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Integrating Research, Industry, and Sustainability into Applied Inorganic Chemistry Education: An Outcome-Based Curriculum Reform

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ABSTRACT

Applied Inorganic Chemistry is a professionally significant course for students majoring in Applied Chemistry because it connects fundamental inorganic theory with industrial production, inorganic synthesis, environmental governance, safety management, and frontier materials research. However, the course is difficult to teach effectively within limited contact hours because students must understand not only reaction principles and production processes, but also thermodynamic feasibility, kinetic control, process selection, resource utilization, pollution prevention, and research-oriented inorganic synthesis. This study develops a teaching reform framework based on the teaching schedule of Applied Inorganic Chemistry offered by the College of Chemistry and Environmental Engineering at Yangtze University. The syllabus allocates 32 lecture hours to ten content modules, including synthetic ammonia, sulfuric acid, nitric acid, soda ash, caustic soda and chlorine, inorganic synthesis chemistry, thermodynamics and inorganic synthesis, and representative inorganic synthesis methods. It also adopts a two-part assessment structure consisting of in-class performance and tests, and a final research review assignment. Building on outcome-based education, constructive alignment, active learning, problem-based learning, formative assessment, green chemistry education, and discipline-based chemistry education research, this paper proposes a coherent reform model for transforming the course from a mainly content-delivery course into a research-oriented, case-supported, literature-informed, and sustainability-integrated learning experience. The proposed model aligns course outcomes, module-level anchor problems, industrial cases, frontier reading tasks, staged research-review training, formative feedback, and assessment rubrics. The article provides a detailed course context analysis, a reconstructed outcome framework, module-by-module teaching design, a research-review pipeline, a rubric-based assessment system, and an implementation and evaluation plan. As a design-based curriculum study, this paper does not claim empirical improvement in student performance; instead, it presents an implementable and evaluable teaching reform design suitable for future teaching cycles.

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Introduction

Applied Inorganic Chemistry occupies a distinctive position in undergraduate professional education for Applied Chemistry because it links basic inorganic chemistry with the chemical industry, inorganic materials, environmental treatment, energy conversion, and sustainable manufacturing. The field cannot be adequately learned through memorizing isolated product names, reaction equations, or process-flow diagrams. Instead, students must understand how inorganic principles are translated into production decisions, synthesis strategies, process conditions, safety practices, and environmental choices. The course therefore stands at the junction of chemistry and engineering: it is chemical because it concerns equilibrium, redox chemistry, acid-base reactions, coordination, solid-state transformation, electrochemical processes, and phase control; it is engineering-oriented because it concerns feedstock preparation, purification, catalytic conversion, absorption, electrolysis, heat recovery, waste treatment, scale-up, and process optimization.

For students in Applied Chemistry, this course has a special professional function. In general, inorganic chemistry, students usually learn the periodicity of elements, the structures and properties of common inorganic compounds, coordination chemistry, and qualitative reaction patterns. In Applied Inorganic Chemistry, however, they must move from knowing what inorganic substances are to understanding how such substances are produced, purified, controlled, evaluated, and improved. For example, synthetic ammonia is not only a reaction between nitrogen and hydrogen. It is a case in which gas-source selection, raw-gas purification, catalyst performance, thermodynamic equilibrium, kinetic acceleration, high-pressure equipment, energy consumption, and low-carbon development interact. Sulfuric acid production is not simply the oxidation of sulfur dioxide; it requires catalytic oxidation, heat management, sulfur trioxide absorption, gas cleaning, and tail-gas control. Nitric acid production is not merely ammonia oxidation; it demands attention to nitrogen oxide absorption, energy recovery, toxicity, safety, storage, transportation, and emission mitigation. These examples show that applied inorganic chemistry asks students to reason through complete systems rather than separate facts [1-4].

The teaching schedule of Applied Inorganic Chemistry at Yangtze University provides a compact but rich structure for such professional learning. The course is offered by the College of Chemistry and Environmental Engineering, uses 32 lecture hours, and covers ten chapters: introduction, synthetic ammonia, sulfuric acid, nitric acid, soda ash, caustic soda and chlorine, introduction to inorganic synthesis chemistry, chemical thermodynamics and inorganic synthesis, inorganic synthesis methods I, and inorganic synthesis methods II [1]. The second half of the course shifts from industrial inorganic products to inorganic synthesis, including thermodynamic guidance, Ellingham diagrams, coupled reactions, potential-pH diagrams, low-temperature synthesis, high-temperature synthesis, high-pressure synthesis, hydrothermal and solvothermal synthesis, anhydrous and anaerobic synthesis, and electrolytic synthesis. This design gives the course a dual identity: it is both an industrial inorganic chemistry course and a preparative inorganic chemistry course.

The same design, however, creates a substantial teaching challenge. Thirty-two hours are not sufficient for exhaustive coverage of every product, process, synthesis method, environmental issue, and research frontier. If the course is delivered only through continuous lectures, students may remember process descriptions without developing transferable reasoning. They may know that ammonia synthesis requires high pressure but not be able to explain the compromise between thermodynamic equilibrium and reaction rate. They may know that sulfur trioxide is absorbed in concentrated sulfuric acid but not understand how absorption, heat release, corrosion, and emission control must be integrated. They may list hydrothermal synthesis as a method without explaining how solvent, temperature, pressure, mineralizer, and crystallization kinetics affect phase and morphology. Therefore, the central problem is not how to add more content to the syllabus, but how to reorganize the existing content so that students use it to solve authentic chemical, industrial, and research problems.

A second challenge concerns assessment. The teaching schedule states that the course assessment includes ordinary classroom questioning and attendance, in-class tests accounting for 30 percent, and a major assignment in the form of a research review accounting for 70 percent [1]. This assessment structure is potentially powerful because it indicates that the course is intended to cultivate literature reading and research synthesis, not only examination performance. Yet a final review paper can easily become a superficial compilation if students are not guided in topic selection, database searching, source evaluation, argument construction, citation, and revision. A high-weight research review is educationally valid only when the research process is scaffolded throughout the semester. Thus, the reform must connect the final report with weekly teaching rather than leaving it as an isolated end-of-course task.

A third challenge concerns sustainability and professional values. The course is located in a college of chemistry and environmental engineering; therefore, safety, environmental responsibility, and green development are not external topics but disciplinary necessities. Industrial inorganic chemistry involves high temperature, high pressure, corrosive media, toxic gases, strong oxidants, strong alkalis, chlorine, nitrogen oxides, sulfur oxides, waste salts, energy consumption, and carbon emissions. Inorganic synthesis also involves solvent selection, atmosphere control, autoclave safety, electrochemical hazards, and waste management. If sustainability is added only as a moral statement at the end of a chapter, students may not understand its chemical meaning. A more effective approach is to embed sustainability in process decisions: why a purification step prevents catalyst poisoning, why heat recovery affects energy efficiency, why tail-gas treatment affects social responsibility, why membrane electrolysis improves environmental performance, and why solvent, temperature, pressure, and atmosphere must be selected responsibly.

This paper proposes a reform model for Applied Inorganic Chemistry that is outcome-based, constructively aligned, case-supported, research-oriented, and sustainability-integrated. The model is not presented as a completed empirical intervention. Instead, it is a design-based curriculum study grounded in the Yangtze University syllabus and relevant education and chemistry literature. Its purpose is to show how the existing course can be transformed from a mainly content-delivery course into an integrated learning system in which students learn to explain industrial processes, use thermodynamic and synthetic reasoning, evaluate safety and environmental issues, read traceable literature, and write a research review with evidence. The paper therefore contributes a practical framework that can be implemented, evaluated, and revised in future teaching cycles.

Course Context and Syllabus Analysis

The course analyzed in this study is Applied Inorganic Chemistry, course code 753866, offered in the first semester of the 2025-2026 academic year at the College of Chemistry and Environmental Engineering, Yangtze University. The teaching schedule lists the instructor as Professor Kangle Ding, the teaching unit as Applied Chemistry, and the target students as 2023 Applied Chemistry students. The course has 33 students and 32 total teaching hours, all assigned to classroom teaching [1]. The textbook is Zhang Xianglin's Applied Inorganic Chemistry, and the main reference books include James E. House's Inorganic Chemistry, Inorganic Chemical Products, and Inorganic Synthesis and Preparative Chemistry [1-4]. These materials show that the course draws from industrial inorganic chemistry, general inorganic chemistry, and preparative inorganic chemistry.

The first six chapters of the course are organized around representative inorganic products and production processes. The introduction receives 2 hours. Synthetic ammonia receives 4 hours and includes an overview, raw-gas preparation, raw-gas purification, ammonia synthesis, and technological development. Sulfuric acid receives 2 hours and includes production methods, catalytic oxidation of sulfur dioxide, absorption of sulfur trioxide, and the full contact-process flow. Nitric acid receives 2 hours and covers dilute nitric acid production, tail-gas treatment and energy utilization, concentrated nitric acid production, toxicity, safety, storage, and transportation. Soda ash receives 2 hours and covers production principles and process introduction. Caustic soda and chlorine receive 2 hours and cover production principles and process introduction [1]. These topics represent classical inorganic chemical industries and remain important for understanding the relationship between chemical principles and national industrial systems.

The last four chapters shift toward inorganic synthesis and research-oriented knowledge. The introduction to inorganic synthesis chemistry occupies 6 hours and includes the research content and significance of inorganic synthesis chemistry, hot fields, and frontier development. Chemical thermodynamics and inorganic synthesis occupy 4 hours and include the Gibbs-Helmholtz equation, Ellingham diagrams, coupled reactions, standard equilibrium constants, and potential-pH diagrams. Inorganic synthesis methods I and II occupy the final 8 hours and include low-temperature synthesis, high-temperature synthesis, high-pressure synthesis, hydrothermal and solvothermal synthesis, anhydrous and anaerobic synthesis, and electrolytic synthesis [1]. This sequence is valuable because it allows students to move from understanding established industrial processes to thinking about how new inorganic compounds and materials are designed and prepared.

The syllabus therefore contains three implicit learning trajectories. The first trajectory is industrial-process reasoning. Students move from raw materials and reaction principles to process flow, purification, conversion, product handling, and technology development. The second trajectory is synthesis-method reasoning. Students move from broad understanding of inorganic synthesis to thermodynamic judgment and method selection. The third trajectory is research-literacy development. The assessment requires a research review, which means that students must consult domestic and international literature and write a paper on a selected topic. These trajectories are compatible, but they must be made explicit. If they remain implicit, students may treat the course as a sequence of independent product chapters followed by unrelated synthesis methods.

The hour distribution also reveals a pedagogical tension. Some chapters are allocated only 2 hours despite their technical complexity. For example, nitric acid production includes reaction chemistry, absorption, tail-gas treatment, energy use, concentrated acid production, toxicity, safety, storage, and transportation. Caustic soda and chlorine involve electrolysis, membrane technology, brine purification, chlorine safety, hydrogen management, and energy consumption. If the teacher attempts to explain all details at equal depth, the course will become overloaded. A more realistic design is to identify anchor problems for each module and use them to organize essential content. For nitric acid, the anchor problem can be tail-gas treatment and energy utilization. For chlor-alkali, the anchor problem can be how electrochemical process design balances product demand, energy use, and safety. For synthetic ammonia, the anchor problem can be how thermodynamics, kinetics, and gas purification determine process conditions.

The assessment design is another key feature of the syllabus. The major assignment accounts for 70 percent of the grade and is described as a research review. This arrangement gives the course a research-oriented character similar to the published teaching reform article that inspired the present format. In that published model, a high-weight final research report is not treated as a simple terminal assignment; it is scaffolded through topic selection, database search, annotated bibliography, concept map, draft outline, peer review, oral presentation, and final submission. The same principle is highly suitable for Applied Inorganic Chemistry. Students can select topics from green ammonia, sulfur dioxide emission control, nitric acid tail-gas treatment, soda ash process comparison, chlor-alkali membrane technology, hydrothermal synthesis of inorganic materials, electrochemical inorganic synthesis, or thermodynamic design of metal extraction.

The course context also suggests an opportunity to connect teaching reform with the identity of the College of Chemistry and Environmental Engineering. Applied Inorganic Chemistry can become a course in which students learn how chemical knowledge supports environmental governance and sustainable industry. Synthetic ammonia connects to food security, carbon emissions, renewable hydrogen, and green ammonia. Sulfuric acid connects to fertilizer production, metallurgy, chemical manufacturing, sulfur resource utilization, and acid mist control. Nitric acid connects to explosives, fertilizers, oxidation chemistry, nitrogen oxide emissions, and safety. Soda ash and chlor-alkali connect to glass, detergents, water treatment, brine resources, electrochemical technology, chlorine risk, and membrane processes. Inorganic synthesis connects to zeolites, functional oxides, battery materials, catalysts, adsorbents, and environmental materials. This breadth means the course can cultivate both professional competence and social responsibility if the teaching design highlights their connection.

In summary, the syllabus already contains many elements of a high-quality applied chemistry course: representative industrial processes, thermodynamic tools, synthetic methods, frontier-oriented content, multimedia classroom teaching, and a research-review assessment. The reform should not replace these elements. It should strengthen alignment among them by clarifying outcomes, designing module-level tasks, embedding sustainability in disciplinary reasoning, and scaffolding the research review.

Table 1: Syllabus-Based Course Structure and Reform Focus

Module	Original focus in the schedule	Hours	Reform anchor problem	Expected learning product
Introduction	Scope and meaning of Applied Inorganic Chemistry	2	Why is applied inorganic chemistry more than descriptive inorganic chemistry?	Professional reflection and concept map
Synthetic ammonia	Raw gas preparation, purification, synthesis and development	4	How do thermodynamics, kinetics and purification jointly determine ammonia synthesis?	Process reasoning worksheet
Sulfuric acid	SO2 oxidation, SO3 absorption and contact-process flow	2	Why must oxidation, absorption and heat management be designed as a system?	Flow diagram analysis
Nitric acid	Production, tail-gas treatment, energy use, toxicity and safety	2	Why is tail-gas treatment a core part of nitric acid production?	Safety-environment case note
Soda ash	Production principle and process introduction	2	How should a process route be compared when resources and by-products matter?	Route comparison table
Caustic soda and chlorine	Production principle and process introduction	2	How does electrolysis connect product demand, energy and chlorine safety?	Electrochemical process analysis
Inorganic synthesis introduction	Significance, hot fields and frontiers	6	How does an inorganic chemist design a compound or material?	Research topic proposal
Thermodynamics and synthesis	Gibbs-Helmholtz equation, Ellingham diagram, equilibrium constant, potential-pH diagram	4	How can thermodynamic diagrams guide synthesis decisions?	Thermodynamic interpretation task
Synthesis methods I	Low-temperature, high-temperature and high-pressure synthesis	4	How should temperature and pressure be selected for target phases?	Method selection memo
Synthesis methods II	Hydrothermal/solvothermal, anhydrous/anaerobic and electrolytic synthesis	4	How do medium, atmosphere and redox control affect products?	Final research review link

Needs Analysis: Key Problems in Traditional Teaching

A reform model should begin with a realistic understanding of the problems that traditional teaching may create. The first problem is fragmentation of knowledge. When each chapter is taught as a self-contained description, students may memorize process steps without seeing the recurring logic across processes. For example, purification appears in ammonia synthesis, sulfuric acid gas treatment, nitric acid absorption, brine treatment, and inorganic synthesis atmosphere control. Heat management appears in sulfur dioxide oxidation, nitric acid production, high-temperature synthesis, and autoclave reactions. Redox control appears in nitric acid, chlor-alkali, metal extraction, electrolysis, and potential-pH diagrams. If these recurring ideas are not highlighted, students may fail to transfer knowledge from one chapter to another.

The second problem is overreliance on teacher explanation. Multimedia lectures are necessary because the course contains many technical processes, diagrams, and theoretical tools. However, continuous teacher explanation can make students passive. They may understand a process while the teacher explains it, but be unable to reconstruct the reasoning independently. For example, students may accept that a catalyst is used in ammonia synthesis but not be able to explain how catalyst activity, equilibrium conversion, and operating temperature interact. They may accept that hydrothermal synthesis uses water at high temperature and pressure but not be able to predict why mineralizers, pH, supersaturation, and autogenous pressure affect crystallization. Active learning is therefore not an optional decoration. It is necessary for transforming received information into usable understanding [24-27].

The third problem is the gap between industrial facts and chemical principles. Some students may treat industrial-process chapters as production technology and synthesis chapters as chemical theory, thereby missing the unity of the course. In reality, industrial processes are applied chemical principles under economic, environmental, and safety constraints. Similarly, inorganic synthesis is not merely a laboratory technique; it is a process of selecting conditions to control phase, oxidation state, composition, and morphology. Teaching should therefore repeatedly connect principles with decisions. A process condition should be explained not only by stating what it is, but by asking what problem it solves. A synthesis method should be introduced not only by listing procedures, but by asking what kind of product control it enables.

The fourth problem is superficial treatment of sustainability. In industrial chemistry education, safety and environmental issues are sometimes placed at the end of a chapter after the main process has already been taught. This arrangement unintentionally tells students that environmental governance is secondary. A better model is to treat sustainability as a constraint inside process reasoning. In ammonia synthesis, energy consumption and carbon emissions affect future development. In sulfuric acid production, sulfur dioxide conversion and absorption efficiency are environmental and economic issues at the same time. In nitric acid production, nitrogen oxide absorption and tail-gas treatment determine environmental responsibility and resource efficiency. In chlor-alkali production, membrane technology, mercury-free processes, brine quality, chlorine storage, and hydrogen utilization are chemical, technical, safety, and environmental issues simultaneously. This integrated view is consistent with green and sustainable chemistry education [17-20].

The fifth problem is insufficient scaffolding for the final research review. Many undergraduates can search the Internet, but searching is not the same as academic literature use. A reliable research review requires a focused question, traceable references, understanding of methods and evidence, comparison of viewpoints, and proper citation. If students are only told to submit a review at the end, they may rely on low-quality sources, translate paragraphs mechanically, or summarize papers one by one without forming an argument. Because the research review accounts for 70 percent of the course grade, it must be taught as a process. Students need instruction in topic narrowing, database selection, DOI tracing, annotated bibliography, evidence mapping, draft organization, peer feedback, and revision.

The sixth problem is the difficulty of evaluating higher-order learning. Traditional tests can measure whether students remember definitions and process steps, but they may not capture whether students can analyze, compare, evaluate, and design. A reformed assessment system should therefore include short tests for essential knowledge, case tasks for process reasoning, literature tasks for research literacy, and rubrics for the final review. The goal is not to make assessment more complicated, but to make it more aligned with the desired learning outcomes. Students should know in advance what counts as strong chemical reasoning, credible evidence use, environmental analysis, and scientific writing.

These problems are not unique to Applied Inorganic Chemistry. They are common in compact professional courses that sit between basic science and engineering practice. The response should not be to abandon lectures or overload the course with activities. Instead, the reform should retain the necessary structure of lectures while redesigning lectures as conceptual preparation for problem solving. The teacher explains essential ideas; students then use those ideas in focused tasks. This balanced model is feasible for a 32-hour course and is consistent with the published Catalysis Principles teaching reform paper that combines lectures, problem-based tasks, staged research reports, and transparent assessment.

Theoretical Framework

The reform proposed in this article is grounded in seven connected bodies of scholarship: outcome-based education, constructive alignment, active learning, problem-based learning, formative assessment, chemistry education research, and green chemistry education. These theories are not treated as separate slogans. They are used as design tools for solving concrete teaching problems in Applied Inorganic Chemistry.

Outcome-based education begins with the question of what students should be able to do after completing the course. In a professional chemistry course, outcomes should be expressed as performances rather than only as topics. A topic is synthetic ammonia; a performance is the ability to explain how raw-gas preparation, purification, catalyst selection, thermodynamic equilibrium, and process conditions jointly determine ammonia synthesis. A topic is hydrothermal synthesis; a performance is the ability to select hydrothermal or solvothermal conditions for a target inorganic material and justify the selection using solubility, nucleation, crystal growth, pressure, solvent, pH, and safety considerations. Expressing outcomes as performances helps the teacher design activities and rubrics that make learning visible [21-23].

Constructive alignment provides the next layer of logic. Biggs defines constructive alignment as the systematic connection among intended learning outcomes, teaching-learning activities, and assessment tasks [21]. If the course intends to cultivate process reasoning, students must perform process reasoning during class and in assessment. If the course intends to cultivate literature use, students must practice literature search and evidence evaluation before the final paper. If the course intends to cultivate safety and environmental responsibility, students must analyze safety and environmental constraints in chemical cases. Alignment therefore prevents the common mismatch in which teachers claim to value higher-order thinking but assess only memory. In Applied Inorganic Chemistry, alignment requires the 32 hours of content, the in-class tests, the research review, and the feedback system to point toward the same professional competencies.

Active learning explains how students can practice these competencies during class. Freeman and colleagues reported that active learning increases student performance in science, engineering, and mathematics courses [24]. Prince also reviewed evidence that active engagement improves learning in engineering education [25]. Active learning does not mean that lectures disappear. In a compact course with many technical processes, lectures remain necessary. However, lectures should be interwoven with tasks that require students to predict, interpret, compare, justify, and reflect. For example, after a short explanation of the contact process for sulfuric acid, students can interpret a simplified process-flow diagram and identify where temperature control, SO2 conversion, SO3 absorption, and tail-gas management interact. After learning Ellingham diagrams, students can determine which reducing agent is feasible under a given temperature range and explain the chemical reason.

Problem-based learning provides a broader design principle. Hmelo-Silver describes problem-based learning as a method in which students learn through complex problems and self-directed inquiry [26]. Applied Inorganic Chemistry is particularly suitable for problem-based design because industrial and synthetic decisions are rarely single-variable questions. A process route must satisfy thermodynamic, kinetic, economic, safety, and environmental constraints. A synthesis method must control product composition, structure, and morphology while managing practical risks. A problem-based module does not need to consume an entire week. Even a two-hour chapter can begin with one authentic anchor problem that organizes the lecture and subsequent activity. The anchor problem gives students a reason to learn the theory.

The ICAP framework proposed by Chi and Wylie helps calibrate the depth of classroom engagement [27]. Students may be passive when they only listen, active when they identify or mark information, constructive when they generate explanations, and interactive when they compare explanations with peers. A 32-hour course cannot turn every activity into a full project, but it can move students beyond passive listening. For example, students may actively label sections of a nitric acid process diagram, constructively explain why tail gas requires treatment, and interactively compare alternative control methods. The final reasoning. In ammonia synthesis, energy consumption and carbon emissions affect future development. In sulfuric acid production, sulfur dioxide conversion and absorption efficiency are environmental and economic issues at the same time. In nitric acid production, nitrogen oxide absorption and tail-gas treatment determine environmental responsibility and resource efficiency. In chlor-alkali production, membrane technology, mercury-free processes, brine quality, chlorine storage, and hydrogen utilization are chemical, technical, safety, and environmental issues simultaneously. This integrated view is consistent with green and sustainable chemistry education [17-20].

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Formative assessment is necessary when students are expected to perform complex tasks. Nicol and Macfarlane-Dick connect formative feedback with self-regulated learning, arguing that students need feedback that helps them monitor and improve their own work [28]. Sadler emphasizes that formative assessment should help students understand standards, compare their work with those standards, and close the gap [29]. These principles are directly relevant to the research review. If feedback is provided only after final submission, it cannot improve learning. Therefore, the final review must be divided into milestones: topic selection, research-question formulation, literature search, annotated bibliography, evidence mapping, outline, draft, peer review, and final revision. Each milestone should receive focused feedback.

Chemistry education research provides discipline-specific guidance. Johnstone's well-known account of chemical representation emphasizes the need to connect macroscopic, submicroscopic, and symbolic levels [30]. In Applied Inorganic Chemistry, this representational challenge is expanded to include industrial diagrams and thermodynamic plots. Students must connect macroscopic phenomena such as gas purification, absorption, crystallization, electrolysis, and precipitation with microscopic explanations such as adsorption, redox potential, nucleation, ion mobility, and phase stability, as well as symbolic representations such as equilibrium constants, reaction equations, Ellingham diagrams, and potential-pH diagrams. Multiple-representation research further shows that students need explicit support to translate among diagrams, equations, tables, and verbal explanations [31].

Discipline-based education research also suggests that professional science courses should be evaluated by how students use knowledge, not only by how much content is covered [32]. In this sense, Applied Inorganic Chemistry should help students develop a form of professional vision. They should learn to see a process-flow diagram as a chemical argument, a thermodynamic diagram as a decision tool, a synthesis route as a set of trade-offs, and a research paper as evidence rather than authority. Process-oriented guided inquiry and problem-based laboratory education show that students can develop reasoning and information literacy when tasks are carefully scaffolded [33-35]. Even though the present course has no separate laboratory hours, published figures, datasets, process diagrams, and literature excerpts can serve as objects for inquiry.

Green chemistry and sustainable chemistry education are essential for the value dimension of the course. Anastas and Warner's green chemistry principles emphasize prevention, atom economy, safer chemicals, energy efficiency, renewable feedstocks, and inherently safer design [17]. Eilks and Rauch argue that sustainability should be integrated into chemistry education rather than added as a peripheral issue [18]. Zuin and colleagues further emphasize the relationship among green chemistry, sustainable chemistry, and broader societal responsibility [19]. These ideas are not external to Applied Inorganic Chemistry. They are part of the subject itself. Industrial inorganic chemistry involves some of the most important examples of chemical risk, resource use, and emission control. Inorganic synthesis involves decisions about solvent, energy, atmosphere, pressure, and waste. A reformed course should therefore turn sustainability into a recurring analytical lens.

The integrated theoretical framework can be summarized as follows. Course outcomes define the observable performances students should demonstrate. Constructive alignment ensures that activities and assessment match those performances. Active and problem-based learning create opportunities for students to practice professional reasoning. Formative feedback scaffolds the high-weight research review. Chemistry education research guides representational and conceptual support. Green chemistry education ensures that environmental and safety values are embedded in disciplinary decision making. This framework guides the methodology, outcome reconstruction, module design, and assessment system described in the following sections.

Methodological Design of the Teaching Research

This paper adopts a design-based curriculum research orientation. Design-based research is appropriate when the purpose is to develop an educational intervention for a real teaching context and to generate design principles that can be evaluated and refined. The present study does not report classroom outcome data. Instead, it analyzes the syllabus, reconstructs learning outcomes, aligns teaching activities with assessment, and proposes instruments for future implementation. This distinction is important for research integrity. The article does not claim that the reform has already improved student achievement; it claims that the reform is coherent, literature-grounded, and ready for implementation and evaluation.

The first step of the methodological design is documentary analysis. The course teaching schedule is treated as the primary document. It provides the course name, instructor, teaching unit, target students, hour allocation, textbook, reference books, teaching content, teaching form, and assessment structure [1]. Each element is translated into a pedagogical constraint. The 32-hour length constrains the depth of activities. The lecture-based teaching form constrains the extent of classroom restructuring. The final research review creates an opportunity for research-literacy training. The industrial and synthesis modules create the need for conceptual integration.

The second step is outcome reconstruction. The broad statement that students should master the basic content of Applied Inorganic Chemistry and understand frontiers in inorganic synthesis is converted into six outcome clusters: conceptual and process explanation, thermodynamic and synthetic reasoning, industrial and environmental evaluation, synthesis-method selection, research literacy, and scientific communication with professional responsibility. These outcomes are written as observable performances, allowing them to guide both activities and assessment.

The third step is literature alignment. Educational theories and chemistry education studies are selected not as decorations but as solutions to syllabus-specific problems. Constructive alignment solves the problem of connecting objectives, teaching, and assessment. Active learning and problem-based learning solve the problem of passive content reception. Formative assessment solves the problem of a high-weight final report. Chemistry education research solves the problem of connecting process diagrams, microscopic reasoning, symbolic equations, and thermodynamic plots. Green chemistry education solves the problem of integrating safety and sustainability into chemical reasoning.

The fourth step is module-level design. Each syllabus module is redesigned through five components: an anchor problem, a concise conceptual lecture, a case or data task, a literature or frontier extension, and a formative product. The anchor problem gives students a reason to learn the theory. The lecture provides conceptual tools. The case task makes reasoning visible. The literature extension connects the chapter with research. The formative product gives the teacher evidence for feedback.

The fifth step is assessment design. The original grade structure is preserved in spirit but clarified in practice. In-class performance and tests account for the continuous learning component, while the final research review remains the major assignment. The review is divided into milestones so that students receive feedback before the final submission. A rubric is developed to assess research question, chemical reasoning, evidence quality, industrial and environmental relevance, and scientific writing.

A future empirical study can evaluate the reform through mixed methods. Quantitative data may include concept-test scores, case-task scores, rubric scores at different milestones, and final report performance. Qualitative data may include student reflections, peer-review comments, research-topic evolution, interviews, and teacher observation notes. The analysis can examine whether students move from descriptive summaries to mechanism-based and evidence-supported reasoning. Ethical considerations should be addressed before implementation: students should be informed if their coursework is used for research, participation in research analysis should not affect grades, and student work should be anonymized.

Reconstructed Course Outcomes

The reformed course is organized around six outcome clusters. These outcomes preserve the syllabus intention while making expected learning visible and assessable.

Outcome 1: Conceptual and Process Explanation

Students should be able to explain the basic concepts, production principles, reaction conditions, and process logic of major inorganic chemical products. They should understand synthetic ammonia, sulfuric acid, nitric acid, soda ash, caustic soda, and chlorine not as isolated chapters, but as examples of chemical principles applied in industrial systems. A student who achieves this outcome can explain why raw-gas purification is necessary before ammonia synthesis, why sulfur dioxide oxidation is followed by sulfur trioxide absorption, why nitric acid production is inseparable from tail-gas treatment, and why electrolysis conditions matter in chlor-alkali production.

Outcome 2: Thermodynamic and Synthetic Reasoning

Students should be able to use chemical thermodynamics to judge synthesis feasibility and process direction. This includes understanding the Gibbs-Helmholtz equation, Ellingham diagrams, coupled reactions, standard equilibrium constants, and potential-pH diagrams. The outcome is not satisfied by memorizing diagram names. Students should be able to interpret what a diagram implies for metal extraction, oxidation-reduction, precipitation, dissolution, phase stability, or electrochemical synthesis.

Outcome 3: Industrial, Environmental and Safety Evaluation

Students should be able to evaluate inorganic production processes from the perspectives of raw materials, energy use, product quality, waste treatment, toxicity, storage, safety, environmental regulation, and technological development. They should recognize that safety and environmental issues are not external additions to chemistry. They are part of professional chemical judgment. This outcome connects the course with the college's environmental engineering identity.

Outcome 4: Synthesis-Method Selection and Design

Students should be able to compare low-temperature, high-temperature, high-pressure, hydrothermal, solvothermal, anhydrous, anaerobic, and electrochemical synthesis methods. They should explain how temperature, pressure, solvent, pH, atmosphere, redox potential, precursor choice, and post-treatment affect product composition, phase, morphology, crystallinity, and potential application. This outcome connects inorganic synthesis chemistry with materials research and technological innovation.

Outcome 5: Research Literacy and Evidence Use

Students should be able to search, select, read, cite, and synthesize domestic and international literature. They should know how to distinguish textbooks, encyclopedias, review papers, research articles, patents, industrial reports, and non-academic web sources. They should be able to use DOI, ISBN, publisher information, journal details, and stable URLs to verify traceability. They should also be able to identify a focused question, compare evidence, and write a structured research review.

Outcome 6: Scientific Communication and Professional Responsibility

Students should be able to communicate chemical reasoning through diagrams, tables, process descriptions, short presentations, peer review, and academic writing. They should demonstrate scientific integrity by citing sources properly and avoiding plagiarism. They should demonstrate professional responsibility by considering safety, environmental impact, and sustainable development when discussing inorganic production and synthesis.

Outcome cluster	Representative activity	Assessment evidence	Feedback focus
Conceptual and process explanation	Analyze an industrial process diagram	Short quiz and process worksheet	Accuracy of principle-process connection
Thermodynamic and synthetic reasoning	Interpret Ellingham or potential-pH diagrams	Diagram explanation task	Reasoning chain and correct inference
Industrial, environmental and safety evaluation	Evaluate tail-gas treatment or chlorine safety case	Case-analysis memo	Completeness of safety and sustainability analysis
Synthesis-method selection	Compare hydrothermal, high-temperature and electrochemical routes	Method selection report	Justification of conditions and trade-offs
Research literacy and evidence use	Prepare annotated bibliography with DOI/ISBN	Research-review milestone	Traceability and relevance of sources
Scientific communication and responsibility	Peer review and final research review	Final report and revision note	Argument, writing quality and academic integrity

Overall Course Reform Model

The proposed reform model is named the Process-Synthesis-Sustainability-Research Integration model. The name reflects the four strands that run through the course. The process strand connects chemical principles with industrial inorganic production. The synthesis strand connects inorganic chemistry with materials preparation and frontier research. The sustainability strand integrates safety, environmental responsibility, and green chemistry. The research strand prepares students to read literature and write a research review. These strands are not separate blocks. Each module combines them in different proportions.

The process strand is most visible in the chapters on ammonia, sulfuric acid, nitric acid, soda ash, caustic soda, and chlorine. It uses a repeated logic: raw material, reaction principle, process flow, key operation, risk, environmental control, and technological development. Students learn that a process is not just a sequence of equipment. It is a chemical argument about how to transform feedstocks into products under constraints. In ammonia synthesis, the argument concerns equilibrium, kinetics, purification, catalyst operation, pressure, temperature, and energy. In sulfuric acid production, it concerns SO2 conversion, SO3 absorption, heat recovery, and emission control. In chlor-alkali production, it concerns electrochemical separation, membrane selectivity, brine purification, chlorine handling, and power consumption.

The synthesis strand becomes central in the second half of the course. It uses a design logic: target compound or material, chemical feasibility, precursor selection, reaction medium, temperature, pressure, atmosphere, redox control, phase control, morphology control, and characterization. This strand helps students see that synthesis methods are not recipes. They are strategies for controlling chemical transformation. Low-temperature methods may preserve metastable phases or allow soft chemical routes. High-temperature methods enable solid-state diffusion and ceramic formation but require energy and may limit morphology control. High-pressure synthesis can stabilize unusual phases. Hydrothermal and solvothermal methods use solvents and autogenous pressure to control crystallization. Anhydrous and anaerobic methods protect air-sensitive species. Electrochemical methods allow redox control and may support greener synthesis.

The sustainability strand cuts across both process and synthesis. In the industrial chapters, it appears as raw-material utilization, energy use, emission control, toxicity, corrosion, waste management, and safety. In the synthesis chapters, it appears as solvent choice, pressure hazards, atmosphere control, waste minimization, lower-temperature routes, electrochemical alternatives, and responsible reporting of risks. The teacher should not simply ask students to memorize the twelve principles of green chemistry. Instead, students should use those principles to analyze concrete cases. They should ask whether a process prevents pollution, uses energy efficiently, reduces hazardous substances, enables safer operation, or recovers by-products (17).

The research strand begins in the first week. Students are introduced to the final research review, the meaning of traceable references, and the difference between description and analysis. The teacher provides examples of weak and strong topics. A weak topic is 'sulfuric acid production.' A stronger topic is 'energy recovery and SO2 emission control in the contact process for sulfuric acid production.' A weak topic is 'hydrothermal synthesis.' A stronger topic is 'the influence of mineralizers and pH on phase and morphology control in hydrothermal synthesis of inorganic oxides.' By turning topics into questions, students begin to think like researchers rather than collectors of information.

The classroom cycle for each module consists of five steps: activate, explain, apply, extend, and reflect. Activate means beginning with a problem, image, data table, process diagram, or industrial scenario. Explain means providing the conceptual lecture needed to address the problem. Apply means asking students to perform a short task. Extend means connecting the module with literature or frontier development. Reflect means asking students to summarize what they learned and what evidence supports their conclusion. This cycle respects the lecture-based nature of the syllabus while creating structured opportunities for active learning.

The reform also changes the function of self-study. In a compact course, self-study is unavoidable, but it should be structured. Before class, students may answer guiding questions or read a short excerpt. During class, the teacher uses their preparation in discussion. After class, students complete a small product that contributes to the research review or reinforces the module. For example, before the thermodynamics module, students can review Gibbs free energy and equilibrium constants. During class, they interpret an Ellingham diagram. After class, they connect the diagram with a selected synthesis or extraction problem. This structure makes self-study purposeful.

The model is designed to be feasible. It does not require new laboratory hours, expensive software, or a complete replacement of lectures. The teacher can begin with a small set of cases and gradually expand the case library. In the first implementation cycle, the teacher might introduce anchor problems for only five modules and scaffold the research review with three milestones. In later cycles, the full model can be implemented. This incremental approach is important because sustainable teaching reform must also be sustainable for the instructor.

Module-by-Module Teaching Design

Introduction: From Descriptive Inorganic Chemistry to Applied Inorganic Reasoning

The introduction should establish the identity and logic of the course. Many students enter Applied Inorganic Chemistry after studying general inorganic chemistry. They may expect another survey of elements and compounds. The teacher should therefore begin by asking: What changes when inorganic chemistry becomes applied? This question helps students recognize that the course is about using inorganic principles to solve real production and synthesis problems. The teacher can present a simple comparison: a descriptive statement says that ammonia is produced from nitrogen and hydrogen; an applied statement explains why the process uses purified gases, catalysts, high pressure, heat management, and recycling. A descriptive statement says that hydrothermal synthesis uses hot water under pressure; an applied statement explains how solvent, solubility, pH, nucleation, growth, and autoclave safety control the product.

The lecture can introduce the four recurring lenses of the course: process, synthesis, sustainability, and research. Students are shown the full course map and asked to identify how earlier chapters on industrial products connect with later chapters on synthesis methods. The teacher can also introduce the research review assignment at this stage. Rather than presenting it as a final burden, the teacher frames it as a semester-long inquiry. Students receive a topic bank and a short guide to literature traceability, including DOI, ISBN, publisher, journal volume, issue, page, and stable database information.

A suitable activity is a professional identity reflection. Students select one inorganic product or synthesis method and write a short paragraph explaining why an applied chemist must understand both chemical principles and social responsibility. The reflection is not graded for complex content at this stage; it is used to diagnose students' initial understanding. The teacher can collect common misconceptions, such as treating environmental treatment as an afterthought or equating applied chemistry with simple industrial operation. These misconceptions become reference points for later modules.

Synthetic Ammonia: Thermodynamics, Kinetics and Purification as an Integrated System

Synthetic ammonia is an ideal early module because it contains nearly all core elements of applied inorganic reasoning. The anchor problem is: Why does ammonia synthesis require high pressure, a suitable temperature, a catalyst, and strict gas purification? Students can first predict what conditions would favor ammonia formation based on the reaction stoichiometry and exothermic nature. They then confront the practical conflict between thermodynamic equilibrium and kinetic rate. Lower temperature may favor equilibrium conversion, but the reaction rate becomes too slow. Higher temperature accelerates kinetics but lowers equilibrium conversion. High pressure favors ammonia formation but increases equipment and energy demands. A catalyst provides a feasible pathway but requires protection from poisons.

The teacher can organize the module through three linked diagrams: a reaction-equilibrium diagram, a simplified process-flow diagram, and a catalyst-operation diagram. The process-flow diagram should include raw-gas preparation, purification, compression, synthesis, cooling, separation, and recycling. Students are asked to identify which steps are chemical reactions, which are separation or purification operations, and which are necessary for catalyst protection. This helps them see that the process is a system rather than a single reactor.

The sustainability extension can introduce green ammonia and renewable hydrogen. Students should not be expected to master the entire field, but they can understand why ammonia synthesis is connected with carbon emissions and energy systems. The research-review link may invite students to compare conventional fossil-based hydrogen production with electrolysis-based hydrogen for ammonia synthesis. The learning product for this module is a process reasoning worksheet in which students explain each major operating condition and identify one environmental or technological development direction.

Sulfuric Acid: Contact Process as Process Integration

The sulfuric acid module has only 2 hours, so it should not attempt to cover every industrial detail. The anchor problem is: Why must sulfur dioxide oxidation, sulfur trioxide absorption, heat recovery, and tail-gas control be designed as a system? Students first recall that sulfuric acid is a high-volume industrial chemical. The teacher then explains that sulfur dioxide catalytic oxidation is reversible and exothermic, and that the absorption of sulfur trioxide is not simply dissolution in water. Process efficiency depends on coordinating conversion, temperature, gas composition, absorption medium, corrosion control, and emission requirements.

A concise lecture can introduce the contact process and the role of vanadium-based catalysts without overloading students with equipment details. Students examine a simplified process-flow chart and mark where gas cleaning, conversion, heat exchange, absorption, and emission control occur. The activity asks them to explain what would happen if one part of the system performed poorly. If oxidation conversion is low, SO2 emissions increase and product yield decreases. If absorption is ineffective, acid mist and SO3 release become problems. If heat is not managed, catalyst performance and equipment safety may be affected. This systems analysis helps students understand why chemical industry relies on integration.

The sustainability extension can focus on sulfur oxide control and heat recovery. Students compare a purely product-centered view of sulfuric acid with a process-centered view that includes energy and emissions. The research-review link may include topics such as tail-gas control in sulfuric acid plants, sulfuric acid production from metallurgical off-gases, or energy efficiency in the contact process. The learning product is a flow-diagram annotation with a short explanatory note.

Nitric Acid: Tail-Gas Treatment, Energy Utilization and Safety

Nitric acid production provides an excellent case for integrating reaction chemistry, environmental governance, and safety. The anchor problem is: Why is tail-gas treatment a core part of nitric acid production rather than an optional environmental add-on? Students begin with the oxidation of ammonia to nitrogen oxides and the absorption of nitrogen oxides to form nitric acid. The teacher emphasizes that nitrogen oxides are both reactants in the process and pollutants if released. This dual identity helps students see why absorption efficiency, gas circulation, oxidation state, and tail-gas control are central chemical concerns.

The teaching task can use a simplified nitrogen flow. Students trace nitrogen from ammonia to nitric oxide, nitrogen dioxide, nitric acid, and tail gas. They identify where oxidation, absorption, and emission control occur. They then answer a scenario question: if the absorption tower efficiency decreases, what chemical, environmental, and safety consequences might follow? This question requires students to connect chemistry with environmental responsibility. The teacher can also discuss energy recovery because ammonia oxidation is strongly exothermic. Heat management is therefore not only a safety issue but also an energy-efficiency opportunity.

The module should include toxicity, storage, and transportation because the syllabus explicitly lists these topics. Instead of treating them as a list of warnings, the teacher can connect them to chemical properties: strong oxidizing ability, corrosiveness, volatility, decomposition, and incompatibility with reducing substances or organic materials. The research-review link may include NOx control technologies, nitric acid plant energy recovery, or safety management in oxidizing acid production. The learning product is a safety-environment case note.

Soda Ash: Route Comparison and Resource Thinking

Soda ash production is useful for cultivating route-comparison thinking. The anchor problem is: How should a process route be evaluated when raw materials, by-products, environmental impact, regional resources, and product demand all matter? Students often learn a process as if it were the only possible route. A reform-oriented design instead asks them to compare. The teacher can introduce the basic production principle and process features, then ask students to identify criteria for evaluation. These criteria may include raw-material availability, energy consumption, salt and limestone use, ammonia circulation, by-products, waste liquid, equipment complexity, and regional suitability.

The classroom activity is a route comparison table. Students are not required to calculate complete industrial economics. Instead, they organize qualitative criteria and justify why different regions or periods may favor different process choices. This activity helps students understand that applied chemistry involves decision making under constraints. It also prepares them for later synthesis-method comparison because the same logic applies: no method is universally best; a method is suitable for a specific goal under specific constraints.

The sustainability extension can focus on waste and by-product management. Soda ash production illustrates that a process can be chemically effective yet environmentally challenging if by-products and effluents are not handled responsibly. The research-review link may include cleaner soda ash production, by-product utilization, or historical evolution of inorganic chemical processes. The learning product is a route comparison table with a short conclusion.

Caustic Soda and Chlorine: Electrolysis, Product Coupling and Risk Management

The chlor-alkali module should be organized around electrochemical reasoning and product coupling. The anchor problem is: How does electrolysis connect product demand, energy consumption, membrane selectivity, hydrogen utilization, and chlorine safety? Students first learn that caustic soda and chlorine are produced together. This co-production is important because market demand for one product affects the economics of the other. The teacher then introduces the electrochemical principles of brine electrolysis, ion migration, electrode reactions, and separation requirements.

The activity can ask students to analyze why brine purification and membrane performance are essential. If divalent ions or impurities enter the system, membrane performance and product purity may suffer. If chlorine and hydrogen are not properly separated and managed, safety risks increase. If electricity consumption is high, process sustainability is affected. Students can construct a cause-effect map connecting electrochemical principle, process operation, product quality, safety, and environmental performance.

The sustainability extension can introduce the historical transition away from mercury processes and the importance of membrane technology. Students do not need to memorize every industrial variant, but they should understand why process technology evolves when safety, environmental regulation, and energy efficiency change. The research-review link may include membrane chlor-alkali technology, brine purification, chlorine storage safety, or hydrogen by-product utilization. The learning product is an electrochemical process analysis memo.

Introduction to Inorganic Synthesis Chemistry: From Product Production to Material Design

The introduction to inorganic synthesis chemistry is a turning point in the course. The anchor problem is: How does an inorganic chemist design a compound or material rather than merely produce a known product? This question helps students move from industrial-process descriptions to synthesis thinking. The teacher can explain that inorganic synthesis aims to control composition, crystal structure, oxidation state, coordination environment, defects, particle size, morphology, surface area, and functionality. These goals cannot be achieved by following recipes blindly; they require understanding of thermodynamics, kinetics, reaction medium, and characterization.

Because this module receives 6 hours in the schedule, it can serve as the main bridge to the final research review. The teacher can introduce hot fields such as porous materials, functional oxides, catalysts, battery materials, photocatalysts, adsorbents, magnetic materials, and environmental materials. However, frontier content should be concept-driven. Students should not simply hear a list of fashionable materials. They should learn how research questions are formed: What property is needed? What structure may provide it? What synthesis method can produce that structure? What evidence shows success? What limitations remain?

A useful classroom activity is a target-product design discussion. Students are given a target, such as a porous adsorbent for water treatment, a functional oxide with controlled morphology, or a catalyst support with high surface area. They identify what structural features are needed and what synthesis strategy might be appropriate. The research-review link is direct: students choose or refine their final review topics during this module. The learning product is a research topic proposal that includes a tentative title, research question, keywords, and three traceable references.

Thermodynamics and Inorganic Synthesis: Diagrams as Decision Tools

The thermodynamics module should be taught as a set of decision tools rather than as abstract formulas. The anchor problem is: How can thermodynamic diagrams guide the extraction, reduction, oxidation, precipitation, or stability control of inorganic compounds? Students have already studied physical chemistry, but they may not automatically transfer thermodynamics to synthesis design. The teacher should explicitly connect Gibbs free energy, equilibrium constants, temperature dependence, and redox potential with real synthesis decisions.

Ellingham diagrams are particularly useful because they show how oxide stability changes with temperature and how reduction feasibility can be evaluated. Students can practice reading the relative positions of lines and explaining why a reducing agent becomes effective in certain temperature ranges. Coupled reactions can be introduced as a strategy for making an unfavorable reaction proceed by linking it with a favorable one. Potential-pH diagrams can be used to discuss aqueous stability, corrosion, precipitation, dissolution, and electrochemical synthesis. The goal is for students to reason from diagrams to decisions.

The classroom activity can present a simplified thermodynamic diagram and ask students to identify feasible conditions for a target transformation. Students must write a reasoning chain rather than only state an answer. For example: the diagram indicates that the target oxide becomes less stable relative to the reducing agent above a given temperature; therefore, reduction is thermodynamically feasible, but kinetic and practical constraints must still be considered. The learning product is a thermodynamic interpretation task, and the research-review link may include thermodynamic design of metal extraction, redox synthesis, or stability control of inorganic materials.

Low-Temperature, High-Temperature and High-Pressure Synthesis: Conditions and Phase Control

The first synthesis-method module should help students compare how temperature and pressure control inorganic reactions. The anchor problem is: How should temperature and pressure be selected when the target phase, particle size, crystallinity, and stability are all important? Low-temperature synthesis can be introduced as a route for metastable compounds, soft chemical transformations, ion exchange, precipitation, sol-gel processes, or materials with controlled morphology. High-temperature synthesis can be introduced as a route for solid-state reactions, ceramics, oxides, and highly crystalline phases. High-pressure synthesis can be introduced as a route for stabilizing unusual phases or dense structures.

The key teaching point is that each method has trade-offs. Low-temperature methods may offer better compositional and morphological control but may produce poorly crystalline or hydrated products. High-temperature methods may produce stable crystalline phases but require more energy and may cause grain growth or volatilization. High-pressure methods can access unusual structures but require specialized equipment and strict safety management. Students should learn to select methods based on goals, not preferences.

The activity can use a method-selection memo. Students are given three target cases: a metastable oxide, a ceramic material requiring high crystallinity, and a dense phase that is not stable under ordinary pressure. They choose possible synthesis routes and justify them. The sustainability extension asks students to consider energy use, equipment risk, and waste. The research-review link may include soft chemistry, solid-state synthesis, high-pressure materials, or low-temperature routes to functional inorganic compounds.

Hydrothermal, Solvothermal, Anhydrous, Anaerobic and Electrolytic Synthesis: Medium, Atmosphere and Redox Control
The final synthesis-method module focuses on medium, atmosphere, and redox control. The anchor problem is: How do solvent, pressure, atmosphere, and electrode potential affect the product of inorganic synthesis? Hydrothermal and solvothermal synthesis are especially suitable for showing how solvent properties, temperature, autogenous pressure, mineralizer, pH, supersaturation, nucleation, and crystal growth influence product phase and morphology [14-16]. Students can compare hydrothermal synthesis with high-temperature solid-state synthesis and identify why solution-mediated growth can produce crystals or morphologies that are difficult to obtain by dry methods.

Anhydrous and anaerobic synthesis can be taught through the problem of air-sensitive compounds. Students should understand that water and oxygen are not just impurities in a general sense; they can change oxidation state, hydrolyze precursors, alter coordination environments, or destroy target compounds. Electrolytic synthesis can be taught as a method that controls redox processes through electrode potential, current, electrolyte, electrode material, and cell design. This module therefore reinforces the connection between chemical principle and experimental condition.

The activity can ask students to choose between hydrothermal, anhydrous, and electrolytic methods for three targets: a crystalline oxide with controlled morphology, an air-sensitive inorganic compound, and a product requiring controlled oxidation state. Students justify their choices and identify safety precautions. The final research-review link is explicit: students are asked to connect their chosen review topic with at least one synthesis or process principle from the course. The learning product is a final evidence map supporting the research review.

Research Review Design and Scaffolding

The final research review is the most important assessment in the syllabus because it accounts for 70 percent of the grade. This high weight can be justified only if the review measures advanced learning outcomes: research literacy, evidence use, chemical reasoning, industrial or synthesis relevance, scientific writing, and professional judgment. Therefore, the report cannot be treated as a one-time final assignment. It must be scaffolded as a semester-long research process.

The first stage is topic orientation. During the first two weeks, the instructor introduces broad topic areas that match the syllabus. These may include green ammonia, ammonia synthesis catalysts, sulfuric acid energy recovery, SO2 emission control, nitric acid tail-gas treatment, soda ash production and waste management, membrane chlor-alkali technology, chlorine safety, hydrothermal synthesis of inorganic materials, high-pressure synthesis, electrochemical synthesis, thermodynamic diagrams in metal extraction, or potential-pH diagrams in aqueous synthesis. Students are encouraged to choose topics that are specific enough to analyze but broad enough to support literature synthesis.

The second stage is research-question formulation. Students are asked to transform a topic into one main question and two or three subquestions. A descriptive topic such as 'hydrothermal synthesis' is not enough. A stronger question is: How do mineralizer concentration and pH affect phase and morphology control in hydrothermal synthesis of inorganic oxides? A descriptive topic such as 'chlor-alkali production' can become: How does membrane technology improve safety, energy efficiency, and product purity in modern chlor-alkali production? The teacher can provide a template: object, variable, mechanism, evidence, and significance. This template helps students move from topic names to researchable arguments.

The third stage is literature search and source validation. Students submit a preliminary reference list with traceability markers. A high-quality source should include DOI, ISBN, publisher information, journal name, volume, issue, pages, or a stable organizational URL. Students should learn that not all sources are equal. Textbooks provide established background. Encyclopedias provide industrial summaries. Review articles provide field synthesis. Research articles provide specific evidence. Patents provide technical claims but require careful interpretation. Non-academic websites may be useful for orientation but should not be the main evidence base. The teacher can ask students to mark each source type and explain why it is credible.

The fourth stage is annotated bibliography. Students summarize selected sources in their own words and identify how each source contributes to the research question. An annotation should include the source's purpose, method or scope, main finding, relevance to the student's topic, and limitation. This task prevents students from collecting references without understanding them. It also helps the teacher identify weak or irrelevant sources early.

The fifth stage is concept and evidence mapping. Students create a map that connects course concepts, literature evidence, and report sections. For example, a student writing about green ammonia may connect thermodynamics, catalyst operation, hydrogen source, energy demand, carbon emissions, and technology development. A student writing about hydrothermal synthesis may connect solubility, supersaturation, nucleation, crystal growth, morphology, solvent, pH, temperature, and product function. The evidence map helps students see whether their report has an argument or merely a list of summaries.

The sixth stage is draft writing and peer review. Students submit an outline or partial draft and receive feedback from peers and the teacher. Peer review should be structured by questions: Is the research question clear? Are the sources traceable? Does each section support the argument? Are chemical principles explained accurately? Is sustainability or safety considered where relevant? Are citations used properly? Peer review also helps students learn by reading other students' work.

The seventh stage is final submission with revision note. The final report should include title, abstract, keywords, introduction, main body, discussion, conclusion, and references. The revision note explains how the student improved the paper after feedback. This note encourages metacognition and discourages last-minute writing. It also gives the teacher evidence of learning process, not only final product.

The instructor should provide model sentences and examples for scientific writing. Many students can understand literature but struggle to write in academic English. Useful sentence frames include: 'The observed change can be attributed to...', 'Compared with process A, process B shows...', 'This evidence suggests that...', 'However, this conclusion is limited by...', and 'From the perspective of green chemistry, the main advantage is...'. Such support does not reduce academic rigor. It helps students express chemical reasoning more clearly.

Academic integrity must be addressed explicitly. Students should learn the difference between quotation, paraphrase, summary, translation, and synthesis. They should understand that changing a few words from a source is not acceptable if the structure and idea are copied without citation. If generative tools are permitted by institutional policy, students should be told that such tools cannot replace source verification, chemical reasoning, or original organization. A report with fluent language but untraceable references, unsupported claims, or inaccurate chemistry should not receive a high score.

Table 3: Research Review Milestones

Stage	Timing	Student task	Teacher feedback focus	Evidence retained
1 Topic orientation	Weeks 1-2	Select broad area and keywords	Scope and relevance	Topic statement
2 Research question	Weeks 3-4	Formulate main question and subquestions	Analytical depth	Research-question sheet
3 Source validation	Weeks 4-6	Submit traceable preliminary references	Source quality and DOI/ ISBN details	Reference list
4 Annotated bibliography	Weeks 6-8	Summarize and evaluate key sources	Understanding and relevance	Annotations
5 Evidence mapping	Weeks 9-11	Connect concepts, evidence and report sections	Logic and coherence	Concept map
6 Draft and peer review	Weeks 12-15	Submit draft and review peers	Argument, evidence and writing	Draft and review form
7 Final submission	Week 18	Submit final report and revision note	Overall achievement	Final report

Assessment Rubric and Feedback System

A transparent assessment system is necessary for fairness and alignment. The original syllabus includes ordinary classroom performance, in-class tests, and a major research review. The reformed design preserves this structure while clarifying what each component measures. The 30 percent in-class component can include attendance, questioning, short concept checks, module case tasks, diagram interpretation, and participation in peer discussion. The 70 percent research review can include process milestones and final paper quality.

The in-class component should not be reduced to attendance. Attendance matters, but attendance alone does not show learning. Short concept checks can assess whether students understand essential principles. Case tasks can assess whether they can apply those principles. For example, a short ammonia quiz may ask students to explain the effect of pressure and temperature. A sulfuric acid task may ask students to identify why absorption must be controlled. A thermodynamics task may ask students to interpret an Ellingham diagram. These tasks provide immediate feedback and help students prepare for the research review.

The research review rubric should evaluate five dimensions. The first dimension is research question and organization. A strong paper states a focused question, explains its significance, and organizes sections around an argument. The second dimension is chemical principle and mechanism reasoning. A strong paper accurately uses concepts from Applied Inorganic Chemistry and explains why processes or synthesis methods work. The third dimension is evidence quality and literature use. A strong paper uses traceable sources, compares evidence, and cites correctly. The fourth dimension is industrial, environmental, safety, or innovation relevance. A strong paper connects the topic with real production, synthesis design, sustainability, or frontier development. The fifth dimension is scientific writing and academic integrity. A strong paper is coherent, precise, properly formatted, and original in organization.

Feedback should be staged. After topic orientation, feedback focuses on scope. After research-question formulation, feedback focuses on whether the question requires explanation rather than description. After source validation, feedback focuses on reference traceability. After annotated bibliography, feedback focuses on understanding and relevance. After evidence mapping, feedback focuses on logic. After draft submission, feedback focuses on argument, evidence, and writing. Final feedback summarizes strengths and future directions. This staged feedback turns assessment into a learning process.

Rubrics also support students with different backgrounds. Some students may have strong chemical knowledge but weak English writing. Others may write fluently but use weak sources or superficial chemistry. A rubric clarifies that language quality alone is not enough; chemical reasoning and evidence matter. It also clarifies that correct facts alone are not enough; the student must organize them into a research argument. This transparency reduces anxiety and makes expectations more equitable [30-50].

Table 4: Suggested Final Research Review Rubric

Dimension	Weight	High-quality performance	Common weakness to correct
Research question and organization	15%	Focused question, clear significance, logical structure	Topic too broad or purely descriptive
Chemical principle and mechanism reasoning	25%	Accurate use of process, thermodynamic, redox or synthesis concepts	Process described without explaining why
Evidence and literature quality	25%	Traceable sources, comparison of evidence, correct citation	Unstable web sources or unverified references
Industrial, safety, environmental or innovation relevance	15%	Connects chemistry with production, sustainability, risk or frontier development	Values added as slogans without chemical analysis
Scientific writing and academic integrity	20%	Coherent academic English, original synthesis, correct format	Translation-like writing or patchwork copying

Teaching Resources and Implementation Plan

The reform can be implemented without changing the official 32-hour schedule. The key is to prepare reusable teaching resources. Three resource packages are recommended. The first is a concept package, including concise slides, reaction equations, thermodynamic diagrams, process-flow diagrams, safety notes, and key questions. The second is a case package, including simplified industrial scenarios for ammonia, sulfuric acid, nitric acid, soda ash, chlor-alkali, and inorganic synthesis. The third is a literature package, including traceable textbook chapters, encyclopedia entries, review papers, and selected research articles with DOI or ISBN information.

The teacher should begin the semester by explaining the course map and assessment pipeline. Students need to know from the beginning that the final review is built step by step. In the first two weeks, the teacher introduces broad research areas and source-traceability requirements. In the middle weeks, the industrial modules provide cases and concepts that students can use in their topics. In the later weeks, synthesis and thermodynamics modules provide tools for deeper analysis. Near the end, students conduct peer review and revise their final papers.

Digital platforms can support the reform. The teacher can upload guiding questions before class, collect short worksheets after class, provide model annotations, and use online discussion boards for topic refinement. However, technology should serve pedagogy. A digital platform is useful only if it helps students prepare, submit, receive feedback, or revise. It should not become a repository of unused files. The teacher can use simple templates for research questions, annotated bibliography, evidence maps, and peer review to reduce student confusion.

The reform should be implemented gradually. In the first cycle, the teacher may select five modules for full anchor-problem design: synthetic ammonia, nitric acid, chlor-alkali, thermodynamics, and hydrothermal synthesis. The research review may include three mandatory milestones: topic statement, annotated bibliography, and draft. In the second cycle, the teacher can expand to all modules and add peer review. In the third cycle, the teacher can build a database of student difficulties and refine cases. This iterative model is realistic because teaching reform requires teacher time, student adaptation, and institutional support.

Quality assurance should include both teaching-process evidence and learning-outcome evidence. Teaching-process evidence includes whether tasks were completed, whether students used the feedback, and whether the schedule remained feasible. Learning-outcome evidence includes improvement in concept checks, quality of case analysis, traceability of references, and depth of final reports. The teacher can also collect anonymous student feedback on which activities helped them understand the course and which tasks were too difficult or too time-consuming.

The teacher should also maintain a reference-validation routine. Because the final review emphasizes traceable sources, students should be encouraged to verify DOI numbers, ISBNs, publishers, and journal details. The teacher can provide a list of reliable databases and explain how to check whether a paper is peer-reviewed. This is especially important in an era when students can easily find information but may not know how to judge source quality. Reference validation is not a mechanical requirement; it is part of scientific integrity.

Quality Assurance and Future Empirical Evaluation

A design-based teaching reform should be evaluated after implementation. The proposed evaluation plan uses multiple sources of evidence because no single measure can capture the complexity of learning in Applied Inorganic Chemistry. Concept tests can measure whether students understand key principles. Case tasks can measure whether they can apply principles to industrial or synthesis situations. Research-review milestones can measure development in literature use and argument construction. Student reflections can reveal changes in confidence and professional identity. Interviews can provide deeper insight into difficulties and learning strategies.

A pre-course diagnostic can include questions on equilibrium, redox potential, process diagrams, and synthesis methods. The purpose is not to grade students but to identify prior knowledge and misconceptions. A post-course assessment can use similar but not identical tasks to evaluate growth. For example, students may be asked before and after the course to explain the relationship between thermodynamics and kinetics in ammonia synthesis, or to select a synthesis method for a target inorganic material and justify the choice.

Case-task analysis can focus on reasoning quality. A weak answer may list facts without connecting them. A moderate answer may identify several factors but not prioritize them. A strong answer explains relationships among chemical principle, process operation, safety, and environmental consequences. Rubrics can be used to code these differences. Over time, the teacher can identify which modules produce strong learning and which require redesign.

Research-review analysis can examine how student writing develops across milestones. The teacher can compare the topic statement, annotated bibliography, evidence map, draft, and final paper. Improvement may appear in narrower questions, better source quality, more accurate chemistry, clearer argument, and stronger citation practice. Peer-review records can also show whether students learn to evaluate evidence and writing.

Student feedback should ask about both effectiveness and workload. A reform may be educationally strong but too demanding if not calibrated. Students can be asked which tasks helped them understand industrial processes, which tasks helped them write the research review, and which instructions were unclear. The teacher should use this feedback for revision. Design-based research is iterative; each cycle should produce evidence for improving the next.

If the reform is later reported as an empirical study, ethical requirements should be followed. Students should be informed that course assessment and research analysis are different. Participation in research analysis should be voluntary where required, and refusal should not affect grades. Student work should be anonymized. Examples of student writing should be used only with permission. These practices protect students and strengthen research credibility.

Discussion

The proposed reform has several strengths. First, it respects the existing syllabus. It does not require removing major chapters or changing the official hour allocation. This is important because university courses often operate within fixed teaching plans. Reform is more likely to be adopted if it improves the use of existing content rather than demanding an entirely new structure. The present model keeps the ten chapters but links them through recurring strands.

Second, the reform strengthens coherence. The original syllabus contains both industrial inorganic chemistry and inorganic synthesis chemistry. Without explicit connection, these parts may seem separate. The reform connects them through shared concepts: thermodynamics, redox control, process constraints, material design, safety, and sustainability. Students can see that industrial production and laboratory synthesis are both forms of controlled chemical transformation. This coherence can reduce cognitive overload because students learn a few powerful ways of thinking rather than many disconnected facts.

Third, the reform makes the research review educationally meaningful. A final paper worth 70 percent of the grade is appropriate only if it measures advanced learning and if students are prepared to succeed. The staged pipeline turns the review into a process of inquiry. It teaches students how to move from a broad interest to a focused question, from scattered sources to evidence, and from notes to argument. These abilities are valuable beyond the course because they support graduation projects, postgraduate study, and professional development.

Fourth, the reform embeds environmental and safety values in disciplinary reasoning. This is especially important for a college of chemistry and environmental engineering. Students should not see safety and sustainability as moral slogans separated from chemistry. They should learn that a process condition, separation step, purification requirement, or synthesis method often has safety and environmental implications. This professional habit is essential for responsible chemical practice.

Fifth, the reform is compatible with students' development level. The course is not redesigned as a fully open-ended project course, which might be unrealistic within 32 lecture hours. Instead, it combines concise lectures with focused tasks. Students receive enough structure to learn difficult content and enough activity to practice reasoning. The research review adds a longer inquiry experience without consuming all class time.

There are also challenges. The teacher must prepare cases, templates, rubrics, and literature packets. This workload can be significant in the first implementation cycle. Students may also differ in English reading ability, literature-search experience, and writing confidence. Therefore, the teacher should provide examples, sentence frames, and staged feedback. Another challenge is balancing depth and breadth. If too many tasks are added, the course may feel overloaded. The teacher must choose tasks that directly support learning outcomes and remove activities that do not add value.

A further challenge is reference traceability. Students may use sources that are easy to find but not reliable. The teacher should emphasize DOI, ISBN, publisher, journal information, and stable institutional sources. Students should also learn that a reference is not strong merely because it has a DOI; they must judge relevance, evidence, and quality. This ability is part of research literacy. It is especially important in a course where the final report depends heavily on literature.

Overall, the reform represents a shift from coverage to usable understanding. Coverage asks whether the teacher has presented all chapters. Usable understanding asks whether students can use those chapters to analyze processes, evaluate choices, and build evidence-supported arguments. This shift is consistent with modern higher education and with the professional nature of Applied Chemistry.

Conclusion

Applied Inorganic Chemistry is a compact but professionally important course. The Yangtze University teaching schedule already contains a strong foundation: representative industrial inorganic processes, inorganic synthesis theory, thermodynamic tools, synthesis methods, multimedia classroom teaching, and a research-review-based assessment structure. The challenge is to align these elements so that students do not merely memorize process descriptions, but learn to reason, evaluate, investigate, and communicate like beginning applied chemists.

This paper proposes an outcome-based, constructively aligned, research-oriented, and sustainability-integrated reform model for the course. The model connects industrial production with inorganic synthesis, embeds safety and environmental responsibility into chemical reasoning, scaffolds the final research review through staged tasks, and provides an assessment system compatible with the original syllabus. The module-by-module design shows how each chapter can be taught through anchor problems, conceptual lectures, case tasks, literature extensions, and formative products.

The central message is that Applied Inorganic Chemistry should be taught as a course of integrated professional reasoning. Students should learn how inorganic principles become industrial processes, how synthesis methods create functional materials, how thermodynamics and process constraints guide decisions, and how scientific literature supports responsible innovation. Future teaching cycles should implement the model, collect empirical evidence, and refine the design based on student learning data.

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