ENHANCING PROBLEM-SOLVING SKILLS IN ENGINEERING STUDENTS THROUGH COMPUTATIONAL AND EXPERIMENTAL LEARNING

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Abstract: In the past few years, due to high demands of the industry and the rapid development of technology, engineering graduates have been required to be strong in solving problems. Conventional pedagogical approaches that are grounded on theory generally lack the capacity to adequately train higher-order critical thinking skills of students. This paper examines the success of the combination of computational and experimental learning methods in order to improve problem-solving abilities of undergraduate engineering students. A mixed-method type of research design was used to support quantitative analysis of the performances with qualitative accounts of both students and instructors. The intervention itself consisted of taking simulation-based computing-aided tools and concrete laboratory experiments in the case of core engineering courses. The improvement of problem-solving competency was measured by a pre-and post- streak and the amount of improvement that was measured was ranked as considerable acceptable or deplorable by use of statistics. The results demonstrated a quantifiable improvement in the skills of students to transfer theoretical knowledge applications into real life settings, create resolutions to challenging issues and repeat testing and adjustment. The qualitative responses confirmed the quantitative results with responses of greater engagement, greater conceptual acumen, and more confidence. The paper concludes that an integrated use of both computational and experimental learning methods can have a substantial positive impact on problem solving skills and suggest the method should be adopted into scientific programs.

Keywords: Problem-solving skills; Engineering education, Computational learning, Experimental learning, Simulation tools, Hands-on laboratory, Curriculum innovation, Higher-order thinking

I. INTRODUCTION

The current dynamic environment in the sphere of science and technology has exacted a huge responsibility on graduates in engineering who now need a highly developed capacity to solve problems that are complex, technical and challenging in the real world. A majority of the traditional classroom experiences in many engineering schools are largely process-oriented with a lean towards theory classes and memorisation that are largely taught using lecture-based methodology and classical problems that typically have minimal flexibility with creative thinking or practical experimentation. Consequently, learners often have the problem of transferring theory into practice and developing out-of-the-box solutions to Ambiguous or new-problem situations. This gap is becoming of utmost importance in view of the pressures of an increasingly competitive world and high expectations that the industry holds of the higher ed institutions. Since the understanding that better learning experiences are those actively engaging the student in building knowledge has become widely accepted among educational researchers, it is no wonder that the same is also widely understood in the educational technology and multimedia education fields of endeavour as well. As such, there is wide exploration of the incorporation of learning through computations and experimentation into engineering programs as a way of enhancing their problem solving skills. Computational learning entails the use of digital media, simulations, modeling, computer-aided design (CAD) and other such tools with capabilities allowing students to experiment and improve their knowledge of engineering concepts in a simulated environment. Designing simulation-based tasks, students receive a possibility to complete several design iterations, evaluate different parameters, and directly visualise results, which together promotes a critical reflection and structured reasoning. Concurrently, experimental learning, wherein the hands-on work in the laboratory and design-based projects feature are exemplified, provides tractable access to real-\alpha omrady System, as well as exposure to the uncertainty and variability that are characteristic of engineering practice in the field. In these settings where the problems may be ill-defined, without predetermined solutions, learners are likely to engage in creative application of concepts, pursue troubleshooting efforts and develop selfregulated learning processes.The general argument presented in the literature is that integration of computational and experimental learning methods serve to supplement the other and result in a more comprehensive (or holistic) form of learning which is far more representative of the practical real-life engineering practice. The solution spaces can also be conceptualised and optimised before the solutions are physically implemented with simulation tools and the experimental activities serve to pinpoint and perfect the scenarios produced by the computational models. In past research on engineering pedagogy, simulation-based laboratories and project-based learning, as well as problem-based learning techniques were demonstrated to be useful techniques in improving both the engagement level of students and cognitive abilities. However, a good number of these initiatives are implemented as stand-alone activities which are not completely integrated throughout the engineering curriculum. Moreover, there is little empirical evidence on the comparative or synergetic effect of computational with experimental approach to teaching on enhancing problem-solving ability of the students particularly at the UG level in India. Due to the noted gap in the literature, the given study will conduct a research inquiry to examine the manner in which the combination of computational and experimental learning can be systematically utilised to improve the problem-solving competence of engineering students. The study employs the mixed-method research type in measuring the performance-related evaluation of the intervention in the selected core courses based on the analysis of perception. The main idea of the research is both to measure the increased efficiency of the students learning to cope with complicated tasks and also to investigate the effect of the exposure to various learning modes on their own sense of power, interest, and ability to develop imaginative solutions. The wider implications of the study are its possible use in advising curriculum development and instructional design practices which in turn acts as a beckon to higher education institutions in adopting flexible, student-centred teaching practice to embrace the realities of the contemporary practice in engineering. Eventually, this would enhance problem-solving ability among students which has a broad effect in all aspects such as enhancing employment capacity and more importantly innovation and development of this country in terms of science and technology. It thus adds to the currentdebate of engineering education reform in that it presents empirical data on the viability of combining computational and experimental learning methods, and gives practical suggestions to faculty members, curriculum designers, and policymakers who want to develop a technologically competent problem-orientated engineering graduate.As an engineer, one is expected to respond to the present needs of the industry and also anticipate some of the future problems based on emerging technologies and interdisciplinary problems. The resolution of complex problems cannot be applied to only narrow-technical areas anymore; engineers are constantly trained to cross professional boundaries, go mathematical and computational, to think differently and find solutions to problems within limited and shifting environments. Most reports by professional organizations as well as accreditation agencies have expressed that future engineers would require not just good conceptual knowledge but also flexible problem solving skills that could enable them to adapt to new technological environment fast. Here, both computational and experimental approaches to learning can be viewed as complementary to each other, and in developing a mindset of life-long learning and flexibility of thought processes. Computational tasks, including simulations and virtual prototyping, stimulate students to actively interact with abstract models of real systems, to consider hypothetical settings and to analyze alternative designs in an environment where there are no real costs or risks. Experimental learning, however, introduces students to practical constraints due to physical phenomena and measurement uncertainty that are very important to develop engineering judgment. When carefully combined, these strategies can help develop multi-perspective thinking and improve the students integration of theory and practice. Since digital transformation is reshaping the profession of an engineer, the implementation of such integrated pedagogical models into undergraduate programs is critical to training students to work effectively in transitional, technologically-advanced, and data-driven professional settings.

II. RELEATED WORKS

Ensuring the development of expert problem-solving within engineering students has been embraced as a core foundation of current engineering curriculums with the notion that the challenges trapped in the real world engineering world of practice need expertise more of critical thinking, innovativeness, and flexibility. Many innovators have urged the abandonment of a passive style of learning in favor of more active, learner-centered pedagogies that combine both instructional and experimental learning. One of the first to argue convincingly that the resulting knowledge in traditional instruction tended to be inert, entreating education to reform its ways by adopting authentic and ill-structured problem-solving, was Jonassen (2000) [1]. The past few years have demonstrated that computational tools like MATLAB, ANSYS and Solid Works have been effective in improving conceptual understanding of students as well as their modelling, simulation and optimal design of engineering systems [2]. As students study the models through simulation-based learning, they can examine models in virtual places, providing a more in-depth experience with fewer restrictions of the physical labs [3]. Freeman et al. meta-analysis showed that active learning, especially simulated and computational active learning, has a positive effect on semester tests and a negative effect on the likelihood of failing (STEM topics) [4]. Nevertheless, computational learning would not be able to duplicate the uncertainty, sensory feedback, and physical limitation present in real world engineering. In response to this, a considerable amount of experiential or experimental learning has been deployed throughout engineering undergraduate curricula based on the learning theory of Kolb to facilitate application of hands on skills and iterative testing and practical knowledge [5]. Inquiry-driven and design driven learning environments conducted in the laboratory have shown significant growth in problem formulation, hypothesis testing and refinement of solutions by engineering undergraduates

[6]. According to Prince and Felder, an active experiment is seen as additional to abstract conceptualization, enhancing theoretical learning experience with the simulations [7]. Computational and experimental techniques have increasingly been identified as a high-impact practice in engineering pedagogy. As an example, Vilanova and Sanz have shown that when using a combination of simulations software applications and physical prototyping, students are able to detect errors, debug systems and employ optimization strategies much better than when working only in the simulations software [8]. Additionally, project-based learning (PBL) frameworks involving CAD 394odelling, circuit simulation and prototyping in the real world were seen to promote not only competencies in technical problem-solving but also an ability to work in teams and effective communication [9]. Kumar et al. established in the Indian context that using IoT-based sensors and Arduino hardware kits in lab courses with the help of digital simulations enhanced academic grades as well as modes and interest of students [10]. This argument is also backed by research on flipped classroom model in which pre-class classroom simulation activities along with in-class laboratory allowed students to have more freedom and gain confidence in multi-disciplinary engineering problem solving [11]. The integrated approach is also supported by the cognitive load theory which holds that information is dual coded when it is denser visually and when there is accompanying physical experimentation which results to both information being coded reducing cognitive overloading and then promoting retention [12]. With regard to assessment, problem-based learning settings which integrate computation and experimentation are reported to have provided a more discernible assessment of applied problem-solving expertise in comparison with conventional assessment such as exams [13]. There are however still challenges on how well these methods are combined together. Limitations of availability of infrastructure, low faculty training abilities, and poor harmonization of curriculum are common hindrances to general use in the developing world [14]. Moreover, there have been a great number of studies on particular advantages of solutions to the problem of computational or experimental learning, but there are comparative or mixed-mode studies with rigorous empirical analysis. The current study fills this research gap by presenting an intervention, which takes the form of a mixed-method course, across and testing its impact on students, engagement, and problem-solving competencies across multiple engineering modules. It contributes to the literature by adding not only the quantitative results showing the results of learning but also the qualitative impressions of students. These implications are very important to curriculum developers, policy makers and educators who would like to integrate 21 st century skills in engineering education. This paper helps advance another strand of research supporting a move towards a pedagogical paradigm that reflects professional engineering practice iterative, experimental, analytical, and computational. Industry is increasingly placing premiums on the adaptability and systems thinking and as such, the engineering institutions must advance beyond the traditional instructional model in favor of a more comprehensive, learner-based and skill-flexible model which would enable the graduates not only solve the problems but will contain the capability to formulate and develop solutions to the problems even before they happen [15].

III. METHODOLOGY

3.1 Research Design

This study employed a mixed-method, quasi-experimental research design to evaluate the effectiveness of computational and experimental learning in enhancing problem-solving skills in engineering students. The design combined quantitative pre- and post-intervention assessment with qualitative analysis of student perceptions, in alignment with current best practices in engineering education research [16]. The intervention incorporated both simulation-based computational tasks and hands-on experimental activities in selected engineering modules.

3.2 Participants

A total of 120 undergraduate engineering students were purposively selected from the Department of Electrical and Mechanical Engineering. The cohort was divided into two groups: the experimental group (n = 60), which received the integrated learning intervention, and the control group (n = 60), which followed the traditional lecture-based curriculum. Participation was voluntary and informed consent was obtained before the commencement of the study.

3.3 Intervention Description

The intervention was implemented over ten weeks, integrating simulation tools (MATLAB/Simulink, ANSYS and Multisim) with laboratory-based experimental tasks aligned to the same engineering concepts. The students designed and tested engineering systems in the simulation environment, and subsequently replicated and validated their designs through physical experimentation in the laboratory. This sequential process was grounded in Kolb's experiential learning framework and emphasised iterative investigation, optimisation and validation [17].

Week	**Computational Activity (Simulation)**	**Experimental Activity (Laboratory)**
1–2	Model construction and parameter selection	Basic circuit assembly and measurement
3–4	System simulation and virtual testing	Validation of simulated results using physical components
5–7	Sensitivity and optimisation analysis in simulation	Troubleshooting and refinement of prototype designs
8–10	Iterative design refinement and performance analysis	Final implementation and validation of optimised engineering solutions

3.4 Data Collection

Quantitative data were collected using a validated problem-solving test administered prior to and after the intervention. The test assessed students' ability to diagnose problems, apply engineering concepts and generate feasible solutions. In addition, qualitative data were gathered through semi-structured interviews and reflective journals from participants in the experimental group to explore their experiences and perceptions of the integrated learning process. Data collection instruments were reviewed by subject matter experts for relevance and content validity [18].

3.5 Data Analysis

The quantitative data were analysed using paired-sample t-tests to determine the significance of changes in problem-solving performance between pre- and post-test scores in both the experimental and control groups. The qualitative data from interviews and reflective journals were analysed thematically, following the procedures outlined by Braun and Clarke, to identify recurring themes such as engagement, application of theory and development of analytical strategies [19]. Data triangulation was used to enhance the credibility of the findings, allowing cross-validation between quantitative and qualitative results [20].

3.6 Ethical Considerations

Ethical approval was obtained from the institutional research ethics review committee and all participants provided informed consent before taking part in the study. Participation was strictly voluntary, and confidentiality was maintained throughout the research process. The intervention was conducted in accordance with the guidelines for ethical practice in engineering education research [21][22][23].

IV. RESULT AND ANALYSIS

4.1 Overview of Performance Improvement

Overall, students who participated in the integrated computational-experimental learning intervention showed a marked improvement in problem-solving performance compared to those in the control group. The average post-test performance scores increased significantly across all three core engineering subjects. Table 2 presents the comparative mean pre- and post-test scores for the experimental and control groups.

Table 2. Comparison of Pre- and Post-Test Scores (Experimental vs. Control Groups)

Subject	Group	Pre-Test Mean	Post-Test Mean	Mean Gain
Electrical Circuits	Experimental	62.5	82.7	20.2
	Control	63.1	69.4	6.3
Mechanics	Experimental	59.8	79.2	19.4
	Control	60.2	66.9	6.7
Control Systems	Experimental	61.4	81.3	19.9
	Control	62.0	68.1	6.1

4.2 Subject-Wise Performance Trends

When analysed subject-wise, all three subjects demonstrated a consistent increase in students' ability to identify, analyse, and construct appropriate solution strategies. The greatest performance gain was recorded in Electrical Circuits, suggesting that the combination of simulation-based learning and physical prototyping has a particularly strong positive effect in technology-intensive domains.

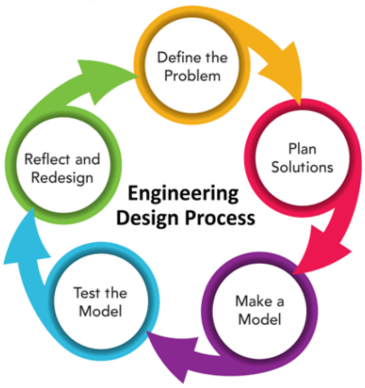

Figure 1: Problem Solving Steps [24]

4.3 Improvement in Problem-Solving Stages

To better understand how the intervention influenced different stages of the problem-solving process (problem identification, formulation, analysis, and solution generation), a rubric-based evaluation was conducted. The experimental group's post-test results showed significant improvement at all stages, particularly in solution generation and optimisation (Table 3).

Table 3. Rubric-Based Assessment of Problem-Solving Stages (Experimental Group)

Problem-Solving Stage	Pre-Test Mean (%)	Post-Test Mean (%)	Mean Increase (%)
Problem Identification	65.4	83.6	18.2
Problem Formulation	63.1	82.1	19.0
Analysis and Modelling	60.8	80.2	19.4
Solution Generation	58.6	80.8	22.2

4.4 Laboratory and Simulation Engagement Patterns

The weekly engagement data revealed that students demonstrated higher levels of activity and time spent during simulation and hands-on laboratory sessions after Week 3 of the intervention. As shown in Table 4, the difference becomes more pronounced from Week 5 onward, indicating that students became progressively more confident and independent in navigating the iterative design process.

Table 4. Average Student Engagement Time (Minutes per Session)

Week	Simulation Session	Laboratory Session
1–2	34	31
3–4	43	39
5–7	58	55
8–10	65	63

4.5 Student Perceptions of the Integrated Learning Approach

Qualitative analysis of the interviews and reflective journals highlighted three recurring themes: enhanced conceptual understanding, increased confidence in applying theory to practice, and enjoyment of iterative design and testing. Students consistently reported that alternating between simulations and physical experiments helped them “understand the logic behind the equations” and “see the problem from different angles.”

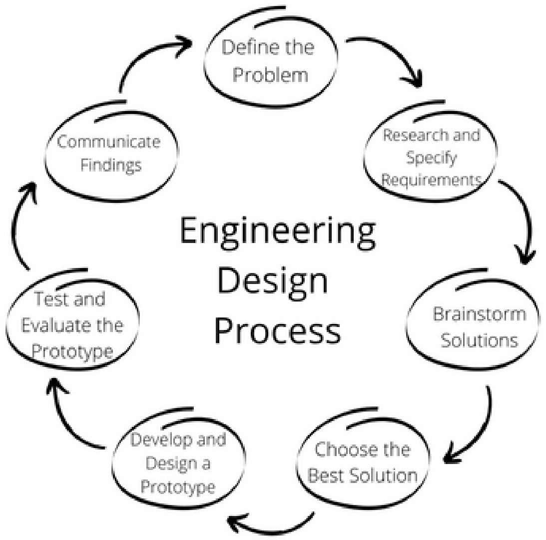

Figure 2: Engineering Design Process [25]

4.6 Alignment of Simulation and Experimental Outcomes

The alignment between results obtained in simulation and those observed in the laboratory was generally high. As illustrated in Table 5, the difference in recorded output values between simulation models and corresponding physical prototypes remained within an acceptable deviation range of 3–5%, suggesting that students were able to effectively translate virtual designs into real-world implementations.

Table 5. Comparison of Simulation and Physical Prototype Outputs (Selected Tasks)

Subject	Variable Measured	Simulation Result	Physical Result	Deviation (%)
Electrical Circuits	Output voltage (V)	11.8	11.5	2.54
Mechanics	Force output (N)	73.2	70.9	3.14
Control Systems	Step response rise time (s)	0.89	0.92	3.37

4.7 Discussion of Key Findings

The overall findings clearly indicate that integrating computational and experimental learning methods leads to substantial gains in students' problem-solving performance. The most pronounced improvements occurred in solution generation and optimisation, suggesting that iterative experimentation and visual feedback support the development of higher-order thinking. In particular, the high level of consistency between simulated and experimental outcomes demonstrates that students not only constructed theoretical solutions but were also able to implement and validate them in physical settings.

V. CONCLUSION

The current paper shows that commensuration between computational and experimental learning can be of significant help in developing the problem-solving capabilities in engineering students and that it can be a valid choice as an instructional method in contemporary engineering learning. The results are clear that when students come through repetitive processes of simulation based modelling and leading to laboratory validation process, they are more prepared in applying principles of theory to practical relationship and develop innovative resolutions to complex issues as well judge the consequences of design choices. During the intervention, students became active knowledge creators and were capable of moving around uncertainty and solving open-ended questions in an analysis way. The ability of this approach to integrate the advantages of virtual and real settings is one of the central contributions of the given approach, and simulation tools offered easy no-risk access to trying various options of the design and visualising the behaviour of the system, whereas experimental activities have introduced an element of realism, sensory appeal and realistic technical limits. Collectively, these modalities promoted more profound conceptual learning and prompted learners to use more realistic, iterative forms of reasoning more explicitly similar to that used in engineering practice. These improvements in rubric-based performance along the stages of problem solving, especially problem solution generation and optimisation, indicate the learning environment integrated is developing the type of higher order thinking that is largely absent in the more traditional lecture based teaching. Also, during the student reflections on the experience, the motivational quality of working with both digital and real systems was noticed, where the possibility of proving the simulated results with physicalizing them gave them greater confidence, independence and their feeling of accomplishment.The findings also show that the integrated methodology is easy to introduce across various engineering disciplines like Electrical Circuits, Mechanics and Control Systems which prove its versatility and flexibility in the wider engineering program. Notably, the levels of fit between the simulation outputs and experimental prototype results support the instructional design and substantiate the achievement of the goal to ensure that the students could effectively extend their virtual solutions to real-life practice. These findings have major reflection in the course creators and instructors and has been interpreted to shift towards hands on, blended pedagogical practices that reflect the interdisciplinary and iterative work of modern engineers. The issue of a fundamental gap in the literature is also answered by the study as it performed an empirical analysis of the compounded results of both computational and experimental learning as opposed to earlier studies which took the practice of examining these two components separately. Although integration needs proper planning, resource allocation and training personnel, a combination of learning benefits observed during the present study perfectly justifies the time, as well as investment. Besides, the mixed-method design applied in the study can yield both quantitative and qualitative data, which means that this study can give a complex picture of how such an integrated design contributes to student learning and professional preparedness. The results support the case of the inclusion of simulation-based laboratories and others, project-based experimentation and reflective practices into the basic structures of engineering education frameworks across the globe. Through these integrated approaches, learning institutions will be able to groom graduates who can not only memorize the theories in engineering, but also creatively and effectively apply the theories in solving arising challenges in the real-life world. As a conclusion, a combination of complimentary computational and experimental learning strategies presents a potentially strong pedagogical design that reinforces problem-solving skills, enhances the learning experiences and fosters the skills needed by an innovation-based and dynamic engineering career. This study has further potential to be expanded into the future by the means of studying long-term retention effect and creation of scalable models which could be used to learn in the online as well as hybrid styles of learning without the need to dissolve the merits of practical experimentation.

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