

A Gamified, Level-Based Framework for Guiding Experimental Innovation in Sustainable Cementitious and Concrete Materials

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ABSTRACT

This study presents the development and evaluation of a Gamified Research Scaffolding Framework (GRSF) designed to enhance undergraduate competency in experimental research proposal development within cementitious and concrete materials courses. Students in construction-related programmes often face challenges in structuring research problems, justifying material selection, and aligning experimental design with research objectives, leading to weak proposals and repeated revision cycles. To address these challenges, the GRSF integrates gamification principles with structured instructional scaffolding through a six-level progression model, encompassing problem discovery, material selection, aim and objective development, experimental design, sustainability evaluation, and proposal assembly. Laboratory activities are embedded as mission-based tasks to reinforce hands-on learning and alignment with standardised testing procedures. The framework also incorporates sustainability assessment in line with Education for Sustainable Development (ESD) and promotes responsible use of artificial intelligence tools. A mixed-method approach was employed using a quasi-experimental design involving two undergraduate classes: a control group ($n = 25$) following conventional supervision and an intervention group ($n = 27$) exposed to the GRSF. Quantitative data included proposal scores, revision cycles, and approval rates, while qualitative data were collected through student surveys, feedback, and lecturer observations. The results indicate a significant improvement in proposal quality (26.1%), a reduction in revision cycles (42.2%), and a substantial increase in first-submission approval rates (from 40% to 81%) for the intervention group. Student engagement was also high (mean = 4.50/5), indicating improved motivation and confidence. The findings demonstrate that the GRSF provides a structured and effective approach to enhancing research competency, laboratory engagement, and sustainability awareness in engineering education.

Keywords: gamification, research scaffolding, concrete materials; laboratory-based learning, engineering education, sustainability, education for sustainable development

INTRODUCTION

The inclusion of laboratory-based learning in Advanced Concrete Technology courses plays a critical role in developing students' practical competencies in material behaviour, testing procedures, and experimental validation. In engineering and built environment education, hands-on laboratory experience is essential for bridging the gap between theoretical knowledge and real-world application. Through structured experimental activities, students gain direct exposure to material properties, mix design processes, and performance evaluation, thereby enhancing their technical skills, critical thinking, and problem-solving capabilities required for professional practice.

In the context of cementitious and concrete materials, laboratory work is particularly significant due to the complex interactions between material composition, environmental conditions, and performance outcomes. Understanding key properties such as workability, strength development, durability, and permeability requires not only theoretical knowledge but also experiential learning through controlled experimentation. Consequently, laboratory-based instruction is fundamental in preparing students to design, execute, and

interpret material tests in accordance with recognised standards. In recent years, higher education institutions have been guided by accreditation bodies such as the Malaysian Qualifications Agency to embed Value-Based Education (VBE) and Education for Sustainable Development (ESD) within curriculum design. VBE emphasises the cultivation of ethical awareness, professional responsibility, and value-driven decision-making, while ESD focuses on equipping students with the knowledge and competencies required to address global sustainability challenges, including environmental protection, resource efficiency, and climate resilience. Within Advanced Concrete Technology, the integration of ESD is particularly critical due to the significant environmental impact of conventional concrete production. Ordinary Portland Cement (OPC) is a major contributor to global carbon emissions, while the extraction of natural aggregates leads to resource depletion and ecological degradation (Jalal, Srivastava, & Tiwari, 2025). As a result, students must be equipped not only with knowledge of conventional materials but also with the ability to develop and evaluate sustainable alternatives, such as supplementary cementitious materials, recycled aggregates, and low-carbon binders.

Embedding ESD within laboratory-based learning enables students to critically assess the environmental implications of material selection and production processes. Laboratory investigations can be designed to evaluate the performance of sustainable materials, analyse durability and long-term behaviour, and compare environmental benefits alongside mechanical performance. This approach promotes sustainability as an integral component of engineering decision-making rather than an optional consideration. Furthermore, the integration of VBE within laboratory activities reinforces ethical responsibility in material innovation. Students are encouraged to consider broader societal and environmental impacts, including safety, sustainability, and responsible resource utilisation. This aligns with the development of competent and responsible engineers capable of balancing technical performance with ethical and environmental considerations (Bello & Maladzi, 2025). Despite its importance, traditional laboratory instruction often emphasises procedural execution rather than conceptual understanding and sustainability integration. Students frequently conduct experiments without fully understanding the rationale behind material selection, the linkage to research objectives, or the broader environmental implications. This limitation highlights the need for structured pedagogical approaches that integrate experimental learning with sustainability and value-based education principles (Galt, Clark, & Parr, 2012).

In parallel, the increasing demand for sustainable construction and low-carbon material systems has intensified the need for graduates capable of developing experimentally validated innovations in cementitious and concrete materials. However, despite exposure to advanced materials content, undergraduate students often struggle to translate theoretical knowledge into structured and coherent experimental research proposals. Common issues include vague problem statements, unsupported material selection, poorly defined objectives, and misalignment between research aims and laboratory methodology. These deficiencies frequently result in repeated revision cycles, delayed project progression, and reduced student confidence.

Traditional supervision approaches, which rely heavily on iterative feedback after proposal submission, may not provide sufficient cognitive scaffolding to guide novice researchers through the complexities of experimental planning. While gamification has been recognised as an effective strategy to enhance engagement and motivation, its application in engineering education has largely been limited to assessment activities rather than structured research development processes (Díaz-Ramírez, 2020). To address these challenges, this study proposes the Gamified Research Scaffolding Framework (GRSF), a structured, level-based approach that transforms research proposal development into a progressive, mastery-oriented learning process. The framework comprises six competency levels, namely problem discovery, material selection, aim and objective development, experimental design planning, sustainability evaluation, and proposal assembly. Advancement through each level requires evidence-based justification and lecturer verification, ensuring constructive alignment and quality control.

By integrating structured templates, laboratory-based learning, sustainability evaluation, and guided ethical Artificial Intelligent (AI) usage within a gamified progression model, the framework aims to enhance both cognitive and practical competencies. This study evaluates the effectiveness of the proposed framework using a design-based research approach and quasi-experimental comparison between control and intervention cohorts. The findings contribute to the advancement of structured research pedagogy in engineering and built environment education, particularly in the context of sustainability-oriented concrete materials innovation.

LITERATURE REVIEW

Gamification, defined as the application of game design elements in non-game contexts, has emerged as a prominent pedagogical strategy to enhance student motivation, engagement, and learning outcomes in higher education (Rivera & Garden, 2021). In educational settings, gamification integrates elements such as points, levels, badges, and leaderboards into instructional design to create interactive and learner-centred environments (Øvensen, Scholz, Andersen, & Prinz, 2025). These elements are intended to stimulate intrinsic motivation by fostering a sense of autonomy, competence, and relatedness among learners.

Recent large-scale reviews indicate that gamification is increasingly adopted across science, technology, engineering, and mathematics (STEM) education as a response to limitations in traditional lecture-based teaching approaches. Empirical studies consistently demonstrate that gamified learning environments can enhance student engagement, participation, and persistence, particularly when aligned with clear pedagogical objectives (Tsay, Kofinas, & Luo, 2018). Furthermore, gamification has been shown to improve problem-solving skills and promote active learning by encouraging students to engage in iterative and goal-oriented tasks (Meylani, 2025). However, the effectiveness of gamification is highly dependent on its design and implementation. While some studies (Khaleghi, Aghaei, & Mahdavi, 2021; Lumsden, Edwards, Lawrence, Coyle, & Munafò, 2016) report improved performance in practical and applied tasks, others (Vermeir, White, Johnson, Crombez, & Van Ryckeghem, 2020) highlight mixed results in cognitive outcomes, suggesting that poorly designed gamification may lead to superficial engagement or cognitive overload. Therefore, current research emphasises the importance of integrating gamification with sound pedagogical frameworks, such as scaffolding and constructivist learning, to ensure meaningful learning outcomes.

Gamification has gained significant attention in engineering education due to its potential to address challenges related to student engagement, abstract concept understanding, and skill development (Ortiz-Rojas, Chiluiza, & Valcke, 2019; Zubair, Khan, Hassan, Ahmed, & Aziz, 2024). Studies in engineering programmes indicate that gamification can enhance motivation, participation, and sustained interaction with learning materials, particularly in complex and technical subjects. In addition, gamification supports the development of higher-order thinking skills by encouraging students to engage in problem-based and project-based learning environments (Riwayatiningasih et al., 2025). The use of structured progression systems and feedback mechanisms has been shown to promote continuous learning and self-regulated behaviour among engineering students. Research (Li, Ma, & Shi, 2023) also highlights that gamification is most effective when aligned with specific learning outcomes and when integrated into the overall instructional design rather than applied as an isolated activity. Nevertheless, the literature (Bai, Xu, Ailikamujiang, & Sun, 2024) also identifies limitations, including the need for careful design to avoid overemphasis on competition and reward systems. Poorly structured gamification may reduce intrinsic motivation or fail to support deep learning (Chen & Wang, 2025). Consequently, recent studies (Khalil) advocate for competency-based gamification models, where progression is linked to mastery of knowledge and skills rather than accumulation of points or rewards.

Laboratory-based learning is a critical component of engineering and built environment education, as it provides opportunities for students to develop practical skills, validate theoretical concepts, and engage in experiential learning. The integration of gamification into laboratory environments has been shown to enhance both technical competency and student engagement. Empirical studies indicate that gamified laboratory activities positively influence students' motivation, engagement, and learning outcomes (Kim, Rothrock, & Freivalds, 2018). For instance, research in engineering laboratory settings demonstrated that the incorporation of game elements such as badges, levels, and leaderboards significantly improved student participation and satisfaction (Sánchez-Carmona, Robles, & Pons, 2017), with a majority of students reporting increased motivation due to ranking and scoring systems. Similarly, studies on "game labs" and educational escape rooms have shown that gamification can improve conceptual understanding, practical skills, and independent learning behaviours in laboratory environments (Abdullah & Juhana, 2025).

Gamified laboratory environments also support active and collaborative learning. By framing laboratory tasks as missions or challenges, students are encouraged to engage more deeply with experimental procedures, data analysis, and problem-solving processes (Deniz, Victor, Dirk, Xun, & Raymond, 2014). This approach aligns

with experiential learning theory, where knowledge is constructed through direct interaction with materials and processes.

However, the literature (Fleischman & Ariel, 2016) emphasises that the effectiveness of gamified laboratory learning depends on the alignment between game mechanics and learning objectives. Gamification should enhance, rather than distract from, experimental learning. Therefore, structured frameworks that integrate laboratory activities with clearly defined research goals and assessment criteria are essential for achieving meaningful learning outcomes.

METHODOLOGY

Research Design

This study employed a design-based research approach combined with a quasi-experimental design to develop and evaluate the effectiveness of the GRSF in enhancing students' competency in experimental research proposal development. The design-based research approach enabled the systematic design, implementation, and refinement of the framework within an authentic classroom environment, while the quasi-experimental design facilitated comparison between a control and an intervention group.

Participants and Context

The study involved two intact undergraduate classes enrolled in the Advanced Concrete Technology (DCT573) course in the Bachelor of Science in Construction Technology programme at the Faculty of Built Environment, Universiti Teknologi MARA (UiTM) Perak Branch. A total of 52 students participated in the study, comprising 25 students in Class A and 27 students in Class B. Class A served as the control group and followed the conventional supervision-based approach to proposal development, while Class B served as the intervention group and was exposed to the GRSF. Both classes were at a comparable academic level and had prior foundational knowledge in concrete materials and construction technology. To ensure comparability, both groups were evaluated using the same course outcomes, assessment rubric, and proposal evaluation criteria.

Game Design and Assessment

The implementation of gamification within the GRSF was designed to enhance student engagement while maintaining academic rigor and alignment with structured research development. Rather than applying gamification as a superficial motivational tool, the framework integrates game design elements into the pedagogical process to support competency-based progression in experimental proposal development. Gamification was operationalised through a level-based progression system, in which each level corresponds to a specific research competency. Students progressed sequentially through six structured levels, namely problem discovery, material selection, research aim and objective formulation, experimental design, sustainability evaluation, and proposal assembly. Advancement between levels was contingent upon the completion of defined tasks and lecturer validation, ensuring that students demonstrated mastery before proceeding. This progression mechanism functioned as a quality control system, preventing the accumulation of conceptual and methodological errors.

To reinforce engagement, each level incorporated clearly defined learning missions, where students were required to complete structured tasks such as developing a problem statement canvas, constructing a material justification matrix, and designing an experimental testing plan. These missions were supported by guided worksheets, literature-based evidence requirements, and AI-assisted prompts for idea refinement. The integration of such structured tasks ensured that gamification remained aligned with learning objectives rather than focusing solely on entertainment. In addition to progression-based mechanics, achievement recognition elements were incorporated through milestone-based badges awarded upon successful completion of each level. These badges served as indicators of competency attainment, promoting a sense of accomplishment and ownership of learning. While optional leaderboard elements were introduced to encourage peer benchmarking, particularly in sustainability evaluation and proposal quality, the framework prioritised mastery and progression over competition to maintain intrinsic motivation.

Gamification was further extended into laboratory-based activities, where experimental tasks were framed as mission objectives. Students were required to execute laboratory procedures, including specimen preparation and standardised testing, in accordance with their approved experimental design. Completion of laboratory missions contributed to overall progression within the framework and reinforced the linkage between theoretical planning and practical implementation. To ensure academic integrity, the framework incorporated a guided AI usage protocol, requiring students to declare and justify the use of AI tools in their research development. This approach promotes responsible digital literacy while leveraging AI as a cognitive support tool for literature synthesis and idea generation.

Overall, the implementation of gamification within the GRSF is characterised by the integration of structured progression, mastery-based advancement, and competency-driven assessment. This approach transforms research proposal development from a passive, feedback-driven process into an active, iterative, and student-centred learning experience, thereby enhancing both engagement and academic performance.

Framework Development

The GRSF was developed through a structured, multi-stage process to address identified deficiencies in students' experimental research proposal development within cementitious and concrete materials courses. The development process comprised three key stages: diagnostic analysis, framework design, and constructive alignment.

Diagnostic Analysis

An initial diagnostic analysis was conducted to identify recurring weaknesses in student research proposals from previous cohorts enrolled in the Advanced Concrete Technology course. This analysis involved a systematic review of submitted proposals, lecturer feedback records, and assessment outcomes over two academic sessions. The findings revealed several critical deficiencies. First, students frequently demonstrated unclear and poorly structured problem statements, often presenting general sustainability issues without defining specific, researchable technical problems. Second, material selection lacked scientific justification, with students selecting materials based on perceived sustainability trends rather than evidence from peer-reviewed literature. Third, there was a notable misalignment between research aims, objectives, and experimental methodology, resulting in inconsistent or irrelevant testing procedures. Fourth, students exhibited difficulty in designing feasible experimental plans, including inappropriate mix proportions, unrealistic specimen quantities, and incorrect selection of testing standards.

In addition, it was observed that many students approached laboratory work as a procedural requirement rather than a research-driven activity. This resulted in limited understanding of the relationship between experimental outcomes and research objectives. These issues contributed to multiple revision cycles, delayed proposal approval, and reduced student confidence in conducting experimental research. The diagnostic analysis therefore highlighted the need for a structured pedagogical framework that could guide students systematically from problem identification to experimental design while ensuring alignment with sustainability and research objectives.

Framework Design

Based on the identified gaps, a six-level gamified research scaffolding framework was developed to support progressive and competency-based learning. The framework was designed to transform the conventional linear proposal development process into a structured, level-based progression model.

The six levels are defined as follows:

1. **Problem Discovery** – Students identify a sustainability-related issue in construction and develop a structured problem statement supported by literature and industry evidence.
2. **Material Selection** – Students justify the selection of binders and sustainable materials using peer-reviewed research and decision matrices.

3. Research Aim and Objectives Development – Students formulate a clear, measurable research aim and aligned objectives.
4. Experimental Design – Students develop a detailed mix design matrix, specimen plan, and testing methodology in accordance with recognised standards such as ASTM, BS EN, or Malaysian Standards.
5. Sustainability Evaluation – Students assess the environmental impact of their proposed materials using criteria such as waste utilisation, carbon reduction potential, and feasibility.
6. Proposal Assembly – Students integrate all validated components into a comprehensive and structured research proposal.

Each level is supported by structured worksheets, guided prompts, and evidence requirements to ensure systematic development of research competencies. Progression through the framework is controlled through an unlocking mechanism, whereby students must obtain lecturer verification before advancing to the next level. This ensures mastery of each stage and prevents the accumulation of conceptual and methodological errors. The framework also incorporates gamification elements such as milestone-based progression, achievement recognition, and optional peer benchmarking to enhance student engagement. However, the design prioritises academic rigor and competency development over competitive elements.

Constructive Alignment with CLO, PLO, and ESD

The GRSF was constructively aligned with Course Learning Outcomes (CLOs), Programme Learning Outcomes (PLOs), and Education for Sustainable Development (ESD) principles to ensure coherence between instructional design, learning activities, and assessment. At the course level, the framework supports CLOs related to:

- Understanding material properties and performance (cognitive domain)
- Conducting experimental testing and analysis (psychomotor domain)
- Demonstrating sustainability awareness and ethical responsibility (affective domain)

At the programme level, the framework contributes to PLOs associated with problem-solving, technical competency, teamwork, communication, and sustainability integration. The structured progression ensures that each level develops specific competencies aligned with these outcomes. In addition, the integration of ESD principles is embedded throughout the framework, particularly in material selection and sustainability evaluation stages. Students are required to consider environmental impact, resource efficiency, and long-term performance in their decision-making processes. This aligns with the broader goal of developing graduates who are capable of addressing sustainability challenges within the construction industry.

The framework also supports VBE by encouraging ethical consideration of material usage, safety, and environmental responsibility. Through the combination of technical and value-based competencies, the GRSF ensures a holistic approach to engineering education.

Laboratory Integration

Laboratory activities were systematically integrated into the GRSF as structured “mission-based” tasks to reinforce the linkage between theoretical proposal development and practical experimental execution. Rather than treating laboratory sessions as isolated procedural exercises, each experimental activity was aligned with specific research objectives defined in the earlier stages of the framework. This approach ensured that laboratory work functioned as an extension of the research development process, enabling students to validate their proposed materials and methodologies through hands-on experimentation.

Within the framework, laboratory exercises were primarily implemented during the experimental design and proposal implementation stages. Students were required to prepare concrete or mortar specimens based on

their proposed mix designs and to conduct standardised tests in accordance with recognised testing standards, including ASTM, BS EN, and Malaysian Standards. These tests included, but were not limited to, compressive strength, flexural strength, workability, and durability-related assessments. The use of standardised procedures ensured the reliability and validity of experimental outcomes while familiarising students with industry-relevant testing practices. The mission-based structure required students to complete laboratory tasks sequentially, with each completed task contributing to their progression within the framework. Students were also required to document experimental procedures, record data systematically, and interpret results in relation to their research objectives. This reinforced the alignment between experimental work and research inquiry, addressing a common issue in undergraduate laboratory learning where activities are conducted without clear conceptual linkage.

Furthermore, laboratory integration promoted experiential learning by providing students with opportunities to engage directly with materials, observe real-time performance behaviour, and reflect on discrepancies between expected and actual outcomes. This hands-on approach enhanced students' psychomotor skills, technical competency, and analytical ability, while also fostering collaborative learning through group-based experimentation.

Data Collection

A mixed-method approach was employed to evaluate the effectiveness of the GRSF in improving students' research competency and engagement. Data collection comprised both quantitative and qualitative measures to provide a comprehensive assessment of learning outcomes.

Quantitative data were obtained from proposal quality scores, number of revision cycles required for approval, and first-submission approval rates. Proposal quality was assessed using a structured rubric that evaluated key components, including clarity of problem formulation, identification of research gap, justification of material selection, alignment between objectives and methodology, feasibility of experimental design, and integration of sustainability considerations. The number of revision cycles was recorded as an indicator of proposal clarity and coherence, while first-submission approval rates were used to measure the effectiveness of the framework in supporting early-stage mastery.

Qualitative data were collected through student perception surveys, open-ended feedback responses, and lecturer observational reflections. The survey instrument employed a Likert-scale format to assess students' perceived clarity in research development, confidence in experimental planning, level of engagement, and awareness of responsible AI usage. Open-ended responses provided additional insights into students' learning experiences, challenges, and perceived benefits of the framework. Lecturer observations were documented throughout the implementation period, focusing on student participation, independence, collaboration, and overall engagement during both classroom and laboratory activities.

Data Analysis

Quantitative data were analysed using descriptive and inferential statistical methods. Descriptive statistics, including mean and standard deviation, were calculated to summarise proposal performance, revision cycles, and approval rates for both control and intervention cohorts. To determine the significance of differences between groups, independent and paired sample t-tests were conducted where appropriate. These analyses enabled the identification of statistically significant improvements in student performance following the implementation of the GRSF.

Qualitative data were analysed using thematic analysis to identify recurring patterns and key themes in student feedback and lecturer observations. Responses from open-ended survey questions were coded and categorised into themes related to cognitive development, engagement, structured learning, and research confidence. Lecturer observations were triangulated with student responses to enhance the validity of the findings.

The combination of quantitative and qualitative analysis provided a comprehensive evaluation of the framework, capturing not only measurable performance improvements but also changes in student behaviour, perception, and learning experience.

RESULTS

Proposal Score Improvement

A comparative analysis was conducted to evaluate the effect of the GRSF on students' proposal development performance. Table 1 presents the descriptive statistics for both the control and intervention cohorts.

Table 1 Comparison of proposal quality scores

Group	n	Mean Score	Standard Deviation
Class A (Control)	25	66.40	5.20
Class B (Intervention)	27	83.75	4.10

The results indicate a substantial improvement in proposal quality among students exposed to the GRSF. The intervention group achieved a mean score of 83.75, compared to 66.40 in the control group, representing an improvement of approximately 26.1%. This increase suggests that the structured, level-based scaffolding approach effectively enhanced students' ability to develop coherent and well-aligned research proposals. Specifically, students in the intervention group demonstrated improved clarity in problem formulation, stronger evidence-based justification of material selection, and more consistent alignment between research objectives and experimental methodology.

In addition to the increase in mean scores, the lower standard deviation observed in Class B (SD = 4.10) compared to Class A (SD = 5.20) indicates reduced variability in student performance. This suggests that the framework not only improved overall performance but also contributed to greater consistency across students, including those with moderate academic ability. Such an outcome is indicative of effective instructional scaffolding, where structured guidance supports a wider range of learners in achieving desired competencies. To further examine the significance of the observed difference, an independent samples t-test was conducted, which indicated a statistically significant difference between the two groups ($p < 0.001$). This confirms that the improvement in proposal scores is unlikely to be due to chance and can be attributed to the implementation of the GRSF.

From a pedagogical perspective, the improvement in proposal quality can be linked to the framework's emphasis on progressive validation and mastery-based learning. By requiring students to complete and validate each stage of the research process before progressing, the framework reduces conceptual gaps and ensures stronger integration of research components. This structured approach contrasts with traditional supervision models, where feedback is often provided after full proposal submission, leading to fragmented development and repeated revisions.

Revision Reduction

The number of proposal revision cycles required prior to approval was analysed as an indicator of proposal clarity, structural coherence, and alignment between research components are presented in Table 2. A lower number of revision cycles reflects a higher level of initial proposal quality and a more effective research development process.

Table 2 Comparison of revision cycles

Group	Mean Revision Cycles
Class A (Control)	3.20
Class B (Intervention)	1.85

The results indicate that students in the intervention group required significantly fewer revisions compared to the control group. The reduction from 3.20 to 1.85 revision cycles represents a 42.2% decrease, demonstrating a substantial improvement in the quality of initial proposal submissions. This finding suggests that students exposed to the GRSF were able to produce more structured, coherent, and complete proposals at an earlier stage of development. The staged progression model, coupled with lecturer validation at each level, likely contributed to this improvement by enforcing incremental mastery of research components. Students were required to validate problem statements, material selection, and experimental design before proceeding, thereby preventing the accumulation of conceptual and methodological errors.

In contrast, students in the control group followed a traditional supervision approach, where feedback is typically provided after full proposal submission. This often results in multiple revision cycles, as fundamental issues—such as unclear research gaps or misaligned methodologies—are identified at later stages. The higher number of revisions observed in Class A reflects this reactive correction process. From a pedagogical perspective, the reduction in revision cycles highlights the effectiveness of scaffolding and mastery-based learning principles embedded within the GRSF. By breaking down the research process into manageable stages and requiring validation at each step, the framework reduces cognitive overload and promotes structured thinking. Additionally, this outcome has practical implications for instructional efficiency, as fewer revision cycles reduce lecturer workload and allow more time for higher-level feedback and discussion.

First Submission Approval Rate

The first-submission approval rate was analysed as a measure of research readiness and the overall completeness of student proposals at the initial evaluation stage (see Table 3). A higher approval rate indicates that students have successfully integrated key research components, including problem definition, objective formulation, and experimental design.

Table 3 First submission approval rate

Group	Approval Rate (%)
Class A (Control)	40%
Class B (Intervention)	81%

The results show a significant increase in approval rates for the intervention group, with Class B achieving an approval rate of 81%, compared to 40% for Class A. This represents more than a twofold increase, indicating a marked improvement in students' ability to produce complete and acceptable proposals at the first submission.

This substantial improvement can be attributed to the structured progression mechanism within the GRSF. The requirement for lecturer validation at each level ensures that students achieve a minimum competency threshold before advancing, thereby improving the overall coherence and completeness of the final proposal. As a result, students in the intervention group demonstrated stronger alignment between problem statements, research objectives, and experimental methodology. Furthermore, the high approval rate reflects the effectiveness of the framework in promoting early-stage mastery of research skills. Students were not only able to identify relevant research problems but also justify material selection and design feasible experimental plans. This contrasts with the control group, where incomplete integration of research components often necessitated further revision.

The improvement in approval rates also indicates enhanced student confidence and preparedness. By the time students reached the final proposal stage, most critical issues had already been addressed through the structured levels, reducing uncertainty and increasing the likelihood of approval. From an instructional perspective, this outcome demonstrates the potential of the GRSF to streamline the proposal evaluation process and improve overall course efficiency.

Student Engagement Results

Student engagement and perception were evaluated using a 5-point Likert scale survey administered to the intervention group (Class B). The survey assessed students' perceived clarity in research development, confidence in experimental planning, level of engagement, and motivation resulting from the gamified framework. Table 4 present the student engagement survey results.

Table 4 Student engagement survey results

Item	Mean Score	Standard Deviation
Clarity in research development	4.55	0.52
Confidence in experimental planning	4.38	0.60
Understanding of material selection	4.44	0.57
Engagement compared to traditional method	4.63	0.49
Motivation through gamification	4.58	0.55
Awareness of responsible AI usage	4.40	0.62

The overall mean engagement score was 4.50, indicating a high level of positive student perception towards the framework. All measured items recorded mean values above 4.30, suggesting strong agreement among students regarding the effectiveness of the GRSF. The highest-rated item, "Engagement compared to traditional method" ($M = 4.63$), highlights the significant impact of the gamified structure on student participation and motivation. This suggests that the level-based progression and mission-oriented tasks successfully transformed the learning experience into a more interactive and engaging process.

In addition, students reported high levels of clarity in research development ($M = 4.55$), indicating that the framework effectively supported structured thinking and reduced ambiguity in the proposal development process. Confidence in experimental planning ($M = 4.38$) and understanding of material selection ($M = 4.44$) further suggest that students were better able to align theoretical knowledge with practical application. The relatively low standard deviation values across all items indicate consistent responses among students, suggesting that the framework was effective across different ability levels. Moreover, the high rating for awareness of responsible AI usage ($M = 4.40$) reflects the successful integration of ethical digital practices within the learning process.

Overall, the engagement results demonstrate that the GRSF not only improves cognitive outcomes but also enhances affective and motivational aspects of learning. The combination of structured scaffolding and gamification appears to foster a more active, confident, and self-regulated learning environment.

Qualitative Insights from Student Feedback

In addition to quantitative survey results, qualitative feedback from students provided deeper insights into their learning experience with the GRSF. Thematic analysis of open-ended responses revealed several key themes.

Structured learning and clarity

Many students highlighted that the level-based structure helped them better understand the research process. *"The levels help me understand step by step what to do. Before this, I was confused how to start my proposal."*

Improved confidence in research development

Students reported increased confidence in developing experimental plans.

“I feel more confident because we already check each part before going to the next level.”

Enhanced engagement and motivation

The gamified elements contributed to a more engaging learning experience.

“It feels like completing missions instead of doing assignments. It makes us more motivated.”

Better understanding of material selection

Students appreciated the emphasis on evidence-based decision-making.

“Before this I just choose material, now I need to justify using journals.”

Lecturer observations further supported these findings, noting improved student participation, reduced dependency on lecturer guidance, and more structured discussion during supervision sessions.

DISCUSSIONS

The findings of this study demonstrate that the GRSF significantly enhances students’ performance, engagement, and research competency within cementitious material innovation courses. The improvements observed across multiple indicators, including proposal quality, revision cycles, approval rates, and engagement levels, provide converging evidence of the framework’s effectiveness. The substantial increase in proposal scores can be attributed to the structured scaffolding embedded within the framework. By requiring students to complete each research component sequentially, the GRSF ensures that foundational elements—such as problem identification, research gap articulation, and material justification—are well established prior to the development of experimental design. This staged progression reflects principles of instructional scaffolding, where complex tasks are decomposed into manageable components, thereby reducing cognitive overload and enabling more effective knowledge construction.

The marked reduction in revision cycles further highlights the effectiveness of the framework’s mastery-based progression mechanism. In contrast to traditional supervision approaches, where feedback is typically provided after full proposal submission, the GRSF facilitates early-stage validation through lecturer checkpoints at each level. This proactive approach enables the identification and correction of conceptual and methodological errors at an earlier stage, preventing the accumulation of issues that would otherwise require multiple revisions. As a result, students demonstrate improved clarity, coherence, and completeness in their initial submissions. Similarly, the significant increase in first-submission approval rates indicates enhanced research alignment and readiness. Students in the intervention group were better able to integrate key components of the research process, including problem statements, objectives, and experimental methodologies. This is particularly important in laboratory-based courses, where poorly structured proposals can lead to inefficient use of laboratory time, material waste, and compromised experimental outcomes (Wasitoh, Ismaya, & Suryaman, 2025). The GRSF therefore contributes not only to academic performance but also to more effective utilisation of laboratory resources.

From an engagement perspective, the high Likert-scale scores and consistent qualitative feedback suggest that the gamified structure positively influenced students’ motivation and confidence. The transformation of research tasks into level-based missions provided clear goals and incremental achievements, which supported self-regulated learning behaviour (Maragañas & Dioso, 2025). Students were able to monitor their progress, manage their learning pace, and develop greater ownership of the research process. This aligns with contemporary learning theories that emphasise active engagement and learner autonomy as key drivers of effective learning. These findings are further supported by qualitative evidence, where students reported improved clarity, confidence, and motivation when engaging with the level-based structure of the framework. Furthermore, the integration of sustainability evaluation within the framework ensured that students considered environmental impact alongside technical performance. By embedding sustainability assessment into material selection and experimental design, the GRSF aligns with the principles of ESD. This approach encourages

students to adopt a more holistic perspective on engineering decision-making, considering not only mechanical performance but also resource efficiency, carbon impact, and long-term sustainability. In doing so, the framework contributes to the development of responsible and sustainability-conscious engineering graduates.

Overall, the findings suggest that the GRSF provides a structured and pedagogically grounded solution to common challenges in experimental research training. By integrating gamification, instructional scaffolding, laboratory-based learning, and sustainability considerations, the framework enhances both academic performance and the overall learning experience. The results highlight the potential of structured, competency-based gamification approaches to transform traditional supervision models into more effective, student-centred learning systems.

Despite these strengths, the study is limited by its scope, as it involved two intact classes ($n = 52$) within a single institution. Therefore, the findings should be interpreted within this specific educational context rather than as broadly generalisable outcomes. Nevertheless, the use of a quasi-experimental design combined with multiple data sources—including performance metrics, revision cycles, approval rates, and qualitative feedback—provides a robust and triangulated evaluation of the framework. Future studies involving larger samples across multiple institutions and disciplines are recommended to further validate and extend the applicability of the findings.

CONCLUSION

This study examined the effectiveness of the GRSF in enhancing students' competency in experimental research proposal development within an Advanced Concrete Technology course. The findings indicate that integrating gamification with structured scaffolding and laboratory-based learning significantly improves both academic performance and student engagement.

Students in the intervention group demonstrated substantial improvements across key performance indicators, including proposal quality, revision cycles, and first-submission approval rates. The observed reduction in revision cycles and increase in approval rates suggest that the framework effectively promotes early-stage mastery and improves coherence in research development. In addition, high engagement scores, supported by qualitative feedback, indicate that the gamified structure enhances motivation, confidence, and self-regulated learning behaviour.

The integration of laboratory activities as mission-based tasks further strengthened the alignment between theoretical knowledge and practical application, enabling students to develop hands-on skills and experimental competency. Furthermore, the incorporation of sustainability evaluation within the framework ensured that students considered environmental impact alongside technical performance, thereby supporting the principles of ESD and VBE.

Despite these positive outcomes, the study is limited by its scope, as it involved two intact cohorts within a single institution. Consequently, the findings should be interpreted within this specific educational context. Future research is recommended to validate the framework across larger samples, multiple institutions, and diverse engineering disciplines to enhance its generalisability.

In addition, this study focused primarily on the proposal development phase as a foundational component of experimental research competency. While the results demonstrate significant improvements in proposal quality and readiness, the impact of the framework on the subsequent execution of laboratory experiments was not examined. Future studies should adopt a longitudinal approach to evaluate how the framework influences experimental implementation, data interpretation, and overall research outcomes. Further investigation into the development of a dedicated digital platform to support automated progression, feedback, and AI-assisted learning is also recommended to enhance the scalability and efficiency of the framework.

In conclusion, the GRSF offers a practical, structured, and scalable pedagogical approach to improving research readiness and sustainable material innovation in engineering education. By transforming traditional

supervision into a guided, competency-based learning process, the framework contributes meaningfully to the advancement of teaching and learning practices in the built environment discipline.

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