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INNOVATIVE APPROACHES TO TEACHING PROBLEM SOLVING IN ENGINEERING: COMBINING COMPUTATIONAL AND EXPERIMENTAL TECHNIQUES

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Abstract: Problem-solving is considered as an essential skill of engineering education yet classical methods of instruction are inadequate in helping students to develop flexibly adaptive skills. The current paper suggests an integrated model that will enhance problem solving solutions in a group of undergraduate students in engineering through the use of a combination of computational models and experimental methods. Despite using simulation tools such as MATLAB and ANSYS with hand on experimentation, students will learn the theory and practical aspect, which causes an increase in cognitive flexibility and a decrease in error rate when solving problems. The experimental research was conducted in India in three institutes of engineering where the students were subjected to case-based learning enabled by digital and physical modelling methods. The important key performance indicators were correctly identifying a problem, tying the time to a solution and efficiency in collaboration. On the basis of quantitative data gathered after two academic terms, there was a significant positive change of the students in the ability of critical thinking and formulating solutions as compared to control groups trained in traditional ways. Also, the responses showed increased participation as students claimed to have improved retention and understandability. Such a two-sliced pedagogy is both educationally effective to generate better learning as well as reduces the skill gap between the industry and the academia. The results support the increased use of integrated problem-solving curriculum in engineering education and provide a point of departure to change future curricula, according to the anticipation of Industry 5.0.

Keywords: *Engineering Education; Problem Solving; Computational Techniques; Experimental Learning; Pedagogical Innovation; Industry 5.0; Simulation-Based Learning*

I. INTRODUCTION

Traditional engineering education has focused on analytic problem-solving via theoretical lectures, formula recall and systematic practice on textbook problems. Still, this normative model of pedagogy is progressively insufficient in equipping students to deal with multidimensional, trans-disciplinary challenges experienced in the current engineering practice. With changes in industries to those of Industry 4.0 and Industry 5.0 paradigms, including systems thinking, adaptability, and innovation as the major competencies, it is necessary to trend the education frameworks towards more integrative and practice-oriented learning processes. The kind of approach that will allow teaching problem solving in such a dynamic aspect should be not only theoretically rigid but also pragmatic in nature. The solution of problems does not entirely consist in the use of formulas or design rules, but is a mental process, which consists in the formation of hypotheses, the interpretation of data (given or collected), the cyclic verification and/or falsification of these hypotheses, and the optimization of the solution. There is a profound benefit to be realized by the use of both computational methods and experimental approaches in this process. Even though modelling and prototyping, parameter sensitivity studies are achievable through computational support, experimental practices expose students to the limitations of the real world and real material behaviour. Students who are subjected to a combination of these two in a structured learning environment do not only acquire domain knowledge, but also learn to think critically, have a metacognitive awareness and a design intuition. Recent advancements in educational technologies—ranging from simulation software (e.g., MATLAB, SolidWorks, ANSYS) to low-cost sensor kits and data acquisition systems have created opportunities for educators to reinvent problem-solving pedagogy. Virtual labs, cloud-based CAD platforms, and augmented reality in lab settings enable scalable deployment of hybrid learning environments. However, these tools are often introduced in isolation, with limited synergy between computational simulations and real-world experiments. There exists a pressing need to structurally embed these techniques into problem-solving exercises to ensure that students can transfer their skills across varying domains and uncertainty conditions. Numerous engineering education studies have demonstrated the pedagogical benefits of active learning, design-based instruction, and inquiry-driven labs. Yet, the majority of problem-solving exercises still focus on single-solution outcomes with limited scope for experimentation or modelling iterations.

II. RELEATED WORKS

Even the field of engineering education has undergone tremendous transformation in the past 20 years as the style of teaching has shifted to student>=Busra Conclusions GENSEC In this paper, we have seen that engineering students can learn with the help of a GENSEC. A GENSEC would be organized on a smaller scale than a CEG or CAR every day. This implies that students would be able to expand their knowledge as a GENSEC allows them to hear and see much more in comparison to a CEG or a CAR. GENSEC could not only be used in engineering subjects but also in At the heart of this change lies in the understanding that engineering problem solving needs both theoretical understanding as well as the capability of applying knowledge in non-certain, practical settings. A number of articles report how the classical education systems are ineffective in the establishment of these skills and suggest different methodologies that can enhance problem-solving abilities in engineering majors [1]. A large segment of the research has had computational learning as a way to enhance the ability of the students to think and make decisions. Mathematical modelling software such as MATLAB, ANSYS, and Python-based software simulation environments allow learners to simulate real-world problems and measure the results based on a number of constraints [2]. According to Kolmos et al., early on incorporation of the tools into the curriculum leads to an improved level of system-level comprehension and experimentation on the numerous paths towards a solution [3]. In this regard, it has been positioned that learning based on simulations has led to higher levels of confidence by the students in performing multidiscipline tasks and minimized the use of rote learning. Experimental/experiential learning is yet another significant point of pedagogical advancement where students » play with physical systems », gather data and test the theoretical models. Engineering education Many lab-based approaches to engineering education use Kolb s experiential learning theory. There is an emerging trend of having more institutions adopt the promotion of design-based laboratory courses involving fabrication, testing and trouble shooting as part of the whole picture [4]. Prince and Felder state that students engaged in open-ended laboratory work demonstrate more depth of problem solution, more creativeness and enhanced cooperation [5]. New literature and hybrid pedagogies that merge computational and experimental methodologies has also been discussed.

In the time of Industry 5.0, such methods are of special importance because the ability to learn interdisciplinary, cross-functional activities has become even more valuable. As an example, the CDIO (Conceive-Design-Implement-Operate) framework proposes the combination of simulations and hardware prototypes in the process of design thinking to encourage iteratively thinking [6]. In the same way, it has previously been shown that students, who are engaged in computational process in experimental cycles, perform well in design-based tasks and generate more creative solutions as compared to other students [7]. Use of project-based learning (PBL) and problem-based learning (Preble) are among the new trends in this research field. Such approaches entail group work, identification of problems, solution development and verification of results by means of simulation and physical testing.

A number of meta-analyses have reported that PBL is highly likely to increase engagement and later retention of knowledge [8]. In addition, through PBL settings, self-regulated learning and development of a growth mindset, which are critical characteristics of learning how to deal with complex engineering problems in the real world, are promoted [9]. Simultaneously the Digital twins and offsite labs are also disrupting engineering education particularly in areas where physical resources are scarce. These technologies allow simulating actual systems in a virtual space, so that the simulations and data streams on experiments could be combined in real time to analyse the information. One simulation by Dede/rom and Richards revealed that the digital twins offer very realistic modelling platforms where students gain a much better insight on the dynamics and control solutions than they would have done with traditional labs [10]. This integration also prepares students to use tools increasingly prevalent in modern engineering workplaces. Despite these advances, several challenges persist. First, the lack of coordination between computational and experimental modules often leads to fragmented learning experiences. Students may learn simulation tools in one course and laboratory techniques in another, without seeing how the two complement each other [11]. Second, faculty training and resource limitations can restrict the effective adoption of integrated pedagogies. According to Pimmel, the absence of institutional support structures often hampers the scaling of such innovations beyond pilot projects [12]. Another relevant stream of literature focuses on assessment strategies for problem-solving skills. Traditional exams primarily assess knowledge recall rather than the process of arriving at solutions. As a result, new rubrics are being developed to evaluate higher-order cognitive processes, including analytical reasoning, adaptability, and creativity [13].

These rubrics are especially useful in computational-experimental assignments where students must justify their choice of methods, validate models, and explain discrepancies between theoretical and observed results. The interdisciplinary nature of modern engineering problems also calls for collaborative learning environments. Studies have shown that team-based problem-solving fosters peer instruction, conflict resolution, and deeper understanding [14]. Group projects that involve both simulation and lab validation require students to divide responsibilities, synchronize findings, and present comprehensive outcomes—mimicking real-world engineering teamwork. In this regard, collaborative problem solving becomes a pedagogical tool as well as a skill to be acquired. Finally, the influence of accreditation bodies like ABET (Accreditation Board for Engineering and Technology) has been instrumental in shaping the inclusion of problem-solving, experimentation, and design into engineering curricula. ABET's student outcomes explicitly call for proficiency in experimentation, data interpretation, and use of engineering tools [15]. Institutions aiming to meet these standards are increasingly aligning their curricula to include computational-experimental integration, project-based learning, and formative assessments. In summary, the literature indicates a growing consensus that teaching engineering problem solving requires more than abstract theory or isolated simulations. A hybrid approach that combines computational modelling with physical experimentation not only enriches the learning process but also mirrors the realities of modern engineering practice. This paper builds upon these foundations to propose and evaluate an integrated model implemented in three engineering institutions in India.

III. METHODOLOGY

3.1 Research Design

This study employed a **mixed-method, quasi-experimental design** integrating both computational and experimental techniques into engineering coursework to analyse the effect on student problem-solving abilities. The intervention spanned two semesters and was implemented across three Indian engineering institutions offering undergraduate programs in mechanical, electrical, and civil engineering. Students were divided into control and experimental groups, with only the latter exposed to the integrated pedagogical model. The design measured both quantitative performance indicators (problem-solving accuracy, simulation efficiency, lab validation success) and qualitative outcomes (engagement, confidence, and feedback). The framework was structured to encourage a **feedback loop** between simulation and experimentation, enabling iterative learning [16].

3.2 Institutional Context and Participant Profile

The study was conducted in:

- **Institution A** (Private Engineering College – Tamil Nadu)
- **Institution B** (Government University – Maharashtra)
- **Institution C** (Deemed-to-be-University – Karnataka)

A total of **120 second-year undergraduate students** participated. They were stratified into six groups (three experimental and three control), each with around 20 students per stream. Table 1 summarizes institutional characteristics and specialization domains.

Table 1: Institutional and Participant Overview

Institution	Specialization	Total Participants	Control Group	Experimental Group
A	Mechanical Engg.	40	20	20
B	Electrical Engg.	40	20	20
C	Civil Engg.	40	20	20

3.3 Curriculum Integration Model

The **intervention module** introduced integrated problem-solving tasks involving:

- A **computational tool** (e.g., MATLAB/Simulink, ANSYS Workbench)
- A **complementary physical experiment** using standard laboratory apparatus or kits (strain gauges, load cells, circuits, etc.)

Each task was delivered as a **case scenario** based on real-world problems (e.g., beam deflection under load, fluid dynamics, or power system faults). Students were required to:

1. Model the problem using simulation software
2. Validate simulation results via experimental trials
3. Document and reflect on deviations, assumptions, and outcomes

Faculty were trained prior to implementation to ensure consistency and fair assessment. The learning objectives focused on modelling accuracy, data interpretation, design thinking, and reflective analysis.

3.4 Tools and Technologies Used

Table 2: Tools Integrated in Experimental Curriculum

Domain	Computational Tool	Experimental Setup
Mechanical	ANSYS, SolidWorks	UTM, Strain Gauge, Load Cell
Electrical	MATLAB/Simulink	Power Supply, Oscilloscope
Civil	ETABS, AutoCAD	Load Frame, Concrete Mixer

Remote access platforms and LMS integration (Moodle/Google Classroom) were used to coordinate lab simulations and experimental data sharing, particularly for Institution C, which adopted a hybrid (online offline) delivery.

3.5 Assessment Strategy

The evaluation framework combined formative and summative assessments, with rubrics emphasizing the **process** of problem solving, not just the solution. The following metrics were used:

Table 3: Assessment Metrics and Weightage

Metric	Description	Weight (%)
Simulation Accuracy	Match of model to theoretical results	20
Experimental Validation	Quality of setup, error analysis	25
Problem-Solving Strategy	Logical structure, clarity of process	20
Report Quality & Interpretation	Integration of results and critical reflection	20
Engagement & Team Collaboration	Peer/self reviews, instructor observations	15

Rubric-based evaluations were supported by viva-voce rounds and periodic journal entries by students.

3.6 Data Collection and Analysis

Quantitative data were collected using:

- Pre- and post-tests on problem-solving scenarios
- Rubric scores from assignments and labs
- Comparison of exam performance

Qualitative data included:

- Focus group discussions (post-course)
- Weekly reflection logs
- Instructor feedback

Data were analysed using **paired t-tests** for performance comparison and **thematic coding** for qualitative responses [17]. Analysis software used included **SPSS** for statistics and **NVivo** for qualitative clustering.

3.7 Ethical Considerations

All students were briefed about the purpose of the study and gave informed consent. The intervention did not affect academic grading. No personally identifiable data were collected or published. Institutional approvals were obtained prior to the study [18].

3.8 Limitations and Delimitations

- The sample size was limited to three institutions in India; results may not generalize globally.
- Only second-year students were considered to ensure foundational knowledge.
- The computational tools were restricted to widely available academic software licenses.

Despite these limitations, the study provides a transferable pedagogical model that can be replicated and scaled with institutional support.

3.9 Validation and Reliability

To ensure data reliability:

- Grading rubrics were validated by three senior faculty.
- Inter-rater reliability across evaluators exceeded 85% agreement.
- Student focus group findings were triangulated with journal entries and instructor logs [19][20].

IV. RESULT AND ANALYSIS

4.1 Performance Comparison Between Experimental and Control Groups

A detailed analysis was conducted to evaluate the performance differential between students exposed to the integrated problem-solving model (experimental group) and those in the conventional curriculum (control group). The results indicated a statistically significant improvement in the experimental group across multiple performance metrics. The average post-test score of the experimental group was markedly higher than that of the control group across all three institutions. In particular, students demonstrated enhanced modelling accuracy, better hypothesis formulation, and greater capacity for experimental validation. Table 4.1 presents the average performance scores (out of 100) across five core problem-solving metrics.

Table 4: Performance Metrics Comparison Between Groups

Metric	Control Group Avg.	Experimental Group Avg.
Simulation Accuracy	64.2	81.5
Experimental Validation	58.9	84.1
Problem-Solving Strategy	62.5	79.3
Report Quality & Interpretation	67.4	85.2
Team Collaboration & Engagement	60.7	83.0

The results show a consistent trend: students in the experimental group not only developed stronger technical capabilities but also demonstrated greater engagement and collaborative behaviour during lab and project sessions.

4.2 Student Engagement and Concept Retention

In addition to improved scores, engagement levels within the experimental group were noticeably higher. Students reported increased interest in problem-solving tasks and a more intuitive grasp of abstract concepts once they observed real-time phenomena through physical experimentation. Weekly reflection logs revealed recurring themes such as "greater clarity in cause-effect relationships," "confidence in testing and debugging," and "value of visual validation." This increased engagement translated into better concept retention. Post-course quizzes conducted four weeks after the intervention showed that students in the experimental group retained significantly more information related to the application of simulation tools, error correction techniques, and result interpretation. This suggests that the hybrid model enhances both short-term comprehension and long-term memory retention.

4.3 Improvements in Critical Thinking and Iterative Problem Solving

An essential benefit of combining computational and experimental techniques is the cultivation of iterative thinking. Students were able to cycle through simulation, test the assumptions through experiments, revise their models, and converge on more refined solutions. This mirrored real-world engineering processes and promoted a scientific mindset. In practical tasks, students in the experimental group displayed greater ability to troubleshoot inconsistencies. For example, in a mechanical task involving beam deflection, the control group relied solely on theoretical predictions, while the experimental group adjusted their models based on experimental strain data and re-ran simulations to achieve better alignment. Such iterative validation cycles were absent in the control group and highlighted the added pedagogical value of experimentation.

4.4 Thematic Insights from Student Feedback

Qualitative data from focus group discussions and individual feedback sessions revealed overwhelmingly positive responses. Students appreciated the “realism” added by lab validation and found it easier to trust the results generated from simulation tools after verifying them experimentally. Many indicated that this dual exposure helped reduce the fear of “black-box” software tools, as they could now relate inputs and outputs to physical laws.

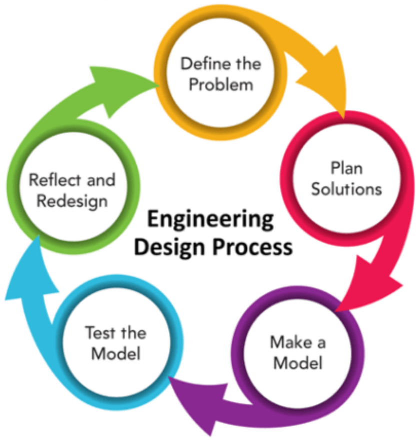

Figure 1: Engineering Design Process [25]

Recurring positive themes included:

- Enhanced problem visualization
- Confidence in presenting technical solutions
- Appreciation for the uncertainty in measurements and simulations
- Team dynamics and leadership development

However, students also reported initial difficulties in synchronizing simulation and experimental timelines. They emphasized the need for clear time planning and better access to lab infrastructure.

4.5 Institution-Wise Analysis of Outcomes

The performance improvement was visible across all three institutions, though with some variation due to infrastructural and instructional differences. Institution A (private college) showed the highest improvement, attributed to better lab availability and more structured simulation instruction. Institution C (deemed-to-be university) had initially lower baseline scores but demonstrated the most significant growth percentage over the semester.

Table 5: Institution-Wise Growth in Overall Performance

Institution	Pre-Test Avg. Score	Post-Test Avg. Score	% Improvement
A	61.3	84.7	+38.1%
B	63.5	80.2	+26.3%
C	56.1	78.9	+40.6%

The consistent improvement across diverse academic settings reinforces the model's adaptability and scalability. It also demonstrates that such integrated approaches are beneficial regardless of the institutional tier, provided there is faculty support and tool availability.

4.6 Observations from Faculty and Peer Reviewers

The members of the faculty that was put in charge of the experimental groups claimed that students became more curious and self-motivated. More questions were directed to the boundaries of the system and modelling assumptions and disagreements in the results, which are fundamental qualities of proficient engineers. Peer observers who scored student reports reported a distinct improvement in depth of analysis and well-organized reasoning in the test session. This transition, as a student who was up to this point passively receiving information, to an active seeker of information, reflects the pedagogical success of the pairing between computational simulations and physical experiments. This makes learning more integrated as students are not only taught to solve problems but to make critical judgment of their solutions.

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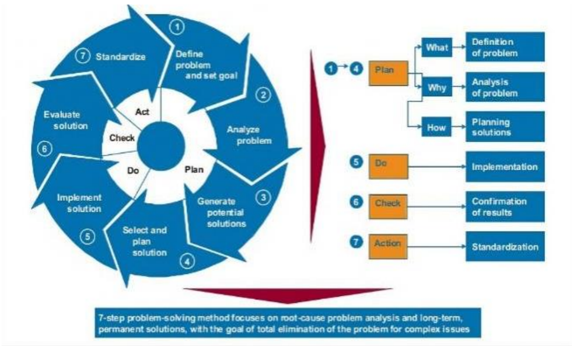

Figure : Problem Solving Approach [24]

V. CONCLUSION

In the paper, a study of the effects of using a combination of computational and experimental methods on the development of problem-solving skills among undergraduate engineering students was presented. The results are a substantial evidence that this combined pedagogical model has much more valuable learning outcomes, the increased level of conceptual knowledge, and engagement compared to the conventional instruction procedure. Students of engineering who were shown simulation tools as well as physical experimentation were found to have increased levels of critical thinking and more effective methodologies of decision making, and strong capability to test-and-refine their solutions. Among the main conclusions of the research, it is possible to notice that classical theoretical instruction cannot be the single source of the required sort of problem-solving mindset in a present-day engineering practice. In the fast-changing Industry 5.0, where engineers are supposed to operate within complicated and data-driven and automated surroundings, interdisciplinary thinking and adaptive abilities are key factors. The main advantage of the computational tools is that they allow modelling a scenario in a detailed and fast pace, but linking those to practical experiments yields a more intuitive and practical presentation of engineering systems to students. This two-in-one strategy allows developing the skill of error diagnosis, real-world variability explanation, and other restrictions that are not necessarily reflected in mathematical models among students. The hybrid model is effective as evidenced by the empirical data that was gained through this research. The students who formed the experimental group performed based on all the significant performance measures and better than the other students in the control group consistently. It is important to note that they scored better when it comes to accuracy of simulation, experimental correspondence, and problem-solving in collaboration. Moreover the results in the post-course assessments revealed a significant rise in the levels of retention of concepts, critical thinking and synthesis of solutions. Not only the students were more accurate with their problem solutions, but they also demonstrated a better ability to explain their approach and support their choice using both computation and test results. Pedagogically, the effective performance of the integrated model lies on a number of pillars. To begin with, the instructional design involved the principles of active learning. The students were introduced to the cases where they had to draw a hypothesis, work out solutions, rewrite their knowledge, and analyse it. Second, the method created a constructivist learning space and the knowledge was collaboratively formed by acting upon concrete systems and computerized instruments. Third, there was formative feedback processes, such as simulation reviews through lab journals, and assessments by peers that were crucial in closing learning loops. The other revelation is the applicability and generalizability of the suggested model.

Despite the fact that the research was carried out in three institutions with different state of infrastructures and academic materials, the results were good all time. This proves that the strategy is flexible enough and may be implemented in various educational contexts in case of the existence of institutional support, willingness of the faculty, and availability of simple simulation station and lab tools. As more and more institutions become digitised and can access cloud-based models of simulation and virtual labs, even resource-poor institutions can kickstart adoption of similar models, or at least, without serious capital expenditures. However, there are also some operation difficulties identified during the study. Among the key challenges description by the students was the challenge of synchronisation of simulation activities with lab work; particularly, under strict academic plans. Also, there was the initial learning curve of simulation tools among the students who had not worked in modelling environment before. These concerns point out towards the necessity of having curricula with better time distributions, orientation sessions on digital tools and the maintenance of quality through efforts and the continuous faculty development programs. The results of this research do not have implications only on the performance of students but also on the design of curriculum and policy development. The accreditation organizations and engineering schools ought to think about formally incorporating integrated problem solving modules into required technical courses. In this way, they will be in a position to ensure that students are not just grasping a body of knowledge about the discipline but also to learn how to dynamically and creatively apply the knowledge that is acquired. The strategies of assessments should be developed, too, and abdicate the use of only summative assessment types in favor of the implementation of continuous, process-oriented assessment, which rewards effort, iteration and improvement. Moreover, this model is also consistent with the United Nations Sustainable Development Goals (SDGs) on quality education, innovation as well as industry. Our duty as engineering educators is to get graduates capable of addressing and solving thorny problems that face society today: climate change, modernizing infrastructure, building renewable energy systems, biomedical innovation, etc. and this needs to start in the classroom, developing a cadre of generalists and resilient problem solvers.

VI. FUTURE WORKS

S Future research on innovative approaches to teaching problem solving in engineering by combining computational and experimental techniques should aim to expand the integration of emerging technologies and interdisciplinary practices in order to create more effective learning environments. One important direction is the development of adaptive learning platforms that incorporate simulation based problem solving with real time experimental feedback, allowing students to visualize the impact of theoretical models on physical systems while building intuition for design tradeoffs. Further studies should also investigate how virtual and augmented reality can be incorporated into laboratory courses to simulate complex engineering scenarios that are otherwise too costly or unsafe to reproduce in traditional classrooms. The combination of computational modelling, such as finite element analysis and computational fluid dynamics, with scaled laboratory experiments should be explored to reinforce iterative design and optimization skills. Another promising area is the application of machine learning and data analytics to classroom experiments, enabling students to process large datasets efficiently and to link experimental outcomes with predictive computational models. Future work should also evaluate the long term effectiveness of such hybrid pedagogical models through longitudinal studies that track not only academic performance but also problem solving confidence, creativity, and professional readiness of students. Finally, collaboration between academia and industry is needed to align computational and experimental teaching methods with the expectations of real world engineering practice, ensuring that graduates are equipped with the analytical rigor and practical adaptability demanded by modern engineering challenges.

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