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Embedding Inquiry-Based Learning in Engineering Chemistry: A Case Study with Mechanical Undergraduates

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Abstract—**This study explores the integration of Inquiry-Based Learning (IBL) into the Engineering Chemistry curriculum for first-year Mechanical Engineering students, with a focus on the Electrochemistry module. Conducted over 16 weeks with 114 students divided into two sections, the research employed a mixed-method design incorporating pre-/post-tests, surveys, reflection journals, and project presentations. The results indicate significant conceptual gains (22.4% in Section A and 27.1% in Section B) and heightened student engagement, particularly in the section supported by digital learning tools. Students demonstrated improved higher-order thinking, interdisciplinary reasoning, and contextual application of chemistry in mechanical contexts such as corrosion protection and material selection. The effective use of chemistry vocabulary and real-world analogies suggested deeper conceptual understanding and increased scientific literacy. The study highlights the feasibility of embedding IBL within existing syllabi without structural overhauls, aligning with the National Education Policy (NEP) 2020's vision of experiential and flexible learning. Recommendations include expanding IBL to other topics and initiating faculty development programs. The findings support IBL as a scalable, impactful pedagogical model to nurture research-oriented, interdisciplinary thinkers in engineering education.**

Keywords—**Inquiry-Based Learning (IBL), Engineering Chemistry, Interdisciplinary Education, Student Engagement, National Education Policy.**

ICTIEE Track—Innovative Pedagogies and Active Learning
ICTIEE Sub-Track: Inquiry-Based Learning in Fostering Curiosity and Critical Thinking among GenZ

I. INTRODUCTION

IN practice, engineering education begins with foundational years of undergraduate study where students develop their scientific reasoning and ability to solve problems in interdisciplinary contexts, all of which reflect core engineering attributes.(Subramaniam et al., 2025)(Horn et al., 2022)(Kolmos et al., 2024) Engineering Chemistry is an important background for many technical aspects of different core engineering disciplines representing important enabling knowledge related to Engineering Chemistry, including in the fields of material selection, energy systems, corrosion science and polymers. For example, applying sound chemistry principles in Mechanical Engineering is important for material selection, thermal systems and digital manufacturing processes.(Gao et al., 2022) While students are not explicitly blind to its importance, Engineering Chemistry is often experienced by students as live-like-connection-less abstractions and memory-driven discourse that is not relatable to real world mechanical applications.(Ramírez et al., 2020)

This disconnect is further aggravated among Gen Z learners who typically require their learning to be interactive, experiential, and connected to authentic engineering problems.(Turner & Zepeda, 2023) They do not respond well to didactic, lecture-based, or rote-style learning because they were born into a world of digital information, rapid technology emergence, and global sustainability concerns.(Novita Sari., Achmad Hizazi., 2021)(Leão et al., 2024)(Hamadeh, 2022) They require meaning in the discipline they are studying, and application in every subject they study. The traditional way of teaching Engineering Chemistry - the content delivered with a focus on theoretical delivery, with assessments based on rote learning - misses the opportunity to establish that link.(Morgan, 2023) An urgent need exists to rethink chemistry education using learner-centric designs that support inquiry, critical thinking and application that are relevant to engineering contexts.(Soriano et al., 2025)(Kleine et al., 2024)

One apparent problem with first year engineering curricula is knowledge compartmentalization in that students too often view chemistry, physics, and mathematics as completely separate knowledge silos.(Campbell et al., 2022) Although Mechanical Engineering students will be expected to apply scientific principles to their future design and analysis work, the challenge is that most of their work in science subjects has largely been passive in the exploratory or experiential sense, which greatly diminishes their retained knowledge and, therefore, their ability to apply it in the future.(Cho, Zhao, et al., 2021) In the case of Engineering Chemistry, the students express anxiety and uncertainty around being able to connect an abstract chemical phenomenon, such as electrode potentials, with applicable mechanical applications, such as understanding why corrosion occurs in pipelines or when particular coatings are required for materials.(van Brederode, 2025) The pedagogical gap observed in higher education has led to a call to action for inquiry-based learning (IBL), a pedagogical approach founded in constructivist theory, whereby students learn by questioning, exploring, and creating meaning through real-world problems.(Thomas et al., 2025)(Beltrano, 2023) IBL enhances conceptual understanding, fosters interdisciplinary thinking, and enhances learner autonomy, all characteristics required of future engineers.(Pierre et al., 2024)(Kotsis, 2025)(Pratama, 2024) Research on the use of active learning strategies has consistently shown that inquiry-based practices not only improve academic achievement but also engagement and metacognitive development of undergraduate engineering students.(Kaçar et al., 2021)(Khasawneh et al., 2022)

Despite this, the implementation of inquiry-based active learning is still largely limited in terms of the documentation of its use in core chemistry modules, and within the first-year discipline specific curriculum of Mechanical Engineering. Most studies to date either target higher sometime necessarily independent students or explore the use of inquiry-based approaches combined in general science courses that can include non-cognate disciplines, creating a significant gap in understanding the effectiveness of inquiry practices within engineering fresher students in domain specific modules such as Electrochemistry and Corrosion. (Abdi Tabari et al., 2024) There is a significant gap in a basic understanding of the course as 'First-Year Engineering' students are unaware that this module exists as a significant domain of electrochemistry and corrosion theory and are not based on type on their understanding of science. Despite this being one of the primary core chemistry modules taught, first-year engineering students regularly undervalue it because they view it as theoretical in nature despite it being directly related to the mechanical engineering domains of material degradation, coatings, and tribology.

Consequently, the study was developed to ascertain the effect of guided, inquiry-based instruction in Engineering Chemistry—in particular, the Electrochemistry and Corrosion module—on first-year Mechanical Engineering students. Data were collected over a 16-week semester during the academic year 2024–25 using two full sections of students (Section A: 56 students; Section B: 58 students) at a Tier-I engineering institution in India.

The following research questions guided the study:

i. How does the adoption of Inquiry-Based Learning in Engineering Chemistry influence the conceptual understanding and interdisciplinary reasoning of first-year Mechanical Engineering students?

ii. What patterns emerge in student curiosity, teamwork, and application skills when exposed to inquiry-driven instruction?

These questions aimed to capture both cognitive and behavioral outcomes of IBL, while also examining its feasibility within the constraints of a standardized undergraduate curriculum.

Based on the above rationale, the study was designed with the following objectives:

- To implement an inquiry-based instructional model in the “Electrochemistry and Corrosion” module of Engineering Chemistry for first-year Mechanical Engineering students.
- To analyze student performance, engagement, and perception across two distinct sections, providing a comparative lens on implementation efficacy.
- To evaluate learning outcomes and behavioral trends, including collaborative dynamics, interdisciplinary linkages, and reflective thinking, as influenced by the IBL approach.

By addressing these objectives, the study not only contributes to the limited literature on inquiry-based chemistry instruction in engineering contexts but also offers an implementable framework for integrating research-oriented learning at the undergraduate level. Furthermore, the findings have the potential to inform curriculum developers, policymakers, and faculty about the transformative potential of IBL in fostering future-ready engineers, particularly when foundational science subjects are taught with contextual depth and interdisciplinary vision.

II. METHODOLOGY

Research Design

This research study employed a mixed-methods research design, using quantitative and qualitative methods to examine how Inquiry-Based Learning (IBL) influenced first-year Mechanical Engineering students' conceptual understanding, engagement, and interdisciplinary thinking relative to Engineering Chemistry. (Aidoo et al., 2022)(Nadkarni et al., 2023)The researchers incorporated a pre-and post-test model to examine students' gains in conceptual knowledge; and employed qualitative methods (observational notes, reflective journals, and structured surveys) to provide additional insights into students' learning experiences and perspectives.(Leko et al., 2021) By including both types of data, the mixed-method approach facilitated an interpretation of the instructional intervention as well an impact on learners more comprehensively.(Cho, Melloch, et al., 2021)

The pedagogical intervention was based on the foundations of constructivist learning theory, which states that new knowledge is built by learners developing understanding using active learning through building off their prior knowledge.(Chi, 2021) In this report, we utilized the instructional strategy of Inquiry-Based Learning to engage students in authentic scientific inquiry related to the topic of Electrochemistry and Corrosion. The inquiry-based learning element was centered on instilling curiosity, critical thinking, and the collaborative investigation of real-world problems, which are necessary skills for engineering practice.(Suhirman et al., 2021)

The IBL case-based model was delivered in three distinct stages: (1) Activation of Curiosity, (2) Guided Research, and (3) Design and Presentation of a Solution. Each stage was embedded into the semester, in order not to impact core delivery. By doing this, we maintained the integrity of the Engineering Chemistry course while providing a richer experience that included student agency and cross-disciplinary use.

Participants

The study was conducted among 114 first-year undergraduate students enrolled in the Bachelor of Engineering in Mechanical Engineering program during the academic year 2024–25 at a Tier-I autonomous engineering institution in India. The cohort was divided into two instructional sections as per the academic structure:

- Section A: 56 students
- Section B: 58 students

All participants were registered for the Engineering Chemistry course, which is a mandatory subject in the first semester of the program. The demographic composition of both sections included a mix of urban and rural backgrounds, with diverse academic profiles based on pre-university scores and language competencies.

Participation in the study was voluntary and embedded within the regular instructional process, ensuring no additional academic burden was placed on the students. Care was taken to maintain parity in instructional time, access to materials, and evaluation criteria across both sections to ensure validity and comparability of outcomes. To maximize peer learning and simulate the heterogeneous nature of real-world engineering teams, team formation was a structured, faculty-led process conducted during the first week of the semester. This process was applied identically to both Section A and Section B to ensure parity between the cohorts.

The formation was guided by two primary data points:

1. Conceptual Pre-test Scores: To gauge students' prior knowledge of chemistry concepts.
2. A Self-Assessment Survey: A brief, voluntary survey administered alongside the pre-test asked students to self-rate their confidence on a 3-point scale in three areas: (a) technical writing and documentation, (b) public speaking and presentation, and (c) digital tool proficiency (relevant for Section B).

Team Formation and Composition:

The team formation process followed these steps:

1. Stratification: Students in each section were first stratified into three tiers based on their pre-test scores: High (top 33%), Medium (middle 34%), and Low (bottom 33%).
2. Allocation: Teams of 4-5 students were then systematically formed by deliberately drawing at least one member from each performance tier. This ensured that no team consisted solely of high- or low-performing students.
3. Skill Balancing: The self-assessment data was used to balance complementary skills within each team. For instance, faculty aimed to place a student who expressed high confidence in public speaking with a student who preferred research and documentation tasks. In Section B, care was taken to distribute digitally proficient students across all teams to act as "tech buddies."

This method prevented the social isolation of lower-performing students and promoted cross-ability peer mentoring. By creating diverse teams, we aimed to foster an environment where students could learn from each other's strengths, thereby enhancing the collaborative and interdisciplinary goals of the IBL intervention.

Module Chosen

The pedagogical intervention was implemented within Module 1: Electrochemistry and Corrosion of the first-semester Engineering Chemistry syllabus. This module was strategically chosen for several reasons:

1. It has direct relevance to Mechanical Engineering applications, such as corrosion resistance in materials and electrochemical principles used in batteries and coatings.
2. It is typically perceived by students as conceptually abstract and disconnected from real-life mechanical systems.
3. It provides multiple opportunities for inquiry, including redox reactions, electrode potential calculations, corrosion mechanisms, and material protection strategies.

The module was allocated three weeks (approximately 6 hours of instruction) within the 16-week semester and served as the platform for introducing structured inquiry within the curriculum.

Lesson Implementation

The IBL model was designed around a three-phase instructional sequence, distributed over three consecutive sessions, to guide students from curiosity to a final, evidence-based solution:

- Phase 1: Curiosity Activation

Students were introduced to authentic engineering problems through real-world case studies and multimedia content (e.g., videos of corroded marine structures, degradation of batteries, failure of pipelines). This phase was designed to spark interest and encourage problem-posing. Students were prompted to formulate initial hypotheses about the causes of these failures based on their prior knowledge, setting the stage for inquiry.

- Phase 2: Guided Research

The objective of this phase was to investigate the scientific principles underpinning the problem. In their teams, students conducted structured research using provided resources, including academic databases, textbooks, and, for Section B, simulation tools. Their task was to investigate the specific electrochemical mechanisms at play (e.g., types of corrosion, relevant electrode potentials, properties of materials in their given context).

Deliverable: The primary deliverable for this phase was not a final solution, but a preliminary research brief (2-3 pages). This brief required students to:

1. Summarize the key electrochemical concepts relevant to their case.
2. Identify at least two potential corrosion mitigation strategies.
3. Provide a preliminary justification for each strategy based on scientific principles. This phase emphasized information literacy, data interpretation, and formulating evidence-based inquiries. Faculty provided formative feedback on these briefs to ensure students were on the right track before proceeding.

- Phase 3: Solution Design and Presentation

Building on their research briefs from Phase 2, teams now focused on synthesizing their findings into a single, actionable engineering solution. This phase involved:

1. Solution Design: Selecting the most appropriate mitigation strategy from their research and designing a detailed plan for its implementation for their specific mechanical application (e.g., specifying the type of sacrificial anode for a pipeline, the coating process for an automotive part).
2. Justification: Articulating a robust defense of their chosen

solution, considering factors like cost, environmental impact, feasibility, and long-term effectiveness.

3. Communication: Preparing a formal group presentation (10-15 minutes) and a concise technical report summarizing their problem, research process, proposed solution, and justification. The solutions were presented to the class and subjected to a structured peer-review session, followed by faculty critique. This final phase emphasized synthesis, engineering design thinking, and professional communication skills.

Team formation was intentionally designed to ensure diversity in academic performance, ability to communicate, and capacity for leadership. The intent was to promote peer learning, shared participation, and exposure to alternative thinking styles. Both sections followed similar templates, with Section B receiving electronic resources (videos, simulation tools) to assess the impact of technology-enhanced IBL.

Data Collection Tools

A multi-modal data collection strategy was employed to capture both the cognitive outcomes and affective dimensions of learning:

- Conceptual Pre- and Post-Tests: To assess students' knowledge of electrode systems, cell potential calculations, and corrosion protection mechanisms. The tests were the same, and the same test was used pre- and post-instructional intervention.
- Reflection Journals: Students maintained brief reflection entries after each session, documenting their learning experiences, questions raised, and connections to mechanical contexts.
- Structured Surveys: A post-intervention survey investigated students' perceptions of relevance, engagement, confidence, and satisfaction. The survey used a 5-point Likert scale as well as closed and open-ended items.
- Instructor Observation Notes: Classroom observations were recorded using a structured template capturing indicators such as participation levels, teamwork behavior, quality of questions asked, and challenges encountered.
- Group Reports: Every team submitted a report that summarized their findings, reflected on their recommended corrosion solution, and stated the rationale. Reports were marked using a rubric based on Bloom's taxonomy and principles of the engineering design process.

Ethical Protocols

The study adhered to the ethical principles of educational research. Students were informed of the purpose of the study. Participation of students in the surveys and the reflections was completely optional. All responses and comments were de-identified, and there was no publicly reported information regarding individual student performance.

The data collected was only used for research and curriculum development purposes, and students' academic grades were not affected by the research participation. The identity of the student and the confidentiality of their academic records were strictly protected regarding student identity.

Qualitative Data Analysis

Qualitative data from reflection journals, instructor observation notes, and open-ended survey items were analyzed using Thematic Analysis, following the six-phase process described by (Every et al., 2025). This method was chosen for its suitability in identifying patterns and meanings within rich textual data, directly addressing our research questions on student engagement and reasoning. The analysis process was as follows:

1. Familiarization: The research team independently read and re-read all qualitative data sources (114 reflection journals, observational notes from 16 weeks, and open-ended survey responses) to immerse themselves in the content and gain a holistic understanding of the data.
2. Generating Initial Codes: The data were systematically coded using qualitative data analysis software (NVivo 12). Initial codes were generated inductively from the data itself (e.g., "fear of being wrong," "connecting to bike parts," "help from tech buddy") as well as deductively based on the study's conceptual framework (e.g., "curiosity," "interdisciplinary link," "collaboration").
3. Searching for Themes: The initial codes were collated and sorted into potential thematic groups. For example, codes such as "asking 'why' questions," "debating solutions," and "going beyond the textbook" were grouped into a broader theme of "Emergence of Higher-Order Thinking."
4. Reviewing Themes: The candidate themes were reviewed against the entire dataset to ensure they were coherent, distinct, and accurately reflected the meanings evident in the data. Some themes were refined, merged, or discarded during this phase. For instance, initial themes around "technology use" and "group work" were refined into the more specific theme of "Technology-Enhanced Collaborative Inquiry" for Section B.
5. Defining and Naming Themes: Each final theme was clearly defined and given a concise, descriptive name. The defining characteristics and scope of each theme were documented to ensure consistency. The final themes included: (a) Shift from Rote Learning to Contextual Inquiry, (b) Emergence of Higher-Order Questioning, (c) Enhanced Interdisciplinary Reasoning through Analogies, and (d) The Role of Digital Tools in Engagement.
6. Producing the Report: In the Results and Discussion sections, the findings were presented using vivid, anonymized extracts from the reflection journals and observation notes to exemplify each theme. This ensured that the findings were grounded in the participants' own voices and experiences, providing a rich and credible account of the IBL intervention's impact.

III. IMPLEMETATION

The Inquiry-Based Learning (IBL) environment for Engineering Chemistry was designed to fit with the length of the semester and the allotted total number of hours for practice sessions, to reduce disruption of authentic experiences while maximizing opportunities for meaningful learning, engagement, and collaborative inquiry. All 114 first-year

Mechanical Engineering students (Section A: 56, Section B: 58) worked on the initial inquiry-based engineering chemistry course (AY 2024–25).

The teaching and learning environment created a progressive inquiry cycle that occurred over 16 weeks while integrating the inquiry cycle with the teaching and learning of the content, research engagement, peer interaction, and reflection. The phased approach supported the development of critical thinking skills, disciplinary nexus, and problem relevance, particularly as it relates to the specific module on Electrochemistry and Corrosion.

Session Flow Overview

In order to have a coherent transition from the acquisition of foundational knowledge to inquiry and application, the semester was designed in five functional phases, aligned against weekly learning objectives. Each of the five functional phases served as a building block for the research-oriented assignment, culminating in a cohesive student outcome.

TABLE I

Session Flow Overview for IBL-Integrated Chemistry Module

Week(s)	Phase	Activities and Outcomes
Week 1–2	Baseline Preparation	Orientation to IBL, diagnostic pre-test to gauge prior knowledge, explanation of expectations, and formation of heterogeneous student teams.
Week 3–6	Conceptual Foundations	Delivery of theoretical content on electrode systems, electrochemical cells, and corrosion mechanisms, with embedded inquiry prompts and problem scenarios.
Week 7–10	Team-Based Inquiry	Guided group research on case-based corrosion issues (e.g., marine structures, pipelines), exploration of electrode choices, and solution ideation.
Week 11–14	Peer Review & Presentation	Team presentations with peer evaluation, faculty critique, and reflective feedback; interdisciplinary reasoning was emphasized.
Week 15–16	Assessment & Feedback	Post-test assessment, final submission of group reports, feedback sessions, and reflective journal collection.

The sequence illustrated in Table I allowed students to engage with chemical theory and apply themselves with hands-on problem solving in a context of existing engineering problems. Instruction aligned to Bloom's higher order learning outcomes of analyze, evaluate and create that better represent the requirements for learning in STEM education.

Differentiation Between Sections

There were two distinct student cohorts; Section A (56 students), and Section B (58 students). The implementation was structured to facilitate comparison of the delivery models for each cohort. Both cohorts received the same substantive content and identical structure to assignments; however, the type of support and delivery model differed for each group.

TABLE II

Differentiation Between Section A and Section B

Aspect	Section A	Section B
Instructional Approach	Standard Inquiry-Based Learning	Inquiry-Based Learning with Technology Augmentation
In-Class Mentoring	Periodic mentoring by faculty during group tasks	Digital supports (videos, simulations) in addition to in-person mentoring
Tools Used	Printed worksheets, physical textbooks	Supplementary tools: pH simulation app, corrosion VR visualization
Peer Engagement Strategy	Peer Review & Presentation	Structured peer-learning through role assignments and tech buddy assistance
Outcomes Measured	Conceptual understanding, teamwork, report quality	Conceptual understanding, digital engagement, media effectiveness.

Table II provides differentiation for comparative opportunities to analyze the effectiveness of integrated IBL models. The tool under Section A was to compare traditional inquiry-based instruction, while Section B referred to a ‘technology-enhanced cohort’. In both scenarios, the teacher's role switched from lecturer to instructional facilitator and guided students in their exploration as a facilitator of knowledge creation not directly teaching them content.

Instructional Practices and Monitoring

To support the inquiry process, weekly checkpoints were established for each team to present interim findings, ask clarification questions, and receive formative feedback. These checkpoints served to reinforce the inquiry cycle (Ask → Investigate → Create → Discuss → Reflect) and ensure timely progress.

Instruction was enriched with:

- Inquiry triggers (e.g., "Why do stainless steel pipelines corrode in saline environments?").
- Visual data (case photos, corrosion diagrams).
- Team-based micro-tasks that culminated in solution presentations.

Faculty members used rubric-based monitoring sheets to track student engagement, collaboration, and conceptual articulation during activities. This provided consistent observational data used later in evaluation.

Challenges and Mitigation Strategies

During implementation, several operational and behavioral challenges emerged, especially in adapting students to non-traditional classroom dynamics. These were addressed through targeted interventions:

- *Section A: Resistance to Group Work*

Students in Section A appeared to have initial discomfort working in structured teams when paired with varying performance students. Faculty implemented models of role rotation (e.g., researcher, presenter, editor) and emphasized the value of diverse peer perspectives while working through engineering legitimacy questions in an engineering problem-solving context.

- *Section B: Technological Barriers*

In response to digital resources, while elements of positive engagement were evident in Section B, some students did demonstrate a lack of proficiency or comfort using the new tools. In response, group tech buddy partnerships were formed where students who were relatively digitally fluent helped support friends during tasks. The faculty also has low bandwidth options, so that everyone could participate.

In both sections, reflective journaling was used as a means to diagnose student struggles and course-correct instructional tactics in real-time. This responsiveness contributed significantly to the successful adoption of the IBL model.

IV. RESULTS

This section provides a detailed analysis of the findings from the implementation of Inquiry-Based Learning (IBL) in the Electrochemistry module with first-year Mechanical Engineering students. The results are categorized into two major parts: quantitative data measuring student performance and engagement, and qualitative data in the process of student reflections and faculty observations. Including images and visual data contributes to understanding and supports the findings.

Performance and Engagement Outcomes

Conceptual Learning Gains

In order to measure knowledge acquisition, students completed pre- and post-tests assessing what they understood about electrode systems, corrosion theory, and basic electrochemical theory. Statistically significant increases were measured from both sections, although section B had considerably greater improvement - a likely result of technology-based supports.

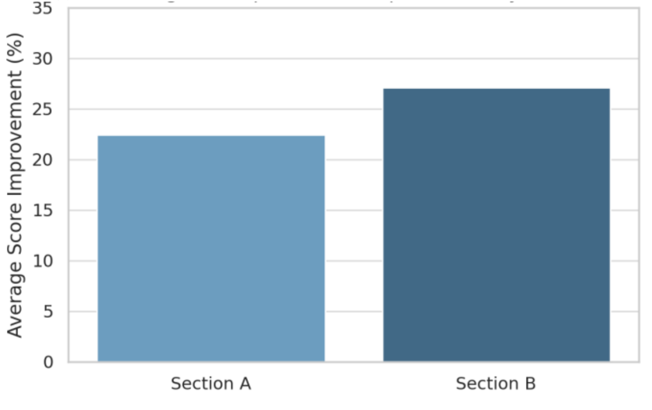

Fig. 1. Conceptual Score Improvement by Section

Section B showed an average increase of 27. 1%, which was greater than the increase of Section A at 22.4%. The use of multimedia learning resources in Section B may be part of the reason for this difference. These results highlight that IBL, especially in the digital space, can significantly enhance engineering students' conceptual understanding.

Weekly Participation Trends

To monitor student engagement across the semester, weekly participation data was collected based on the completion of the group task, in-class participation, and collaboration between peers. The findings showed engagement rates consistently increasing across both sections during weeks focused on research.

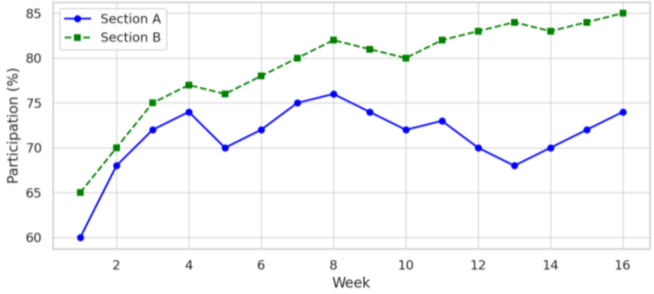

Fig. 2. Weekly Participation trend

Survey on Perceived Relevance and Confidence

A post-intervention survey provided insights into student perceptions. Notable findings include:

- 86% agreed that the link between chemistry and mechanical engineering was “clearer than before.”
- 83% said the group activity improved their communication and articulation skills.
- 78% felt more confident discussing corrosion and material selection in practical contexts.

These results highlight the importance of contextual relevance and collaborative learning in increasing student motivation and confidence.

Corrosion Mitigation Strategies Proposed by Teams

As part of the final deliverables, the student groups were asked to develop actionable corrosion prevention plans. They not only showed a technical understanding of the concepts but also took liberty in using some creativity.

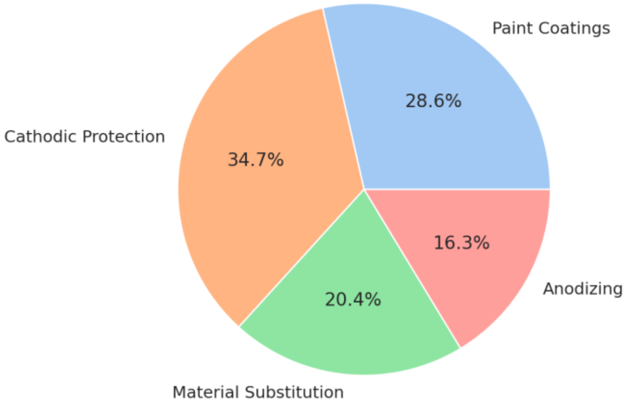

Fig. 3. Corrosion Mitigation Strategies Suggested by Teams

Cathodic protection was the most frequently mentioned method. Protective coatings and substitution of materials were the next most common choice of methods. These were all logical choices in that they demonstrate a reasoned understanding of the electrochemical principles. The distribution of selected methods also speaks to varying levels of creative (divergent) thinking and individual autonomy—aspects of effective inquiry-based pedagogy.

Qualitative Insights

Thematic Reflections and Student Voice

Students were asked to maintain reflection journals during the semester and document their thoughts, struggles, and reflections. A review of the text entries showed common themes of curiosity, real-world connection, collaboration, and confidence development.

Fig. 4. Word Cloud from Student Reflections

Common terms, such as "curiosity," "real-world," "corrosion," and "teamwork," indicated the level of engagement of the students with the module and its applications. These reflections support the emotional and cognitive engagement of the IBL experience, where students seemed to develop concepts which was recognizably more than memorization.

Real-Life Analogies and Practical Thinking

Many students drew analogies from daily life to explain corrosion mechanisms:

- Comparing rusting of bicycles to marine structural degradation.
- Explaining electroplating by referencing mobile phone battery terminals.
- Citing anodized utensils to describe protective oxide layers.

This kind of interdisciplinary reasoning demonstrates the success of the IBL framework in bridging textbook knowledge with tangible experiences, making abstract chemistry content more relatable.

Section B's Enhanced Reasoning via Technology

Section B, which utilized simulations and interactive videos, consistently exhibited more vivid explanations, advanced terminology, and visual representations in their group work.

Faculty observed:

- Greater use of technical vocabulary (e.g., "galvanic series," "ion-selective electrodes").
- Integration of digital diagrams and animated corrosion models in presentations.
- A higher frequency of student-initiated questions, reflecting increased intellectual curiosity.

This reinforces the value of blended IBL models that combine inquiry with multimedia learning for Gen Z learners.

V. DISCUSSION

By adopting Inquiry-Based Learning (IBL) pedagogical approaches to learning in the Electrochemistry module, which was offered to first-year Mechanical Engineering students, we gained valuable insight into how an active interdisciplinary learning model may have had an empirical impact on the engagement and curiosity of students and their vocabulary used and ability to think and problem-solve in the real world. The discussion below will articulate what we learned, identify trends and themes and discuss their relevance to the curriculum and on a policy level, while also acknowledging limitations and developing possible opportunities for future study.

Increased Curiosity and Higher-Order Questioning

One of the most striking observations to emerge from the study was the noticeable surge of student curiosity and the emergence of higher-order questioning as the IBL cycle docket progressed. Both sections, though likely more in Section B, began to demonstrate evidence of higher-order questions that showed evidence of analytical and evaluative thinking. For example, in Week 6, one student queried, "If stainless steel is corrosion-resistant, why does it still rust in coastal applications?" This question indicated that the student then understood material constraints specific to delivery in a given environment.

Another example occurred during the team research phase, where a group evaluating marine corrosion questioned, "Are there ways we can make sacrificial anodes from recycled material and still ensure that they were effective?" These questions show a clear shift away from rote learning to questions that reflect synthesis/application, also consistent with the action of higher-order cognition as defined under Bloom's educational taxonomy.

Perhaps this explosion of curiosity was facilitated by the IBL framework, as particularly noted during the "Guided Research" (Weeks 7-10) by allowing students some flexibility and discretion to assess problems that were relevant to them. Also, students were able to decide the most practical approach for the final deliverables, which afforded an open-ended response style, and three of the students said they went beyond the recommended definitions and research sources in developing a more complex and interdisciplinary approach.

Engagement and Conceptual Gains

The contrast of Sections A and B provides useful insights. Both exhibit an appreciable growth for meaningful conceptual gains (22.4% and 27.1% gains, respectively), therefore demonstrating that IBL will be effective regardless of the mode of delivery. But Section B indicated a higher engagement level in all facets—e.g., participation trends of demonstration teams indicating notable improvement; involves more modelling of collaborative engagement in teams and building capacities and collective efficacy.

A primary difference is the incorporation of multimedia and simulations into the activities in Section B. As an accessible learning mode, videos on galvanic corrosion, interactive tools to build the battery circuit, and animated videos on anodizing likely increase access to opportunity, while providing more motivation for the performance of the learning experience in Section B, especially for visual learners. Connecting abstract concepts (like electrode potential gradients) with visual experiences likely accounted for this.

Observations from the Faculty also indicated that students in Section B were quicker to submit, sought clarification, and were stronger in peer-to-peer mentoring. This suggests that multimodal inputs in more engaged, visually appealing environments may increase attention focused on collaborative accountability.

This complements previous studies on active learning; activating authors have noted that multimodal learning aids enhance inquiry-type models, particularly for Gen Z students who may be more accustomed to visual and accessible information.

Effective Use of Chemistry Vocabulary

Increased use of chemistry vocabulary in ways that were both meaningful and appropriate to engineering design interactions was a significant outcome of the intervention. Terms like electrode potential, passivation, anodizing, and galvanic corrosion regularly occurred in student reports and presentations, in ways that were often contextually relevant to the mechanics. For example, one group comparing aluminum bike frames with composite frames said, "when you use aluminum in the use of composites in the construction of a frameset, the passive oxide layer on aluminum offers a basic level of protection against corrosion and degradation, composites can be designed and manufactured that will not be damaged by electrochemical processes."

There was ample evidence to indicate that the students were not simply remembering definitions but adopting ideas and concepts in ways that were meaningful to them. Such instances of vocabulary usage were particularly important in interdisciplinary fields like design engineering and materials science, where communication across disciplinary boundaries is critical for exchange.

This has implications for the future. Meaningful language use in context implies that instruction that is interdisciplinary is enhancing not only content knowledge, but scientific literacy, which is an important graduate attribute in engineering education.

Interdisciplinary Linkage

The success of the intervention is perhaps most evident in how students were able to link electrochemical principles with real-world engineering problems. Examples include:

- Proposals to use sacrificial magnesium anodes for underground pipelines based on soil salinity data.
- The use of glass electrode pH monitoring in coolant systems for internal combustion engines.
- Evaluation of nanocoating's to enhance corrosion resistance in marine drones.

These examples emerged not from guided instruction, but from student-led inquiry. The structure of the IBL assignment, which allowed exploration of materials in practical settings, provided the scaffolding for students to visualize the role of chemistry in mechanical systems. This approach reflects the NEP 2020 vision of contextual, experiential learning, moving beyond compartmentalized knowledge.

Curricular Implications

The inquiry contributes to learning gains with one inquiry module integrated into a broader core course, and in this study construct, considered within the confines of a existing syllabus. At the end of the course a Module 1 (Electrochemistry) was preserved in terms of content coverage; new pedagogies were used in terms of pedagogical moves followed by exploration and application.

This approach will provide for scaling. In the future the same inquiry approach could be applied to the two modules on materials selection and polymers and energy systems. This will allow for cross-domain thinking and address institutional limitations.

Moreover, the integration of research tasks, reflective journals, and poster presentations aligns directly with the National Education Policy (NEP) 2020, which emphasizes:

- Experiential learning over rote memorization.
- Flexibility through project-based models.
- Contextual learning by linking subjects to real-life applications.

Thus, the findings advocate for the wider adoption of structured inquiry tasks across core science and engineering subjects, particularly in the first year when students are forming their conceptual foundations.

Limitations and Future Research

While the findings of this study are encouraging, it is important to acknowledge its limitations and outline a robust agenda for future research. The primary limitation is the study's scope; the intervention was confined to a single module within one semester, which, while providing a controlled environment, does not allow for an assessment of long-term knowledge retention or the development of a sustained research mindset.

Furthermore, the study was conducted exclusively within the Mechanical Engineering program at a Tier-I institution. While the results are promising, their generalizability to other engineering disciplines (e.g., Civil, Electrical, Chemical) or different institutional contexts requires further investigation.

Building on this foundational study, we propose the following key directions for future research:

1. Longitudinal Tracking of Retention: A critical next step is to conduct a longitudinal study that tracks the participating students into their subsequent years. This would assess whether the conceptual gains and interdisciplinary reasoning skills developed through the IBL intervention are retained and applied in advanced courses, such as Materials Science, Thermal Systems, or Capstone Design projects.
2. Cross-Disciplinary Validation: To test the generalizability of the IBL framework, the same instructional model should be implemented and evaluated in other engineering disciplines. For instance, applying this model to a Chemistry module for Civil Engineering students (focusing on topics like water treatment or concrete chemistry) or for Electrical Engineering students (focusing on battery technology) would reveal discipline-specific adaptations and confirm the broader applicability of the pedagogy.
3. Multi-Institutional Studies: Expanding the research to include a variety of institutions (e.g., liberal arts colleges, polytechnics, universities with different student demographics) would strengthen the external validity of the findings and help identify contextual factors that influence the successful implementation of IBL.

By pursuing these avenues, the research community can build upon our initial findings to develop a more comprehensive and generalizable understanding of how inquiry-based pedagogies can transform foundational science education across all engineering disciplines, ultimately fostering a new generation of adaptable, research-oriented engineers.

CONCLUSION

The goal of this study was to investigate the effectiveness of integrating Inquiry-Based Learning (IBL) into a foundational module, Electrochemistry, in the Engineering Chemistry curriculum for first-year Mechanical Engineering students. The findings indicate that IBL, if thoughtfully incorporated, has a marked impact on conceptual understanding, meaningful engagement, and meaningful learning in terms of real-world relevance.

The IBL framework facilitated the transition from mere content digestion to a more complex engagement level in concepts such as corrosion, electrochemical cells, and protective coating. The IBL Framework incorporating a structured three-phase process of Curiosity Activation, Guided Research, and Presentation in addition to gaining clarity in concepts, also deepened students' understanding of how chemistry principles impact decisions around materials in mechanical engineering practice. The quantitative benefits were listed as great improvements in scores of their assessments (22.4% improvement in section A, a 27.1% improvement in section B) and the qualitative benefits such as the reflective journals and student analogies were evidence of increased higher order thinking and knowledge transfer as being developed in the subject matter. Students also reported having a better idea of the interdisciplinary nature of what they had learnt, while students' team-tasking improved their communication, peer learning and reflective practice.

The results indicate that chemistry becomes much more than a theoretical topic when addressed in a contextual manner through problem-solving. The concepts behind corrosion protection, choosing the right electrode, or storing energy have direct relevance to mechanical design, service, and safety. As the students started to make connections to bike frames, drone bodies, marine structures, and braking systems, they could see chemistry not merely as a science to study, but as a means of providing actionable engineering solutions. Integrated forms of thought are essential to develop engineers capable of responding to interdisciplinary challenges.

Given the observed success of this initiative, we recommend extending IBL across other modules in the Engineering Chemistry curriculum, including Polymers for Engineering Applications or Analytical Techniques, which similarly allow for connections of standard chemistry content to mechanical and material science contexts.

In order to facilitate widespread uptake, there is a need for faculty orientation and capacity-building workshops. Instructors need training on how to design inquiry cycles, supervise research work, and assess interdisciplinary work, while still meeting the demands of the syllabus. With institutional support, this model can be standardized or adapted across several courses and disciplines.

Although the present study was based on a single module over a single semester, it is recommended that future studies track student behaviour, conceptual retention, and problem-solving ability longitudinally to assess any lasting impact. It is also recommended that course offerings, beyond this module, be considered for consideration of the adaptability of the IBL framework across other foundational subjects—such as Thermodynamics, Manufacturing Science, or Mechanics of Materials—which will provide an opportunity to investigate application flexibility and cross-disciplinary applicability.

In conclusion, by embedding systematic research in undergraduate core subjects, and by engaging more with students whereby they come to understand and appreciate both the subject and the content within a context and to appreciate the IBL approach defining students engaging and becoming invested in their learning trajectory, thus creating an opportunity for them to understand and fulfil the aims of the NEP (2020) towards experiential, flexible and holistic learning paths as the students are moving towards being early-stage researchers and scientists and engineers exploring ways to tackle or mitigate complex real-world problems.

REFERENCES

Abdi Tabari, M., Abdel Latif, M. M. M., & Tian, Y. (2024). The impact of computer-mediated task complexity on writing fluency: A comparative study of L1 and L2 writers' fluency performance. Computers and Composition, 73, 102863. https://doi.org/10.1016/j.compcom.2024.

Aidoo, B., Anthony-Krueger, C., Gyampoh, A. O., Tsyawo, J., & Quansah, F. (2022). A mixed-method approach to investigate the effect of flipped inquiry-based learning on chemistry students' learning. European Journal of Science and Mathematics Education, 10(4), 507–518. https://doi.org/10.30935/scimath/12339

Beltrano, N. (2023). Call and response: Inquiry-based learning as a critical pedagogy in the scholarship of teaching and learning to promote transformation and transformational leadership. Imagining SoTL, 3(1), 46–61. https://doi.org/10.29173/isotl678

Campbell, C. D., Midson, M. O., Bergstrom Mann, P. E., Cahill, S. T., Green, N. J. B., Harris, M. T., Hibble, S. J., O'Sullivan, S. K. E., To, T., Rowlands, L. J., Smallwood, Z. M., Vallance, C., Worrall, A. F., & Stewart, M. I. (2022). Developing a skills-based practical chemistry programme: An integrated, spiral curriculum approach. Chemistry Teacher International, 4(3), 243–257. https://doi.org/10.1515/cti-2022-0003

Chi, M. T. H. (2021). Translating a theory of active learning: An attempt to close the research–practice gap in education. Topics in Cognitive Science, 13(3), 441–463. https://doi.org/10.1111/tops.12539

Cho, H. J., Melloch, M. R., & Levesque-Bristol, C. (2021). Enhanced student perceptions of learning and performance using concept-point-recovery teaching sessions: A mixed-method approach. International Journal of STEM Education, 8(1), 1–17. https://doi.org/10.1186/s40594-021-00276-1

Cho, H. J., Zhao, K., Lee, C. R., Runshe, D., & Krousgrill, C. (2021). Active learning through flipped classroom in mechanical engineering: Improving students' perception of learning and performance. International Journal of STEM Education, 8(1). https://doi.org/10.1186/s40594-021-00302-2

Every, E., Ball, L., & van Driel, J. (2025). Mathematics teachers' perceptions of teaching strategies when adopting a STEM approach. Mathematics Education Research Journal. https://doi.org/10.1007/s13394-025-00520-9

Gao, M., Wang, Q., Wang, N., Ma, Z., & Li, L. (2022). Application of green design and manufacturing in mechanical engineering: Education, scientific research, and practice. Sustainability, 14(1). https://doi.org/10.3390/su14010237

Hamadeh, S. A. (2022). How Gen Z can improve community literacy about the 17 SDGs? A realistic approach to construct a futuristic change-maker paradigm. Green Technology, Resilience, and Sustainability, 2(1). https://doi.org/10.1007/s44173-022-00002-2

Horn, A., Urias, E., & Zweekhorst, M. B. M. (2022). Epistemic stability and epistemic adaptability: Interdisciplinary knowledge integration competencies for complex sustainability issues. Sustainability Science, 17(5), 1959–1976. https://doi.org/10.1007/s11625-022-01113-2

Kaçar, T., Terzi, R., Arıkan, İ., & Kırıkçı, A. C. (2021). The effect of inquiry-based learning on academic success: A meta-analysis study. International Journal of Education and Literacy Studies, 9(2), 15–30. https://doi.org/10.7575/aiac.ijels.v.9n.2p.15

Khasawneh, E., Hodge-Zickerman, A., York, C. S., Smith, T. J., & Mayall, H. (2022). Examining the effect of inquiry-based learning versus traditional lecture-based learning on students' achievement in college algebra. International Electronic Journal of Mathematics Education, 18(1), em0724. https://doi.org/10.29333/iejme/12715

Kleine, M. S., Zacharias, K., & Ozkan, D. (2024). Contextualization in engineering education: A scoping literature review. Journal of Engineering Education, 113(4), 894–918. https://doi.org/10.1002/jee.20570

Kolmos, A., Holgaard, J. E., Routhe, H. W., Winther, M., & Bertel, L. (2024). Interdisciplinary project types in engineering education. European Journal of Engineering Education, 49(2), 257–282. https://doi.org/10.1080/03043797.2023.2267476

Kotsis, K. T. (2025). Inquiry-based learning in science: Mathematical reasoning's support of critical thinking. Journal of Research in Mathematics, Science, and Technology Education, 2(1), 60–72. https://doi.org/10.70232/jrmste.v2i1.35

Leão, C. P., Alves, A. C., & Silva, V. (2024). Preparing Generation Z for the future: A challenge-based learning approach in higher education. IMECE 2024 Proceedings, V007T09A014. https://doi.org/10.1115/IMECE2024-145501

Leko, M. M., Cook, B. G., & Cook, L. (2021). Qualitative methods in special education research. Learning Disabilities Research & Practice, 36(4), 278–286. https://doi.org/10.1111/ldrp.12268

Morgan, K. (2023). Evaluation of improvements to the student experience in chemical engineering practical classes: From prelaboratories to postlaboratories. Journal of Chemical Education, 100(12), 4597–4607. https://doi.org/10.1021/acs.jchemed.3c00455

Nadkarni, A., Costa-Pinto, R., Hensman, T., Harman, E. V., Yanase, F., Lister, B. G., Nickson, C. P., & Thomas, J. S. (2023). Evaluating an inquiry-based learning program. Advances in Physiology Education, 47(4), 930–939. https://doi.org/10.1152/advan.00050.2023

Novita Sari, N., & Hizazi, A. W. (2021). Effect of good corporate governance and leverage on profitability-mediated tax avoidance: Study on mining companies listed on the Indonesia Stock Exchange 2016–2019. International Journal of Academic Research in Accounting, Finance and Management Sciences, 11(2), 202–221. https://doi.org/10.6007/IJARAFMS

Zainuddin, M. (2024). Teachers' perceptions of AI tools in enhancing student engagement for English language learning. Research Studies in English Language Teaching and Learning, 2(6), 367–380. https://doi.org/10.62583/rseltl.v2i6.64

Pratama, A. R. (2024). The influence of inquiry-based learning on students' understanding of accounting concepts. Journal of Education Innovation and Curriculum Development, 2(1), 18–24. Retrieved from https://journals.iarn.or.id/index.php/educur/article/view/

Ramírez, J., Soto, D., López, S., Akroyd, J., Nurkowski, D., Botero, M. L., Bianco, N., Brownbridge, G., Kraft, M., & Molina, A. (2020). A virtual laboratory to support chemical reaction engineering courses using real-life problems and industrial software. Education for Chemical Engineers, 33, 36–44. https://doi.org/10.1016/j.ece.2020.07.002

Soriano, S. M., Laura, A., Suz, A., Erro, A. M., Mazo, F. C., & Amato, R. D. (2025). Embedding sustainability within engineering education: The role of multidisciplinary and interdisciplinary approach. Preprints, 1–19. https://doi.org/10.20944/preprints202506.0973.v1

Subramaniam, R. C., Morphew, J. W., Rebello, C. M., & Rebello, N. S. (2025). Presenting STEM ways of thinking framework for engineering design-based physics problems. Physical Review Physics Education Research, 21(1), 010122. https://doi.org/10.1103/PhysRevPhysEducRes.21.010122

Suhirman, S., Prayogi, S., & Asy'ari, M. (2021). Problem-based learning with character-emphasis and naturalist intelligence: Examining students' critical thinking and curiosity. International Journal of Instruction, 14(2), 217–232. https://doi.org/10.29333/iji.2021.14213a

Thomas, M. B., Muscat, A., Zuccolo, A., Luguetti, C. N., & Watt, A. (2025). Navigating pedagogical innovation in higher education: Education academics' experiences with active and inquiry-based learning in intensive teaching. Innovative Higher Education. https://doi.org/10.1007/s10755-025-09807-y

Turner, P., & Zepeda, E. M. (2023). Navigating white waters: Generation Z untraditional college transition amid unprecedented social, health, and academic crisis. Higher Education Studies, 13(2), 87–96. https://doi.org/10.5539/hes.v13n2p87

van Brederode, M. E. (2025). Teaching chemistry as a creative subject. Chemistry Education Research and Practice, 26(3), 594–602. https://doi.org/10.1039/D5RP00068H