of claims. Full-text access was uneven; where only an abstract or publication record was accessible, the source is used for the limited purpose that this material supports. The search was neither exhaustive nor independently screened, and no pooled effects or claims of comprehensive evidence coverage are made.

The synthesis distinguishes three kinds of statement: a proposition drawn from prior scholarship, an original design inference, and a prospective claim about learning. Table 1 makes these distinctions visible for the principal design choices. Chemistry content is checked against an established open textbook rather than inferred from education research (Flowers, Theopold, Langley, & Robinson, 2019). The purpose of this separation is to avoid transferring the authority of a cited study to an untested local design.

Table 1. Evidence-to-design traceability and limits of the evidence

Literature basis	Supported design concern	Original response in this unit	Limit on inference
Harlen (2015); Stowe et al. (2019a, 2019b)	Coherent ideas and chemistry-specific adaptation merit explicit attention.	Express each organising idea as a proposition with an assessable consequence.	Evidence from another topic does not establish equilibrium learning gains.
Taber (2013); Hamnell-Pamment (2024)	Representations and classroom dialogue matter for making chemical meaning.	Require students to reconcile graph, particle account and symbolic relation.	The particular prompts and their sequencing remain untested.
Black and Wiliam (2009); Wiggins and McTighe (2005)	Learning goals, evidence and instructional decisions should be connected.	Attach a response rule to each major diagnostic contrast.	An alignment document is not evidence that teachers enact it.
Reynders et al. (2023); Talanquer and Szozda (2024); Vuorio et al. (2025)	Systems-oriented chemistry needs deliberate teaching and assessment.	Extend from reaction boundaries to a limited production decision.	University and teacher-education work cannot be generalised directly to school pupils.

3.2 Construction and analytic checking of the design

The design was constructed in four passes. First, equilibrium content was reduced to a small set of propositions and prerequisite relationships. Second, a culminating explanatory decision task was drafted before lesson activities. Third, each proposition was linked to an observable student performance and a diagnostic contrast. Fourth, the unit was checked against counterexamples: could a student succeed through a slogan, an irrelevant contextual opinion or a memorised procedure without using the intended idea? When the answer was yes, the task was revised to require an additional justification or a contrasting case.

This is an analytic consistency check, not expert validation or a completed iterative classroom study. Sandoval's (2014) conjecture-mapping approach informs the distinction between a design feature, an anticipated mediating process and an eventual learning outcome. McKenney and Reeves (2025) emphasise the relationship between educational design and robust, relevant scholarship; here that relationship is specified prospectively. The current outputs are the architecture, worked tasks and testable conjectures. The collection of classroom evidence belongs to a subsequent research phase.

4. Design Framework and Worked Unit

4.1 Unit boundary, organising question and big ideas

The unit is organised by the question: "How can a reaction system keep changing while its composition stays stable, and what can we legitimately change to obtain a different outcome?" Ammonia synthesis provides a recurring application, not an experiment to be performed at school. The context is deliberately simplified to distinguish explanatory principles from industrial operating instructions. No ammonia production, pressurised reaction equipment or hazardous demonstration is required. Particle models, printed graphs and teacher-controlled simulations can support the entire sequence.

Four organising propositions are used. First, macroscopic stability can arise from continuing opposing processes. Second, equilibrium composition is constrained by a temperature-dependent relationship among the activities of reacting species; ideal-gas partial pressures provide the school-level approximation used here. Third, the speed of approach to equilibrium and the equilibrium composition are different properties. Fourth, a chemically justified practical choice depends on system boundaries, competing criteria and the limits of the evidence. The fourth proposition is an application principle rather than an additional thermodynamic law. Together they connect the central topic to an assessable decision without expanding the unit into an unrestricted sustainability project.

At entry, a short individual task checks whether students can conserve atoms, distinguish amount from concentration, read a graph with a non-zero horizontal plateau and reason qualitatively about gas compression. The responses determine whether a preparatory lesson is required. The ten-period schedule assumes those prerequisites are sufficiently secure. Where they are not, the appropriate adaptation is additional preparation or reduced application breadth, not faster presentation of the same material.

4.2 A coherent sequence with recurring evidence

Table 2 specifies the proposed sequence. Every phase leaves an inspectable individual record even when students work collaboratively. The same explanatory question is revisited with a new demand: describe the pattern, construct an account, quantify a relationship, test a boundary condition and justify a decision. Continuity is thus created through the reuse and refinement of an explanation rather than through repeated mention of the industrial context.

Table 2. Proposed ten-lesson sequence; one lesson is planned as 45 minutes

Lessons	Central task and resource	Individual evidence	Responsive teaching move
1	Compare an unchanging concentration graph with several explanations; complete prerequisite checks.	Initial explanation of what "unchanging" does and does not establish.	Separate observation from inference; repair graph or concentration prerequisites.
2–3	Use a reversible two-state particle model and reconcile it with macroscopic graphs.	Annotated account of continuing opposing events and stable average composition.	Contrast equal rates with equal amounts; discuss the model's limitations.
4	Interpret equilibrium expressions and compare reaction quotient with equilibrium constant at fixed temperature.	Explain what a numerical comparison predicts and what it does not predict.	Distinguish a relationship describing composition from a reaction-rate law.
5–6	Analyse compression, inert-gas addition and catalyst contrasts; revisit predictions after justification.	Before/after partial-pressure account and reasoned comparison of cases.	Use a contrasting boundary condition when a pressure slogan replaces reasoning.
7	Compare changes in temperature with changes in catalysis for an exothermic reversible reaction.	Separate effects on equilibrium composition from the rate of approach.	Require two distinct claims rather than a single "more product" statement.
8–9	Prepare and critique a bounded ammonia-production recommendation from supplied scenario information.	Claim–evidence–limitation memo with one revision after critique.	Challenge unsupported optimisation and requests for missing evidence.
10	Complete a new-context transfer task and reconstruct the unit's idea connections.	Independent explanation and comparison with the entry response.	Plan subsequent instruction from explanation profiles, not only total scores.

The particle activity in lessons 2–3 represents hypothetical interconversion between two states. Its transition rules are declared to be a teaching model, not the elementary mechanism of ammonia synthesis. Students count opposing transitions over a common interval and explain why similar average counts can coexist with unequal populations. They then identify a limitation: a small, discrete classroom model can fluctuate and cannot establish the detailed kinetics of a real multistep reaction. This limitation is part of the task, not an optional disclaimer after the analogy has already been treated as reality.

Teacher dialogue is planned around requests for clarification and reconciliation. Examples include "Which part is observed and which part is your model?", "What would have to be equal for this graph to remain flat?" and "Can both of your drawings describe the same container?" Hamnell-Pamment's (2024) analysis of upper-secondary equilibrium dialogue supports taking the interactional work of sensemaking seriously. It does not supply a universal script. The prompts proposed here are intended to reveal the student's account without turning uncertainty into a public display of failure.

4.3 Worked contrast: pressure is not a sufficient explanation

Consider the idealised gas-phase reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$. At a fixed temperature, the dimensionless reaction quotient may be expressed using partial pressures relative to a standard pressure p°. The ideal-gas approximation is adequate for this instructional contrast but should not be mistaken for an exact description of a high-pressure industrial reactor (Flowers et al., 2019).

(1)

Suppose a mixture is initially at equilibrium and is compressed isothermally so that each reacting species' partial pressure is immediately multiplied by the same factor λ, before composition changes appreciably. The numerator then scales as λ^2 and the denominator as λ^4. The worked consequence is:

(2)

For compression, λ is greater than one, so the immediate quotient is below its initial equilibrium value. Net forward reaction can then occur until equilibrium is re-established. This derivation is a theoretical worked example, not an experimental result. It makes the explanatory burden visible: students must specify temperature, the initial equilibrium condition, the immediate physical change and the subsequent chemical response. The conclusion concerns the direction of net reaction, not the time needed to reach the new state.

Now add an inert gas at fixed volume and temperature. Total pressure increases, but the reacting species' partial pressures do not change under the ideal-gas assumptions. Consequently, the reaction quotient does not change and this pressure increase alone causes no equilibrium displacement. If an inert gas is instead added at constant total pressure and

temperature, the container expands and the reacting gases' partial pressures decrease. The conditions are therefore essential. A response that predicts a shift solely because "pressure increased" has not demonstrated the intended idea. This contrast targets a well-documented difficulty. Students and teachers often misapply Le Chatelier's principle through rote rules and incomplete control of variables (Quílez-Pardo & Solaz-Portolés, 1995). Textbook formulations of the principle can themselves create language, methodological and ontological obstacles (Quílez, 2021). In a test of 109 chemistry teachers, Cheung, Ma and Yang (2009) found that only one recognised that adding more of a gaseous reactant at constant pressure and temperature can shift equilibrium in either direction, depending on the initial composition. Working from the reaction quotient rather than from a slogan is intended to make such cases decidable.

A catalyst supplies a third contrast: at fixed temperature it changes the kinetics of approach to equilibrium without changing the equilibrium constant or the equilibrium composition (Flowers et al., 2019). Students are asked to draw a possible time-course difference and explain why the final plateau need not change. No inference about a detailed ammonia rate law is drawn from the stoichiometric coefficients. Table 3 translates these contrasts into evidence-sensitive instructional decisions.

Table 3. Diagnostic contrasts and proposed response rules

Student response or task contrast	Interpretation to investigate	Next instructional move
"Nothing changes because the graph is flat."	The student may identify equilibrium with cessation of molecular events.	Require an account of opposing events consistent with a flat graph, then test it against a disturbed system.
"Equilibrium means equal concentrations."	Equal rates may have been confused with equal populations.	Compare unequal particle populations with equal opposing transition counts over the same interval.
Compression and inert-gas addition at fixed volume receive the same explanation.	Total pressure may be substituting for reacting-species partial pressures.	Have the student specify amount, volume and temperature before recalculating relative partial pressures.
"The catalyst produces a larger final yield."	Kinetics and equilibrium composition may not be distinguished.	Contrast time to a plateau with plateau height at the same temperature and initial composition.
A production recommendation states "highest yield is best".	The decision may omit rate, resources or the limits of supplied evidence.	Require a second criterion, a stated trade-off and an explicit missing-data condition.

4.4 Culminating decision and transfer

The culminating task asks students to review a simplified ammonia-production proposal that recommends low temperature, high pressure and a catalyst because all three allegedly "increase equilibrium yield". Students must separate the claims. For the exothermic synthesis direction, lower temperature favours a larger equilibrium proportion of ammonia, whereas an assessment of production per unit time requires kinetic information. Higher pressure favours the side with fewer gas molecules under the stated idealisation, but that qualitative conclusion cannot identify an economically or technically optimal pressure. The catalyst claim must be corrected because equilibrium and kinetic effects are different (Flowers et al., 2019).

The expected product is a concise decision memo containing a claim, a chemical explanation, the evidence used, a boundary condition and information still needed. The exercise does not ask adolescents to determine actual operating conditions. Resource and environmental considerations are introduced as additional questions for which suitable data would be required, not as numerical conclusions generated from the equilibrium equation. This limited extension implements the bounded-systems commitment described above.

Transfer is examined with an unfamiliar, explicitly hypothetical gas reaction, $A_2(g) \rightleftharpoons 2A(g)$, and with a new combination of constraints. Students must determine whether their previous explanation still applies when the change in gas-molecule number is reversed. The task includes a distractor account that reaches the correct answer through an incorrect reason. Evaluating that account is intended to make performance less dependent on recognising the desired direction of change. A delayed parallel task is proposed for evaluation, but no delayed outcomes are available in this article.

5. Assessment and Classroom Implementation

5.1 An analytic account of understanding

The proposed assessment distinguishes four dimensions: conceptual accuracy, coordination of representations, conditional prediction, and evidence-bounded decision-making. Table 4 supplies provisional anchors. Each dimension is scored from 0 to 3, with 0 indicating no relevant evidence or a fundamentally incompatible account. The remaining

anchors describe increasing quality, not validated developmental stages. Scores should initially be reported as a profile; summing them would require a defensible argument about the intended interpretation and weighting.

Table 4. Provisional analytic rubric for individual explanatory performances

Dimension	1: Fragmentary	2: Coherent within the familiar case	3: Coherent and conditional
Conceptual accuracy	Names relevant concepts but confuses rate, amount or equilibrium.	Explains dynamic equilibrium and separates rate from composition.	Sustains the distinction while evaluating an alternative explanation.
Representational coordination	Supplies a graph, drawing or equation without a meaningful connection.	Connects at least two representations without a central contradiction.	Explains correspondences and limitations across the representations used.
Conditional prediction	Gives a direction of change with a slogan or incomplete condition.	Justifies a prediction with reacting-species quantities and stated conditions.	Transfers the reasoning and explains why a superficially similar case differs.
Evidence-bounded decision	Makes a recommendation largely from assertion or one criterion.	Uses relevant chemistry and identifies a trade-off.	Distinguishes supported conclusions, assumptions and missing information.

Note. Score 0: no relevant response, or an account incompatible with the central relationship. These anchors are proposed for piloting; they are not a validated scale.

The content of a response matters more than its length or fluency. Students may use labelled diagrams and short oral explanations alongside writing, provided the same explanatory requirements apply. Formula manipulation and unfamiliar vocabulary should not create unintended barriers to demonstrating the target relationship. Separate diagnostic checks can identify whether an error is chemical, mathematical or representational. Such distinctions are essential before treating a lower score as evidence of weaker conceptual understanding.

The Standards for Educational and Psychological Testing require evidence appropriate to the proposed interpretation and use of scores (American Educational Research Association, American Psychological Association, & National Council on Measurement in Education, 2014). Before research use, the rubric therefore requires review for content coverage, student cognitive interviews, trial scoring and an examination of rater agreement. Disagreement should trigger scrutiny of task wording and anchors, rather than negotiation until a desired coefficient is reached. The rubric cannot be described as reliable or valid on the basis of its presentation in this article.

5.2 Preparation, enactment and adaptation

Before teaching, a chemistry teacher should review the content model, complete the contrast tasks independently, check the local syllabus and prepare equivalent printed resources for any digital activity. A second teacher's review would be useful, but has not been conducted as part of this manuscript. Teachers' own reasoning about equilibrium disturbances can rely on Le Chatelier's principle where it fails (Cheung et al., 2009). Preparation should therefore include working the constant-pressure inert-gas case through the reaction quotient before teaching it. The preparation pack consists of the proposition map, lesson sequence, task sheets, anticipated response patterns and provisional rubric. Activities requiring school-specific approval must be reviewed through the institution's normal procedures; the proposed sequence does not depend on handling ammonia or operating pressurised apparatus.

During enactment, teachers should distinguish the planned lesson from the lesson actually delivered. A brief log records the task used, a small anonymised sample of student reasoning, the instructional change made and any time or access constraint. Evidence is sampled to support decisions, not to turn every utterance into a score. If a class continues to equate equilibrium with equal concentrations, additional reconciliation work should precede the application phase. If prerequisites are secure but time is limited, the production discussion can be shortened without removing the compression–inert-gas contrast.

Implementation fidelity is defined around functions rather than a rigid script. The core functions are repeated use of the organising propositions, explicit representation matching, a contrast that exposes boundary conditions, evidence-responsive revision and an independent transfer opportunity. Teachers may change the context, language support or medium while retaining these functions. An adaptation that removes individual explanations or permits every task to be answered by a memorised shift rule changes the theoretical intervention and should be documented as such.

Participation is supported by private prediction before discussion, rotating group responsibilities, accessible representations and opportunities to revise an explanation without penalty during learning. These are proposed access arrangements rather than demonstrated equity effects. Group products do not replace individual evidence: a persuasive spokesperson can conceal classmates' uncertainty. Where students require language support, the teacher can provide a

sentence frame such as “Under the condition ___, quantity ___ changes, so ___”, while progressively reducing the support in transfer tasks.

6. Prospective Evaluation and Discussion

6.1 Testable conjectures and a staged research plan

Three conjectures follow from the design. First, explicit representation-reconciliation tasks should make contradictions in students’ equilibrium accounts more visible and support their revision. Second, paired boundary-condition contrasts should support more conditional explanations than a sequence limited to single-case shift predictions. Third, separating evidence from recommendations should reduce unsupported claims in the culminating decision task. These conjectures concern different mediating processes and must not be collapsed into a single expectation that “big ideas improve achievement”. Each could fail even if students enjoy the unit.

An initial feasibility phase should examine task comprehension, lesson timing, resource accessibility and whether teachers can act on the elicited evidence. Student think-alouds and teacher planning records would be particularly relevant. A subsequent comparative phase could examine the revised unit against instruction covering the same chemistry with comparable time and assessment exposure. Allocation at class or school level may be needed to limit contamination. Sample size should follow a prospective power or precision analysis incorporating clustering; this article supplies no invented sample, anticipated effect size or recruitment claim.

The principal outcome should be a pre-specified independent explanation or transfer measure, not satisfaction or a teacher-designed total score that rewards intervention-specific wording. Baseline prerequisite knowledge, immediate performance and a delayed parallel task could be collected. Where allocation is not random, baseline differences, teacher effects and selection processes must be described, and causal conclusions limited accordingly. Analysis should reflect clustered observations, report uncertainty and missing-data handling, and retain dimension-level results where a total score lacks justification.

Process evidence is necessary to interpret outcomes. A null result may reflect an ineffective conjecture, an inaccessible task or failure to enact the core functions. Conversely, a positive comparison may arise from additional explanation time rather than the big-idea architecture itself. A more discriminating follow-up would compare a common aligned unit with and without the contrast-and-response component while holding time approximately constant. Such component analysis would test the proposed mechanism more directly than a broad comparison between “traditional” and “innovative” teaching.

6.2 Contribution, limitations and boundary conditions

The framework’s intended contribution is to make curricular coherence inspectable. Backward design already establishes the importance of goals and evidence; representational work already establishes that chemical meaning is not exhausted by symbols. This article combines those commitments into a unit-level specification in which diagnostic evidence has an identified instructional consequence. Compared with system-level coherence projects (He, Chen, et al., 2023; He, Krajcik, & Schneider, 2023; Reiser et al., 2021), the contribution is narrower and closer to a single teacher’s planning decisions. The worked pressure contrast illustrates the added requirement: a prediction is judged in relation to its conditions and explanation, and that judgement directs the next task.

Several limits remain. The literature synthesis is purposive, not comprehensive. Much recent systems-thinking work concerns university or teacher-education contexts, so transfer to school pupils is an inference requiring investigation. A single equilibrium case cannot establish applicability to organic chemistry, electrochemistry or other topics. The unit assumes prerequisites and teacher content knowledge that may be unevenly distributed. The simple gas treatment also postpones activities and non-ideal behaviour that matter in advanced thermodynamics. These boundaries must remain explicit when adapting the materials.

There is also a risk of excessive orchestration. If every representation and decision is prescribed, students may learn to reproduce the teacher’s preferred account rather than exercise explanatory judgement. The independent transfer task and requests to critique a correct answer with an incorrect justification are intended to address this risk, but their effectiveness remains unknown. A successful future implementation would need to demonstrate both conceptual coherence and increasingly independent use of the ideas, rather than compliance with the worksheet sequence.

7. Conclusion

Big-idea-guided unit-based instruction becomes educationally substantive when its organising propositions determine what students must explain, what evidence is collected and how teaching responds. This article has developed a traceable alignment architecture and operationalised it through a ten-lesson equilibrium unit, boundary-condition contrasts, a provisional rubric and an evaluation pathway. The analytical contribution lies in separating topic coverage from explanatory use, kinetics from equilibrium, and plausible instructional design from demonstrated effectiveness. The resulting materials are ready for contextual review and piloting, not for claims of established learning gains. Future

research should test the proposed mediating processes and the conditions under which the architecture supports independent chemical reasoning.

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Ethics and Data Availability

This manuscript presents a conceptual synthesis and a proposed instructional design. No human participants were recruited, no identifiable personal data were collected, and no empirical classroom dataset was generated. Any future school-based evaluation will require the relevant institutional permissions, ethics review and consent or assent procedures before data collection. The illustrative tasks are contained in the article and appendix.

AI-Assistance Disclosure

Generative artificial intelligence was used to assist literature discovery, conceptual drafting, language editing and preparation of this manuscript. The named authors must verify all sources, approve all claims and take responsibility for the final submission; the disclosure must be adapted to the target journal's policy and the actual author workflow.

Conflict of Interest

[Authors to confirm: "The authors declare no conflicts of interest."]

Appendix A. Reusable Task and Scoring Specification

Task A1: A sealed model gas mixture is initially at equilibrium at a stated temperature. The container is compressed without changing temperature. Explain the immediate change in reacting-species partial pressures and the subsequent direction of net reaction for $N_2 + 3H_2 \rightleftharpoons 2NH_3$. Then explain whether adding an inert gas at the original volume and temperature produces the same outcome. State one limitation of treating the system as ideal. Students should not be supplied with the direction of the expected shift.

Task A1 scoring notes: Award conceptual credit for distinguishing a physical perturbation from subsequent reaction. A strong explanation uses the scaling of the quotient, or an equivalent correctly conditioned account, and recognises unchanged reacting partial pressures under inert-gas addition at fixed volume. Merely stating "fewer molecules" is incomplete unless the changed condition and its consequence are explained. Non-ideality is a relevant limitation; an unsupported claim that all textbook relationships are invalid is not.

Task A2: A report states that a catalyst changes the final equilibrium mixture because "it creates more successful collisions". Evaluate the claim at fixed temperature for identical initial mixtures. Draw two possible concentration–time curves, one with and one without the catalyst, that are consistent with your explanation. Identify information that the drawings cannot establish. Expected evidence includes a justified common equilibrium plateau and a distinction between kinetic pathways and the equilibrium relationship; exact curve shapes are not prescribed.

Task A3: For the hypothetical reaction $A_2(g) \rightleftharpoons 2A(g)$, a classmate correctly predicts that isothermal compression favours A_2 but says this is because particles always form stronger bonds when pressure rises. Explain why the prediction does not establish that the reasoning is sound. Provide a condition-sensitive alternative account and compare it with inert-gas addition at fixed volume. This constructed item examines transfer and evaluation of explanations, not knowledge of a real substance called A.

Implementation record: For each task, retain the date, version, time used, available supports, a de-identified response sample, the dimension-level judgement and the teaching action taken. For a future study, maintain separate records of research consent and educational participation. The task examples and expected reasoning above are authored instructional materials, not observed student responses.

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