Embedding Research-Based Learning in Undergraduate Engineering Curriculum: A Case Study on Material Selection Pedagogy

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***Abstract*—This study presents a structured model for integrating Research-Based Learning (RBL) into the second-year Material Selection module of an undergraduate mechanical engineering program. Recognizing the gap between theoretical knowledge and real-world application, the model embeds an interdisciplinary, research-oriented assignment that leverages students' foundational understanding of chemistry to inform material selection decisions. Implemented over a 16-week semester with 88 students across 30 academically balanced teams, the activity emphasized teamwork, inquiry, and applied problem-solving. Quantitative results demonstrated a 73% improvement in conceptual understanding, as measured by pre- and post-intervention assessments. Qualitative analysis revealed enhanced articulation, critical thinking, and interdisciplinary application, particularly in connecting principles of chemical bonding and degradation to mechanical performance. Faculty observations and student feedback confirmed increased engagement, collaboration, and research curiosity. Aligned with the National Education Policy (NEP) 2020 and global engineering education trends, the model demonstrates strong potential for scalability across departments and institutions. It provides a practical framework for early research engagement, preparing students for complex, real-world challenges. The initiative affirms that embedding structured research into the core curriculum not only enhances academic outcomes but also transforms students into confident, inquiry-driven engineers.**

***Keywords*—Engineering Education Reform; Interdisciplinary Curriculum; Material Selection; Research-Based Learning (RBL); Undergraduate Research Integration.**

***ICTIEE* Track—Research-Informed Curriculum and Course Design**
ICTIEE Sub-Track—Integration of Research into Undergraduate Curriculum

I. INTRODUCTION

ON a global scale, engineering education is confronted with a significant disruption, moving away from "sage on the stage" teaching and learning practices and toward experiential/inquiry-based teaching and learning practices (Lee, 2024; Patel, 2023; Singha & Singha, 2024). This transition is necessitated by the increasing demand for graduates who are able to think critically, innovate, and address problems from transdisciplinary perspectives with technical competence.

Global frameworks like ABET and UNESCO advocate for student-centered learning outcomes, including research, teamwork, and creativity (Headley & Benson, 2024; Hussain et al., 2021). In India, the National Education Policy (NEP) 2020 strongly aligns with this vision by mandating the integration of undergraduate research from the outset to foster inquiry and innovation (Shayesteh, 2025).. This approach is well-supported by literature, which shows that early research engagement, such as through CUREs, not only enhances content knowledge but also develops critical transferable skills, leading to better academic performance and increased motivation for STEM careers (Auchincloss et al., 2014; DeChenne-Peters et al., 2023; Ruth et al., 2023).

In engineering, where knowledge rapidly evolves and real-world challenges are increasingly complex, embedding research within core subjects cultivates adaptability, curiosity, and confidence in problem-solving (Sapovadia & Patel, 2025). Furthermore, it bridges the often siloed nature of theoretical content and applied knowledge by providing students a platform to explore, question, and create rather than merely consume information.

This study employs a structured form of Research-Based Learning, aligned with inquiry-driven analysis rather than full-scale discovery research. While elements of Problem-Based Learning (PBL) are inherently present, the model emphasizes literature-supported reasoning, comparison of alternatives, evidence-based justification, and interdisciplinary research skills.

Mechanical Engineering is one of the disciplines that students pursue across India's technical institutions. Knowledge of the fundamentals is important, and mechanical engineering programs are typically based on rubrics of thermodynamics, manufacturing, and materials (Muhammad et al., 2021; Persano Adorno & Pizzolato, 2025). Despite the use of laboratories and mini-projects in many programs, they tended to be (and in some respects, continue to be) knowledge transfer institutions more concerned with examinations, lectures, and heavy content – and at worst, rote learning and an absence of transformative, experiential learning or innovation. If laboratories and projects are used, research exposure would start in either the final year or the PG year, typically arriving too late to help establish the habits, protocols, and ways of work that characterize a research posture.

This article presents a case study of embedding a structured,

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research-based assignment in the second-year Material Selection course, building on first-year Engineering Chemistry to foster interdisciplinary inquiry. The initiative aimed to bridge theoretical learning with practical design, integrate chemistry and mechanical concepts, and develop NEP 2020-aligned competencies like critical thinking.

Involving 88 students in diverse teams over a 16-week semester, this study details the complete design, implementation, and evaluation of the curriculum model. By integrating research as a core component rather than an add-on, this work offers a scalable framework to make engineering graduates more inquiry-focused, aligning with national goals to innovate education.

II. Literature Review

A. Defining Research-Based Learning and Global Best Practices

The nature of Research-Based Learning (RBL) is to centre learning on problem-based inquiry and to embed structured research projects into learners' educational curriculum so that they can construct knowledge through research, experimentation, and analysis. Syra Shakir (2024) claims that RBL leads students to be co-creators of knowledge and therefore bridges the gap between teaching and research, as opposed to students being passive recipients of knowledge (Shakir, 2024).

Internationally, universities in the UK, Australia, Germany, and the US have integrated RBL into their programs through Course-Based Undergraduate Research Experiences (CUREs) and undergraduate research opportunities programs (UROPs) (Daryanes et al., 2025; Merino-Soto et al., 2022; Snelson et al., 2024). Overall, RBL has shown a positive impact on student retention, proficiency development, and motivation to engage in scientific inquiry. Favorable practices include introducing research early, scaffolded assignments, interdisciplinary teamwork, and reflective assessment tools (Y. Yang et al., 2024).

B. RBL in STEM and Engineering Education: Implementation and Lessons Learned

STEM disciplines, notably engineering, are starting to incorporate RBL as a method of moving beyond a rigid curriculum and towards the development of higher-order competencies. In engineering, RBL is integrated through design projects, case-based learning, open-ended labs, and capstone research modules. Vilma Sukackė et al. (2022) found that RBL in science and engineering courses led to greater cognitive engagement and persistence within technical disciplines (Sukackė et al., 2022).

The Massachusetts Institute of Technology (MIT), is one example that employs RBL with undergraduate research internships (Ahel & Schirmer, 2022). The University of Queensland, Australia, also conducts RBL in chemical engineering, through inquiry-guided laboratory modules (Al-Maktoumi et al., 2016). The implementation report gives important lessons in building strong mentorship with faculty, building research skills early on, and connecting student outcomes to course learning objectives. The successful implementations focus heavily on real-world and authentic problems, which address appropriate research, complex interdisciplinary, multi-structured, and applied situations, so students grasp the relevance of fundamental ideas (L. Yang et al., 2025).

C. C. Benefits and Challenges of RBL in Engineering Education

• Curriculum Design: RBL requires a re-conceptualization of curriculum structure from a passive lecture-based transmission of content to an active and dynamic inquiry-based research approach. RBL also encourages flexibility in which the research activities may be integrated into any course structure in a modular format, providing opportunities for learning from the steps taken in a literature review, to hypothesis generation, through to analyzing data and writing a report or paper. SMH Amiri (2025) points out that this is a pedagogic challenge that requires balancing the essential content with discretion for doing student-driven exploration through RBL (Amiri, 2025). In the engineering context, 'balance' means embedding time-limited research tasks informed by the curriculum objectives of the technical learning outcomes, while exploring individual and collaborative challenge and purposeful benefit by engaging both depth and transfer of knowledge.

• Faculty Mindset and Training: The success of RBL largely hinges on faculty attitude and preparedness. Many instructors face challenges transitioning from didactic methods to facilitator roles. Allan Hassaniyan (2024) argue that faculty development programs are essential to cultivate a research-teaching nexus mindset (Hassaniyan, 2024). Faculty resistance often stems from perceived time constraints, workload concerns, or lack of training in mentoring undergraduate research (Li & Li, 2025). Institutions that have succeeded in RBL adoption often provide support mechanisms such as workload redistribution, peer mentoring, and recognition of teaching innovation.

• Student Readiness and Barriers: Students beginning RBL often do so without experience of self-directed learning, research methods, or critical appraisal. This can result in students experiencing anxiety, disengagement, or superficial project completion. However, when properly scaffolded, the RBL experience has been shown to promote agency, curiosity, and academic confidence (Nguyen et al., 2024). Readiness may be addressed by providing workshops on the research process, integrating training on library and digital tools, and ensuring chosen topics are appropriate to students' developmental level. Students may feel more comfortable transitioning to becoming researchers if the intensity of RBL is gradually increased across semesters (Bowyer & Akpinar, 2024; Thiem et al., 2023).

D. Interdisciplinary Learning: Chemistry and Materials Science in RBL

Interdisciplinary learning strengthens the impact of RBL, as students are exposed to an array of ways of thinking and problem-solving. Engineering students have an inherent opportunity to make connections with interdisciplinary practice at the nexus of chemistry and materials science as they address real-world issues such as corrosion resistance, thermal stability, polymer design, and sustainability. Research has shown that students retain understanding for a longer period and apply their understanding more seamlessly when chemistry is contextualized in the applications of engineering (Masbukhin & Kusmawan, 2025; Qizi et al., 2024).

For example, knowledge of chemical bonding, the kinetics of corrosion, and reactions involved in polymerization are all connections to material selection decisions in engineering design. The unique opportunity for RBL in such hybrid areas allows students to transfer their conceptual understanding across disciplinary borders and apply it in practice, a key feature of modern engineering practice (Ghannam & Chan, 2023). This interdisciplinary focus contributes to innovation, as it relates to NEP 2020's focus on holistic education and multidisciplinary and interdisciplinary learning in technical programs.

E. Gaps in the Curriculum and Rationale for RBL in Material Selection

While improvements in pedagogy have been made, material selection is still often taught primarily as a theoretical subject with little opportunity for hands-on experimentation or design exploration. The scope of material selection often engages students as they learn to regurgitate charts, properties, and selection indices without designing real problems or contextualized dilemmas. This disconnect from content to application limits students' reasoning capabilities, their means of rational decision-making, and their justified data-driven decision-making.

Incorporating RBL into Module 5 – Material Selection allows students to engage in design problems dealing with material selection, while working with both real issues and constraints, and the need to apply knowledge from different areas of engineering. This initiative closes a huge gap in developing a critical part of the engineering process and moving from passive to a more applied, active, and skilled knowledge. It also exposes a trade-off that needs to be taken into account when evaluating sustainability, performance, cost, and processing when making decisions- a significant part of engineering practice (Nand et al., 2022).

F. Positioning This Study in RBL Literature

This research advances the breadth of RBL literature because it is a scalable, formally integrated course model in a developing-world context. This study gives students the opportunity to engage in research with their peers, as part of a core 2nd-year course. By integrating research in the second year of a degree, this project can broaden equitable opportunities for participation for all students, including those who have had no prior research experience and may not have opted into an elective research internship or final-year project.

By operating as teams of inquiry, with some interdisciplinary learning, by design and structured assessments, this project provides a scaffold for any STEM educator to operationalize the vision outlined in NEP 2020. It also responds to and mitigates some of the major barriers to faculty and student engagement identified in the literature, and provides some viable solutions for the curriculum integration of RBL. The model supports knowledge gains, including productivity and research mindsets, resulting in pedagogical change with potential to develop undergraduate engineering education.

III. METHODOLOGY

A. Context and Participants

The study was conducted with 88 second-year Mechanical Engineering students at a VTU-affiliated institution in India. The intervention was a mandatory, faculty-supervised research project integrated into the 16-week Material Selection module. It leveraged students' first-year Engineering Chemistry background to facilitate the necessary interdisciplinary links between chemical principles and material selection decisions.

B. Research Design

The research implemented a curriculum-integrated Research-Based Learning (RBL) model, where the research was introduced as a graded assignment within a core course instead of an elective or integrated as a capstone project. This approach allowed students to connect the theoretical and applied early in their engineering degree.

Conceptual understanding was measured through a 15-mark diagnostic quiz designed by the course instructor and reviewed by two subject experts to ensure content validity. The instrument was aligned with course outcomes and assessed data interpretation, property-based reasoning, and application of chemistry concepts in material selection. While not a formally validated standardized tool, the assessment was directly mapped to the competencies targeted by the intervention.

The pedagogical foundation was based on constructivist, experiential, and interdisciplinary learning perspectives. Students constructed knowledge through inquiry, interaction with peers, and the analysis of real-world scenarios. The framework was structured around inquiry-based reasoning on concepts in chemistry and materials science, while developing critical thinking and problem-solving capabilities.

To contextualize this integration, the following Table 1 was developed:

TABLE I
INTEGRATION TABLE FOR RESEARCH-BASED LEARNING IN MODULE 5: MATERIALS SELECTION

Area	Preliminary Concepts Needed (Modules 1–4 + Chemistry)	Concepts Introduced in Module 5	Rationale for Research Assignment
Material Structure & Types	- Atomic bonding (ionic, covalent, metallic) - Crystal structures - Types of materials (metals, ceramics, polymers, composites)	- Classification of engineering materials - Structure-property relationships	Enables students to understand why materials behave the way they do and shortlist appropriate candidates for design problems.
Mechanical Properties	- Stress-strain behavior - Toughness, hardness, fatigue, creep - Testing methods	- Material property charts - Property indices - Limits & constraints for selection	Helps quantify trade-offs (e.g., strength vs weight), critical for making justified material choices in research.
Functional Properties	- Thermal conductivity, electrical resistivity - Corrosion resistance - Thermal expansion	- Functional material property databases - Selection based on functional needs	Supports research of materials for components like heat exchangers, insulators, electronic casings, etc.
Processing & Manufacturing	- Casting, forging, machining basics - Ceramics processing - Plastic molding techniques	- Processing routes - Impact of processing on material performance	Guides research on feasibility and manufacturability of selected materials for practical applications.
Environmental & Economic Aspects	- Corrosion mechanisms (from chemistry) - Biodegradability - Recyclability	- Cost-performance trade-offs - Sustainability & lifecycle thinking	Fosters systems thinking and helps students evaluate eco-friendly material solutions for real-world design challenges.
Design & Data Interpretation	- Graph reading, comparison charts - Engineering design constraints (implicitly taught)	- Design constraints: function, objective, constraints - Use of Ashby material charts	Builds ability to apply research-backed reasoning for selection and represent decisions visually or numerically.

C. Activity Design and Implementation

Given that the RBL model was integrated into the core curriculum for all students, no control group was available for comparison. Therefore, the study relies on within-group pre- and post-intervention comparisons, which indicate learning gains but do not allow causal attribution of these gains solely to the RBL intervention.

The RBL intervention was designed as a design-based research assignment. Students were asked to find an engineering application (e.g., a drone frame, brake rotor, gear shaft), and choose the materials that best suited that application based on technical data, Ashby charts, sustainability factors, and processing constraints.

Teams all worked through a phased assignment cycle involving selection of the topic, literature review, property comparisons, justification for each selection, and presentation.

To guide this activity, a formal charter was developed, as seen in Table 2.

TABLE II
PROJECT CHARTER: RESEARCH-BASED ASSIGNMENT – MODULE 5: MATERIAL SELECTION

Field	Details
Project Title	Smart Material Selection for Engineering Applications: A Research-Driven Approach
Purpose	To develop research and analytical thinking in undergraduate students by applying materials science and chemistry concepts to real-world material selection problems.
Objective	- Enable students to apply theoretical knowledge from Modules 1–4 and Engineering Chemistry. - Introduce tools for data-based material selection. - Foster critical thinking, sustainability awareness, and design-based decision-making.
Scope	In Scope:• Research on material alternatives• Use of Ashby charts, material indices, and performance data• Team-based or individual reports• Internal assessment integration Out of Scope:• Experimental lab testing• Prototyping• High-end simulations
Key Modules Integrated	- Module 1: Basic Material Properties - Module 2: Structure-Property Relationships - Module 3: Thermal, Electrical, Magnetic Properties - Module 4: Ceramics, Plastics, Composites - Module 5: Material Selection - Engineering Chemistry: Bonding, Corrosion, Sustainability
Deliverables	- Topic proposal - Research outline - Final report/poster - (Optional) 5-minute presentation
Team Composition	2–3 students per team (flexible)
Timeline	Week 5: Orientation Week 6: Topic selection Week 7: Outline submission Week 8–9: Research work Week 10: Final submission Week 11–12: Optional presentations
Assessment Criteria	- Problem definition and clarity (5 marks) - Application of chemistry and materials concepts (5 marks) - Use of charts and property analysis (5 marks) - Research depth and justification (5 marks) - Report/presentation quality (5 marks)
Success Indicators	- Active student participation - Well-reasoned material choices - Demonstrated connection between theory and real-world application - Positive feedback from faculty and students
Risks & Mitigation	- Risk: Lack of research experience Mitigation: Provide examples and structured templates - Risk: Redundancy in topics Mitigation: Early approval of proposals - Risk: Unequal team contribution Mitigation: Assign clear roles in group

The activity was mapped across the 16-week semester to align with lectures, ensuring sufficient scaffolding and milestone tracking (Table 3).

TABLE III
ACTIVITY ANALYSIS FRAMEWORK FOR RESEARCH-BASED ASSIGNMENT (16-WEEK SEMESTER)

Week	Activity	Description	Responsible	Deliverables/Notes
Week 1	Course Orientation	Introduce subject, syllabus, and outcomes	Course Instructor	–
Week 2	Foundation Concepts	Start Modules 1 & 2 (properties, structure)	Faculty	–
Week 3	Continue Core Concepts	Deep dive into Modules 2 & 3 (functional properties)	Faculty	–
Week 4	Introduce Research Assignment	Brief students on the objectives, scope, and assessment criteria of the assignment	Faculty	Project Charter & Topic Pool shared
Week 5	Team Formation & Topic Finalization	Form teams (based on category strategy) and finalize topics	Students + Faculty	Submission of Team Registration & Selected Topic
Week 6	Research Orientation & Literature Review Begins	Guide on how to review papers, gather data, use Ashby charts, etc.	Faculty	Orientation session + Sample papers shared
Week 7	Literature Mapping & Outline Drafting	Students map material requirements to design problem + draft outline	Students	Outline Draft Submission
Week 8	Feedback & Mid-Review	Faculty provides feedback on outlines + verify progress	Faculty	Short review/discussion sessions
Week 9	Analysis Phase	Students apply data charts, compare material options, and refine choices	Students	Tables, property justifications
Week 10	Report/Poster Development Begins	Teams work on final deliverables – writing, visuals, referencing	Students	Draft Report/Posters
Week 11	Internal Review (Dry Run)	Internal presentations or peer feedback session	Faculty + Peers	Optional: Scores for internal improvement
Week 12	Final Submission	Report or Poster Submission	Students	Report/Poster (as per format)
Week 13	Research Presentation Days	Optional formal team presentations to faculty panel	Students + Faculty	Evaluation & Feedback
Week 14	Integration with Module 5	Continue Module 5 teaching and relate back to team research	Faculty	Discussion on outcomes of research
Week 15	Reflection & Debrief	Students reflect on research learnings and their application	Students	Optional: Reflection form or blog
Week 16	Consolidation & IA Marks Entry	Internal marks finalization and feedback sharing	Faculty	Grading + Research culture reinforcement

The 16-week structure was intentionally designed to distribute work evenly across the semester. Each task—topic selection, outline development, property analysis, and report preparation—was mapped to weekly teaching plans to avoid additional burden beyond regular coursework. Milestone checkpoints (Weeks 7, 9, and 11) ensured students progressed incrementally rather than rushing at the end. Since the RBL activity replaced a conventional assignment, students did not experience net workload increase. Faculty provided curated resource packs (sample papers, chart databases, and templates) to reduce time spent on data search, helping students manage the assignment without notable time-pressure.

This systematic structure allowed students to apply theoretical concepts to open-ended problems, enhancing knowledge retention and real-world understanding.

Qualitative insights in this study were derived from faculty observations during mentoring checkpoints, structured presentation rubrics, and informal student feedback collected during reflection sessions. Student artefacts—including outlines, comparative tables, and final reports—were reviewed to understand articulation quality and reasoning patterns. These sources collectively informed interpretation of higher-order thinking development.

D. Team Formation Strategy

To ensure balanced learning and equitable participation, students were assigned to teams using a homogeneous distribution strategy. Based on their academic performance from the previous semester or internal assessments, students were categorized as follows:

- Category A (High Performers) – Top 33%
- Category B (Mid Performers) – Middle 34%
- Category C (Developing Learners) – Bottom 33%

Academic balance was achieved by categorizing students into three performance tiers (high, mid, developing) using their most recent semester GPA and internal assessment scores. Each team was formed by selecting one student from each tier, ensuring heterogeneity of academic strength. This prevented clustering of high performers or developing learners within the same group.

Each team was composed of one student from each category, forming 29 teams of three and one team of four. This structure enabled academic balance, peer mentorship, and diverse thinking as observed in Table 4.

TABLE IV
ACTIVITY ANALYSIS FRAMEWORK FOR RESEARCH-BASED ASSIGNMENT (16-WEEK SEMESTER)

Structure: Category	Rationale	Criteria for Selection
Category A: High Performers	To ensure each team has a technically strong member who can guide research direction and maintain academic rigor.	- Top 33% of the class based on previous semester GPA or internal assessment marks. - Demonstrated strength in conceptual understanding.
Category B: Mid-Level Performers	To contribute stable work output and benefit from working closely with high and low performers. Encourages peer learning and balance.	- Middle 34% of the class based on academic performance. - Moderate consistency in class participation and assignments.
Category C: Developing Learners	To provide equitable exposure and research opportunities to students who need more support. Encourages confidence and active participation.	- Bottom 33% of the class. - May include students with irregular performance or lower grades, but potential for improvement.

To prevent passive participation, especially from developing learners, structured roles were assigned within each team (e.g., literature review, data analysis, report writing, or presentation). These roles were submitted in the Team Registration Sheet and verified during milestone checkpoints. Additionally, peer-review scores and faculty mentoring sessions ensured that contributions were monitored and all team members were actively engaged in the research process.

Faculty either directly assigned the teams or approved student-proposed teams that met the prescribed criteria. Each team submitted a Team Registration Sheet with member details, topic title, and role allocation.

E. Evaluation Strategy

The RBL assignment was integrated into the course's Internal Assessment (IA) structure. Student output was evaluated based on three components:

1. Final Report or Poster
2. Oral Presentation (5–7 minutes)
3. Optional Reflection/Peer Review

The presentation was evaluated using a rubric-based system, allowing for transparency, objectivity, and structured feedback (Table 5).

TABLE V
PRESENTATION EVALUATION RUBRIC – RESEARCH-BASED ASSIGNMENT (TOTAL: 100 MARKS)

Criteria	Weightage (Marks)	Evaluation Description
1. Clarity of Problem Definition & Objectives	15 marks	Clearly states the engineering design problem, its constraints, and the goal of material selection. Demonstrates understanding of the real-world relevance.
2. Application of Scientific & Technical Knowledge	20 marks	Effective use of chemistry and materials science concepts (bonding, corrosion, structure, properties, etc.) in framing and solving the selection challenge.
3. Use of Material Property Data & Selection Tools	15 marks	Demonstrates proper use of property charts, Ashby maps, or comparative tables. Shows evidence of critical selection criteria and reasoning.
4. Depth of Research & Literature Integration	15 marks	Incorporates quality sources (papers, data, case studies). Demonstrates understanding of current trends or innovations in materials.
5. Design Thinking & Decision Justification	10 marks	Logical flow in selecting the final material with justified trade-offs (cost, sustainability, availability, performance).
6. Visual Quality of Presentation	10 marks	Use of graphs, tables, diagrams, or models to enhance clarity. Slides/poster is visually clean, organized, and not text-heavy.
7. Communication Skills & Delivery	10 marks	Clear, confident speaking; good pacing; team coordination; ability to engage the audience and respond to questions.
8. Time Management	5 marks	Stays within the time limit (typically 5–7 minutes). Smooth flow without rushing or exceeding time.
Total	100 marks	–

The faculty panel used this rubric during the presentation week, with optional peer assessment to encourage reflective and critical listening. The evaluation emphasized reasoned material selection decisions, even if the outcomes varied between teams.

Marks were scaled to internal assessment scores and feedback was provided to each team for learning reinforcement.

IV. RESULTS AND ANALYSIS

A. Participation and Engagement Metrics

30 teams were created with 88 students using the framework of team groups while ensuring mixed academic ability in teams.

Throughout this process, teams identified research topics related to one of the five broad material categories: metals, composites, ceramics, polymers, and hybrid materials.

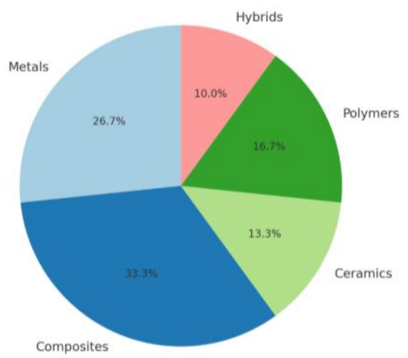

Figure 1: Distribution of Topics by Material Category (n=30 Teams)

A majority of teams selected composites (33%) and metals (27%), reflecting familiarity with conventional materials. However, a notable portion (13%) explored hybrid or sustainable material systems, suggesting emerging interest in eco-friendly and interdisciplinary approaches.

Submission compliance was exceptionally high:

- Final Poster/Report Submission Rate: 100% (30/30 teams)
- Presentation Participation: 97% (29 teams presented; 1 team excused due to valid medical reasons)
- Team Charter and Outline Submissions: 100%

In terms of student engagement, informal polling and faculty records indicate that 83% of students attended all milestone sessions, and 71% reported contributing equally to their team's work, as verified by peer reviews and faculty checkpoints.

B. *Student Learning Outcomes*

To evaluate learning outcomes, a pre- and post-intervention diagnostic quiz (out of 15 marks) was administered to assess the ability to select and justify materials based on performance indices, data interpretation, and application of chemistry concepts as seen in Table 6.

TABLE V
PRE- AND POST-INTERVENTION QUIZ RESULTS (N=88 STUDENTS)

Metric	Pre-Quiz	Post-Quiz
Mean Score	6.4 / 15	11.1 / 15
Median	6.0	11.0
Std Dev	1.9	1.7

This improvement (a 73% average increase) suggests that students developed a stronger grasp of design constraints, material-property trade-offs, and interdisciplinary reasoning. As the diagnostic instrument was instructor-designed and no control group was used, these gains should be interpreted as indicative rather than exclusively attributable to the intervention.

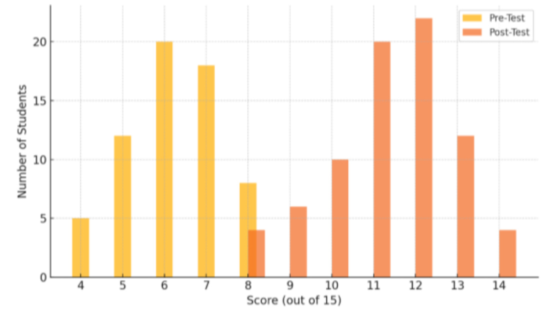

Figure 2: Comparison of Pre- and Post-Test Score Distribution (n=88 Students)

This histogram shows that while most students initially scored between 5 and 7, post-test scores shifted significantly, with the majority scoring between 10 and 13. This distribution shift validates the effectiveness of the intervention.

Examples of Material Selection Decisions

Many teams demonstrated sound reasoning in selecting materials for specific design goals. For instance:

- Team A17 selected GFRP (Glass Fiber-Reinforced Polymer) over Aluminum for a bike frame, citing impact resistance, fatigue strength, and lightweight advantage.
- Team C12 chose Zirconia ceramic for a brake rotor application, highlighting thermal shock resistance and non-metallic wear characteristics.
- Team B08 opted for recycled PLA-based polymer composites for a drone frame, integrating both chemistry of biodegradability and mechanical performance constraints.

Evidence of Interdisciplinary Knowledge Application

Students regularly connected principles from chemistry (e.g., bonding, corrosion kinetics, polymerization reactions) with engineering considerations (e.g., strength-to-weight ratios, sustainability, manufacturing processes).

For example:

- In the drone body case, students evaluated UV degradation and hydrolysis of bioplastics using chemistry literature.
- In the brake rotor analysis, teams correlated ionic bonding structure in ceramics with brittle failure modes and wear behavior.

These interdisciplinary applications validated the decision to connect prior chemistry coursework with engineering design through RBL.

C. *Faculty Observations*

Faculty members involved in mentoring and evaluation noted the following:

Improvements Observed

- Articulation and Communication: Students became progressively more confident in presenting technical ideas. Nearly 75% demonstrated clear use of property charts, data tables, and comparative justifications during presentations.
- Collaboration: The mixed-ability team structure worked effectively. Students reported that having a diverse team encouraged distributed learning and peer tutoring.
- Research Mindset: Students explored scientific databases, referenced recent journal articles, and evaluated sustainability

parameters, indicating increased intellectual curiosity.

Illustrative Examples of Student Outputs

"For example, early drafts of reports often contained property listings without justification (e.g., 'Aluminum is strong and light'). After the intervention, students articulated clear trade-offs, such as: 'Although Aluminum 6061 provides good specific strength, GFRP offers superior fatigue resistance and weight reduction, making it more suitable for dynamic loading conditions in bike frames.' Similarly, pre-intervention quiz responses tended to focus on single-factor decisions, whereas post-intervention reports integrated multiple criteria—including bonding mechanisms, corrosion behavior, and sustainability considerations."

Common Challenges

- Initial Hesitation: Many students lacked prior experience in research or open-ended assignments, leading to initial confusion.
- Data Overload: Some teams struggled with filtering relevant data from material databases.
- Overemphasis on Cost: A few teams narrowed their material selection decisions primarily on cost rather than functional performance or life-cycle analysis.

To better understand students' perceptions, an optional feedback survey was conducted at the end of the semester. The feedback was analyzed for keywords and themes.

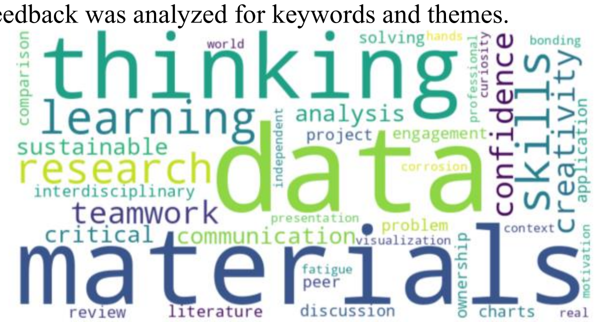

Figure 3: Student Feedback – Word Cloud of Emergent Themes

The research activity indicated themes such as critical thinking and application, sustainability, peer learning, and confidence as clear signals of student growth and engagement. Faculty addressed the challenges they observed by providing formative feedback, holding individual mentoring sessions, and making any course corrections at predetermined interventions (Weeks 5, 8, and 11)

D. *Sample Case Snapshots*

I. Example 1: Bike Frame – Composite vs Aluminum

Team A17 compared Aluminum 6061 with GFRP for a high-performance bike frame:

Criteria	Aluminum 6061	GFRP
Density (g/cm³)	2.70	1.85
Fatigue Resistance	Moderate	High
Criteria	Aluminum 6061	GFRP
Manufacturing Ease	High	Medium
Environmental Impact	Medium	Low (recyclable)
Final Selection	–	✅ GFRP

The team justified GFRP based on its light weight, better damping, and corrosion resistance, integrating both chemical bonding theory and engineering performance data.

II. Example 2: Brake Rotor – Ceramic vs Cast Iron

Team C12 evaluated Zirconia-based ceramic vs Gray Cast Iron:

Criteria	Cast Iron	Zirconia Ceramic
Cost	Low	High
Thermal Conductivity	High	Low
Wear Resistance	Moderate	Very High
Thermal Shock Resistance	Low	Very High
Final Selection	–	✅ Zirconia

The students demonstrated excellent interdisciplinary understanding, relating ionic lattice energy from chemistry to thermal performance in braking systems.

III. Example 3: Drone Body – Recycled Polymer vs Carbon Fiber

Team B08 explored PLA-based bio-composite vs Carbon Fiber for a UAV structure:

Criteria	Carbon Fiber	Recycled PLA Blend
Weight	Very Low	Low
Cost	High	Very Low
Sustainability	Low	High (biodegradable)
Ease of Processing	Moderate	High
Final Selection	–	✅ Recycled PLA

Their selection was based on biodegradability, reduced manufacturing cost, and adequate stiffness for lightweight drones—citing polymer chemistry to justify processing and degradation properties.

V. DISCUSSION

A. *Efficacy in Fostering a Research Mindset*

The model successfully fostered a research-oriented mindset, evidenced by both quantitative gains in conceptual understanding and qualitative improvements in students' ability to articulate trade-offs and develop creative solutions. The structured design—with iterative mentoring and milestone monitoring—was crucial for guiding students with no prior research experience. Furthermore, the team-based approach promoted peer learning and provided crucial support for developing learners, while embedding the project into the core course ensured equitable participation and academic credibility.

One limitation of this study is the use of an instructor-designed diagnostic quiz that, while aligned with course outcomes and reviewed for content accuracy, was not a validated external instrument. Additionally, the absence of a control group limits causal claims regarding the extent to which learning gains were directly attributable to the RBL intervention. Future studies could strengthen the design by incorporating validated assessment tools or comparing across cohorts where RBL and non-RBL approaches are taught in parallel.

However, the design also highlighted certain limitations. Initial discomfort with open-ended tasks, the reliance on surface-level criteria such as cost, and challenges interpreting graphical data all highlighted the need for more effective preparatory support for the activity. A short pre-module ‘mini-workshop’ that introduced design thinking and research tools would likely effectively address this. Also, faculty expressed a desire to provide individualized feedback and acknowledged that faculty-student ratios and time allotment would be critical variables in running and sustaining such models.

While faculty observations and student artefacts provided converging indications of improved articulation and reasoning, the study did not employ formal triangulation methods. Future iterations will use structured coding, multiple-rater validation, and curated portfolios of student work to enhance robustness.

B. Alignment with NEP 2020 and Global Educational Trends

The model strongly aligns with NEP 2020's vision for holistic, multidisciplinary, and experiential learning by connecting theory to authentic engineering problems. Its emphasis on sustainability and interdisciplinary integration also resonates with global frameworks like CDIO and ABET. The only minor divergence is in assessment; while the project was integrated, the university system still relies heavily on summative exams, whereas NEP 2020 advocates for portfolio-based or competency-based evaluations—a systemic issue requiring institutional transition.

C. Role of Interdisciplinarity and Application of Chemistry

The intervention's major strength was its deliberate use of interdisciplinary knowledge. Students effectively applied their first-year chemistry foundation to justify second-year material selection decisions, from polymer degradation to corrosion mechanisms. This demonstrated the real-world value of connecting chemical theory with mechanical function. The success opens the door to extending RBL into other domains like Thermodynamics and Manufacturing, aligning with NEP's call for interdisciplinary curricula.

D. Faculty Development and Implementation Challenges

Scaling up RBL requires substantial training for faculty on mentoring research, evaluating open-ended problems, and facilitating inquiry without giving everything away. Many faculty are used to structured lectures and standardized evaluations, and transitioning to a facilitator will require specific training and professional development.

Providing faculty with workshops on constructivist pedagogy, using research-inquiry tools (like Ashby charts or SciFinder), and rubric-based assessment for research could see faculty return to the model. Support from the institution in terms of reduced loads during implementation semesters or TA support would be beneficial in engaging faculty more generally.

E. Scalability and Adaptability

The model is highly scalable across similar institutions, particularly those affiliated with centralized curriculum boards like VTU. Its integration into existing coursework makes it low-cost and administratively feasible. However, the model’s success hinges on a few key conditions:

- Balanced student grouping based on academic profiles.
- Structured yet flexible timelines with clear milestones.
- Robust evaluation rubrics that assess both content and process.
- Faculty readiness and institutional encouragement.

The semester-long distribution of tasks demonstrates that the model is feasible without imposing undue time-pressure on students. Because the research assignment replaced rather than supplemented existing assessments, and because milestones prevented last-minute workload accumulation, the model remains practical to scale across institutions with similar semester structures.

To adapt this model across different institutional contexts—such as diploma colleges, autonomous universities, or interdisciplinary campuses—customizations will be needed in topic complexity, duration, and depth of research. Nonetheless, the core philosophy of embedding research into foundational learning remains universally applicable.

VI. Conclusion

- *Effective Transformation* The Research-Based Learning (RBL) model successfully transformed second-year undergraduates into early-stage researchers by integrating research into a core Material Selection course.
- *Development of 21st-Century Skills* The intervention was highly effective in developing critical thinking, interdisciplinary reasoning, collaboration, and communication skills.
- *Practical and Scalable Model* The study proved that research can be integrated into the curriculum without wholesale redesign. The model is adaptable and can be aligned with existing semester structures using staged plans, strategic team formation, and clear rubrics.
- *Demonstrable Student Growth* Evidence of success includes:
    - Significant improvements in student engagement, confidence, and articulation (faculty observations).
    - Increased academic ownership and curiosity (student feedback).
    - Deeper conceptual understanding, as shown by pre- and post-assessment gains.
- *Strong Potential for Expansion* The pilot model shows strong potential for scaling across other engineering courses (e.g., Thermodynamics, Fluid Mechanics) and can be adapted for various institution types, including diploma-level and autonomous universities.
- *Alignment with Educational Policy* The model directly supports the vision of the National Education Policy (NEP) 2020 and aligns with global shifts toward inquiry-based, experiential, and competency-driven education.
- *Ultimate Goal: Future-Ready Engineers* This approach makes a meaningful contribution to producing engineers who are not only knowledgeable

but are also capable of inquiry, innovation, and impactful problem-solving.

References

Ahel, O., & Schirmer, M. (2022). Education for sustainable development through research-based learning in an online environment. International Journal of Sustainability in Higher Education, 24(1), 118–140. https://doi.org/10.1108/IJSHE-07-2021-0305

Al-Maktoumi, A., Al-Ismaily, S., & Kacimov, A. (2016). Research-based learning for undergraduate students in soil and water sciences: A case study of hydropedology in an arid-zone environment. Journal of Geography in Higher Education, 40(3), 321–339. https://doi.org/10.1080/03098265.2016.1140130

Amiri, S. M. H. (2025). Project-Based Learning Pedagogy: Bridging Theory and Practice for Real-World Impact (SSRN Scholarly Paper No. 5333995). Social Science Research Network. https://doi.org/10.2139/ssrn.5333995

Auchincloss, L. C., Laursen, S. L., Branchaw, J. L., Eagan, K., Graham, M., Hanauer, D. I., Lawrie, G., McLinn, C. M., Pelaez, N., Rowland, S., Towns, M., Trautmann, N. M., Varma-Nelson, P., Weston, T. J., & Dolan, E. L. (2014). Assessment of Course-Based Undergraduate Research Experiences: A Meeting Report. CBE—Life Sciences Education, 13(1), 29–40. https://doi.org/10.1187/cbe.14-01-0004

Bowyer, D., & Akpinar, M. (2024). Experiences of academics and undergraduate students on research-based learning: A tale of two institutions. Innovations in Education and Teaching International, 61(1), 45–56. https://doi.org/10.1080/14703297.2022.2149606

Daryanes, F., Zubaidah, S., Mahanal, S., & Sulisetijono. (2025). Building students' research skills in environmental science courses with research team-based learning. Eurasia Journal of Mathematics, Science and Technology Education, 21(1), em2567. https://doi.org/10.29333/ejmste/15893

DeChenne-Peters, S. E., Rakus, J. F., Parente, A. D., Mans, T. L., Eddy, R., Galport, N., Koletar, C., Provost, J. J., Bell, J. E., & Bell, J. K. (2023). Length of course-based undergraduate research experiences (CURE) impacts student learning and attitudinal outcomes: A study of the Malate dehydrogenase CUREs Community (MCC). PLOS ONE, 18(3), e0282170. https://doi.org/10.1371/journal.pone.0282170

Ghannam, R., & Chan, C. (2023). Teaching undergraduate students to think like real-world systems engineers: A technology-based hybrid learning approach. Systems Engineering, 26(6), 728–741. https://doi.org/10.1002/sys.21683

Hassaniyan, A. (2024). Revisiting the debate about teaching-research nexus relevance. Research in Education, 00345237241301919. https://doi.org/10.1177/00345237241301919

Headley, M., & Benson, L. (2024). Literature Review Paper: Exploring Engineering Students Perceptions of Engineering Accreditation. 2024 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC), 1–6. https://doi.org/10.1109/WEEF-GEDC63419.2024.10854967

Hussain, W., Spady, W. G., Khan, S. Z., Khawaja, B. A., Naqash, T., & Conner, L. (2021). Impact Evaluations of Engineering Programs Using ABET Student Outcomes. IEEE Access, 9, 46166–46190. https://doi.org/10.1109/ACCESS.2021.3066921

Lee, G., Chai. (2024). Teaching and Learning for a Sustainable Future: Innovative Strategies and Best Practices: Innovative Strategies and Best Practices. IGI Global.

Li, C., & Li, X. (2025). A systematic review of the teaching-research nexus in language teacher education. System, 129, 103595. https://doi.org/10.1016/j.system.2025.103595

Masbukhin, F. A. A., & Kusmawan, U. (2025). Integrating Digital Technology and Project-Based Learning in Secondary School Chemistry: Innovative Strategies for Conceptual Understanding. JTK (Jurnal Tadris Kimiya), 10(1), Article 1. https://doi.org/10.15575/jtk.v10i1.40828

Merino-Soto, C., Fernández-Arata, M., Fuentes-Balderrama, J., Chans, G. M., & Toledano-Toledano, F. (2022). Research Perceived Competency Scale: A New Psychometric Adaptation for University Students' Research Learning. Sustainability, 14(19), Article 19. https://doi.org/10.3390/su141912036

Muhammad, R., Zahid, M. N., Khan, N. A., Rehman, M. U., Khan, N. B., & Akhtar, U. A. (2021). A comparative analysis of outcome-based and conventional education systems in mechanical engineering program. 2021 Sustainable Leadership and Academic Excellence International Conference (SLAE), 1–6. https://doi.org/10.1109/SLAE54202.2021.9788086

Nand, A. A., Menon, R., Bhattacharya, A., & Bhamra, R. (2022). A review of sustainability trade-offs affecting suppliers in developed and less developed countries. Journal of Business & Industrial Marketing, 38(3), 463–483. https://doi.org/10.1108/JBIM-04-2021-0213

Nguyen, V. H., Halpin, R., & Joy-Thomas, A. R. (2024). Guided inquiry-based learning to enhance student engagement, confidence, and learning. Journal of Dental Education, 88(8), 1040–1047. https://doi.org/10.1002/jdd.13531

Patel, J. (2023). Experiential Learning Pedagogies and Practices. In J. Patel (Ed.), Learning to Live Together Harmoniously: Spiritual Perspectives from Indian Classrooms (pp. 129–153). Springer International Publishing. https://doi.org/10.1007/978-3-031-23539-9_7

Persano Adorno, D., & Pizzolato, N. (2025). Benefits of a physics-driven interdisciplinary final project for mechanical engineering undergraduates. International Journal of Mechanical Engineering Education, 03064190251319413. https://doi.org/10.1177/03064190251319413

Qizi, C. D. O., O'g``li, P. U. X., & Rajabboyovna, K. X. (2024). Incorporating Real-World Applications into Chemistry Curriculum: Enhancing Relevance and Student Engagement. FAN VA TA'LIM INTEGRATSIYASI (INTEGRATION OF SCIENCE AND EDUCATION), 2(1), Article 1.

Ruth, A., Brewis, A., & SturtzSreetharan, C. (2023). Effectiveness of social science research opportunities: A study of course-based undergraduate research experiences (CUREs). Teaching in Higher Education, 28(7), 1484–1502. https://doi.org/10.1080/13562517.2021.1903853

Sapovadia, V. K., & Patel, V. (2025). Know Your Student: Curiosity to Innovation, Mapping the Ecosystem of Education to Enhance Student Engagement, Motivation, and Problem-Solving Skills (SSRN Scholarly Paper No. 5203466). Social Science Research Network. https://doi.org/10.2139/ssrn.5203466

Shakir, S. (2024). Safe Spaces to Discuss Wicked Problems: A Staff and Student Co-Creation Project on Addressing the Awarding Gap. Social Sciences, 13(12), Article 12. https://doi.org/10.3390/socsci13120653

Shayesteh, H. (2025). Integrating the United Nations Sustainable Development Goals into Engineering Education: A Practical Framework for Developing Future Leaders in Sustainability. 2025 IEEE Global Engineering Education Conference (EDUCON), 1–10. https://doi.org/10.1109/EDUCON62633.2025.11016529

Singha, R., & Singha, S. (2024). Application of Experiential, Inquiry-Based, Problem-Based, and Project-Based Learning in Sustainable Education. In Teaching and Learning for a Sustainable Future: Innovative Strategies and Best Practices (pp. 109–128). IGI Global Scientific Publishing. https://doi.org/10.4018/978-1-6684-9859-0.ch006

Snelson, C., Ching, Y.-H., Hsu, Y.-C., Perkins, R., & Alfieri, M. (2024). Gamified online course design: A scoping review of the research. Distance Education, 45(2), 260–280. https://doi.org/10.1080/01587919.2024.2338709

Sukackė, V., Guerra, A. O. P. de C., Ellinger, D., Carlos, V., Petronienė, S., Gaižiūnienė, L., Blanch, S., Marbà-Tallada, A., & Brose, A. (2022). Towards Active Evidence-Based Learning in Engineering Education: A Systematic Literature Review of PBL, PjBL, and CBL. Sustainability, 14(21), Article 21. https://doi.org/10.3390/su142113955

Thiem, J., Preetz, R., & Haberstroh, S. (2023). How research-based learning affects students' self-rated research competences: Evidence from a longitudinal study across disciplines. Studies in Higher Education, 48(7), 1039–1051. https://doi.org/10.1080/03075079.2023.2181326

Yang, L., Ni, H., & Zhu, Y. (2025). Data-Driven Mental Health Assessment of College Students Using ES-ANN and LOF Algorithms During Public Health Events. Informatica, 49(13), Article 13. https://doi.org/10.31449/inf.v49i13.7388

Yang, Y., Chan, C. K. K., Zhu, G., Tong, Y., & Sun, D. (2024). Reflective assessment using analytics and artifacts for scaffolding knowledge building competencies among undergraduate students. International Journal of Computer-Supported Collaborative Learning, 19(2), 231–272. https://doi.org/10.1007/s11412-024-09421-8