SvedbergOpen
DISSEMINATION OF KNOWLEDGE
International Journal of Artificial Intelligence and Machine Learning
Publisher's Home Page: https://www.svedbergopen.com/

Research Paper Open Access

Integrating Machine Learning Into Activity-Based Learning: A Critical Review Of Emerging Frameworks In Engineering Education

Dr. K.Murali[1] , Mr. K.Sambath[2] , Mr. G.Ramesh Kumar[3] , Mr. B.Vigneshkumar[4] , Dr. K.V.Boobala Krishnan[5]

[1]Professor, Department of Civil Engineering, Dr.N.G.P. Institute of Technology, Coimbatore , murali.vlb@gmail.com
[2]Assistant Professor, Department of Mechanical Engineering, Sri Ramakrishna Institute of Technology Coimbatore
[3]Assistant Professor (SS), Department of Civil Engineering, Dr.N.G.P. Institute of Technology, Coimbatore
[4]Assistant Professor, Department of Civil Engineering Dr.N.G.P. Institute of Technology, Coimbatore
[5]Assistant Professor (SS), Department of Civil Engineering Dr.N.G.P. Institute of Technology, Coimbatore

Abstract
Active learning has emerged as a transformative approach in engineering education, emphasizing student-centred pedagogy, real-world problem-solving, and the development of critical and transferable skills. This review critically analyses of the recent studies focusing on Problem-Based Learning (PBL), Project-Based Learning (PjBL), and Collaborative Learning (CL) to evaluate their implementation, strategies, and outcomes in higher engineering education. The review synthesizes methods, tools, and learning environments used to facilitate active learning, highlighting benefits such as enhanced engagement, teamwork, creativity, and conceptual understanding. Key trends include the integration of technology, gamification, and interdisciplinary projects to foster self-directed learning. Limitations identified include small sample sizes, contextual constraints, and lack of longitudinal evidence on long-term skill retention. The review identifies research gaps related to scalability, instructor preparedness, and curriculum-wide applications, offering insights for future studies and practical recommendations for optimizing active learning approaches in engineering programs.

Keywords: Active Learning, Engineering Education, Problem-Based Learning, Project-Based Learning, Collaborative Learning.

1. Introduction

Active learning has become one of the most essential pedagogical models in higher education, as a reaction to the growing need to equip a student with critical thinking, problem-solving, and collaborative skills in complicated, real-life situations (2021). The conventional method of education through lectures which can be described as a passive reception of knowledge has been proven inadequate in stimulating profound learning, involvement, and the field-specific abilities essential to present-day careers, especially in the field of engineering (2021). Consequently, there has been a growing trend among educators and researchers towards strategies of active learning that emphasize on the involvement of students (2023), practical experiences and collaborative problem solving as opposed to rote memorization (2021). Active learning is a general pedagogical theory that comprises instruction methods that involve likening students to be cognitively, emotionally and socially interested in the learning content (2022). It focuses on student-centred learning in which students are not passive receivers of information but they are active in the process of building knowledge (2022). Some of the techniques used in active learning are PBL, PjBL, challenge-based learning, collaborative learning, flipped classroom, gamification, and inquiry-based activities (2023). The similarity in these approaches is that they are all centred on experiential learning, reflection, team learning, and practice of theoretical knowledge on practice issues (2021). An example of such is PBL which involves the identification, analysis and solution of open-ended problems (2023), which develops a critical and analytical mind (2022). PjBL, in its turn, also focuses on long-term research and practical use of knowledge to plan and implement projects (2021), which more often than not result in physical components (2021). Another basic element of active learning, collaborative learning, involves the use of teamwork by students and they learn to communicate, negotiate and socialize as well as the technical skills (2021).

Active learning has especially been of importance in engineering (2021), where the curricula should integrate theory and practice (2022). Various researches have shown that active learning enhances student motivation, learning process, and knowledge retention more than the traditional lecture-based strategies (2023). As an illustration, the combination between PBL and PjBL can allow students to implement classroom knowledge in field or laboratory situations (2021), which would simulate real-world professional situations (2021). In addition, active learning strategies will encourage development of transferable skills (2024), which include team work, leadership, project management, and good communication which are most appreciated in the modern workplaces (2021). Active learning is also closely related to the constructivist learning theory which assumes that knowledge is built in the process of interaction with the surrounding environment (2023), with other students and mentors rather than being received passively (2023). Active learning supports not only cognitive but also metacognitive development by keeping the students engaged in the learning process on matters that are contextually relevant, meaningful and often interdisciplinary, allowing the students to observe the process in which they learn, be able to self-evaluate progress and adjust accordingly (2022). This has also been applied in recent pedagogical innovations like Education 4.0 that applies emerging technologies, data-driven learning, and gamified experiences to further increase engagement and skill acquisition (2024). Active learning implementation has many challenges despite its benefits which include careful designed curricula, effective scaffolding, adequate resources, and instructor training (2024). Students too need help in accommodating in self-directed, collaborative learning systems (2023), especially where they are used to traditional lecture-based systems (2025). However, the increasing amount of literature points to the fact that active learning strategies, when properly applied (2023), have a more powerful impact on student engagement, motivation and their capacity to use knowledge in complex, real-world conditions (2022), thus, becoming the pillar of modern higher learning (2021).

Research Questions

1. How are Problem-Based Learning, Project-Based Learning and Collaborative Learning implemented across different engineering courses?
2. What strategies are used by educators to facilitate active learning in PBL, PjBL, and CL?
3. How do learning environments and tools support the implementation of active learning?

2. Review Strategy

The presented study relies on the critical literature review about active learning practices, such as PBL, PjBL and CL in the engineering education. The systematic search of the peer-reviewed sources of 20 recent research papers, such as IEEE, MDPI, Springer, ScienceDirect, and Wiley, were used. The review included the analysis of each article to determine its intent, methodology, implementation strategies, results, and difficulties of active learning techniques. The particular attention was paid to the comprehension of the pedagogical practices, student engagement, interdisciplinary collaboration, and integration of technology to improve the learning process. This plan allowed systematic integration of evidence in order to make recommendations on how active learning can be designed and implemented in the higher education settings.

2.1 Search Strategy

In this work, the literature search was systematic to gather the related works on active learning strategies related to engineering education. Peer-reviewed journals that were indexed in “IEEE”, “MDPI”, “Springer”, “ScienceDirect”, and Wiley were selected as the major sources, and they were accessed mostly via Google Scholar. The search was narrowed to publications dating between 10-15 years to make it up to date. The keywords that were primarily used included PBL, PjBL, CL, Active Learning, Engineering Education, Student Engagement, and Pedagogical Innovation. Qualitative and quantitative research were also entertained and these comprised case studies as well as meta-analysis and systematic reviews. The search strategy entailed screening of titles, abstracts, and full texts in order to see studies that were directly related to the meaning of implementation, outcome, and challenges of active learning methods. This method enabled the identification of 20 applicable articles that were used to conduct the critical review of this study.

2.2 Inclusion and Exclusion Criteria

In ensuring the suitability and the quality of the selected papers, the following inclusion and exclusion criteria were therefore used. The inclusion criteria were designed to ensure that only the recent and relevant findings were included in this study by filtering the papers written in English and published not more than 2025. The chosen articles in particular have addressed the active learning methods, such as PBL, PjBL, and CL, specifically in reference to engineering and STEM education. Empirical research, case studies or experimental results of the implementation strategies, outcomes or challenges were factored in the studies. On the other hand, articles published before the year 2021 or articles that were not an original research article such as editorials, letters, comments, perspectives, special issues, expert reviews and viewpoints were all excluded. Moreover, researches that did not have a clear methodology, dataset description, or validation measure that might impede the reliability and comparability of the review were also removed. This methodical filtering gave the end product of the selection a high quality and evidence-based studies in the context of active learning.

Table 1. Literature inclusion criteria

No.	Criteria	Description
1.	Topic	The selected literature must focus on active learning methodologies, specifically PBL, PjBL, and CL in engineering or higher education.
2.	Period	Studies published between 2021 and 2025 to ensure inclusion of the most recent developments and applications in the field of active learning.
3.	Research Base	Only empirical studies using qualitative, quantitative, or mixed methods are considered to provide evidence-based insights.
4.	Language	Publications must be written in English to ensure consistent comprehension and analysis.
5.	Transparency	Included studies must clearly define their research design, sample size, instruments, and analysis methods.
6.	Reliability and Validity	The results and findings of selected studies must be valid, reliable, and published in peer-reviewed or indexed journals.
7.	Accessibility	Full-text articles must be accessible through recognized academic databases to ensure data verification and quality evaluation.

The inclusion criteria have been outlined in table 1 in order to make sure that the chosen literature can meet the objectives and scope of this study. The following criteria have been created to preserve quality, relevance and credibility of the reviewed works. The parameters help to include only recent, empirical and methodologically transparent studies, which would make it possible to see the picture of the contemporary trends and practices in active learning. The inclusion framework is also meant to guarantee that every chosen article presents quality and valid findings, which present useful information on the practice and the success of active learning techniques in higher education. The implementation of these inclusion criteria will ensure that the literature reviewed creates a body of evidence that is the most precise and up-to-date concerning the area under study.

3. Critical Analysis Review

This division explains the trend in using active learning environment in engineering education. It is a recap of the primary findings, methods, and trends of the latest works in which the task will be to provide an overall concept of the modern state and the issues of the sphere. One of the recent trends in this field is that the learning process is no longer teacher-focused, but it shifted to student-focused, activity-based setups including PBL, PjBL, and CL. This part of the report explains methods such as systematic literature review, critical content analysis to find out how the two may improve student engagement, creativity, and critical thinking. Qualitative analysis of selected papers was conducted in order to find out their methodological approaches, major findings, and limitations. The general approach to the methodology provides sufficient equilibrium to compare the manner of implementation of active learning strategies, their effects on the outcomes of engineering education, and difficulties of the active use of the strategies in different instructional settings.

3.1 Problem Based Learning

Specifically, Ramos-Mejia et al. (2025) created the setting of a PBL course in which the nature of electrochemistry is based on wastewater treatment to develop the conceptual learning and complex thinking of students. The group of study included chemistry and chemical engineering undergraduates and they were exposed to solving problems in teams. The qualitative analysis conducted with the help of Atlas.ti 22 addressed five case studies and revealed eight categories of scientific knowledge and practices which are visualized in a Sankey diagram that displays cognitive complexity. The results proved to show a great change in the level of conceptual learning and the capability of the students to transfer the electrochemical knowledge to the real-world. Nevertheless, the weakness of the study was that it was a group analysis, but not at an individual level to reveal that all participants acquired the complex thinking skills to the same extent.

The authors of the study by Marcinauskas et al. (2024) chose to conduct a comparative study to assess the effectiveness of PBL and Traditional Learning (TL) in a first-year engineering course in physics. The study compared assessment outcomes and observations made by lecturers, and based on data on 460 participants at Kaunas University of Technology. The findings indicated that PBL was much more effective in terms of teamwork, presentation, and critical thinking skills, whereas TL was more effective in terms of individual learning and theoretical understanding. Even though PBL facilitated constant interaction between less motivated students, it required an increased amount of time and effort on the part of the instructor. It did not include quantitative measures of pre- and post-assessment and student self-reflection data thereby restricting the possibility to completely validate the differences in learning outcomes between methods.

The purpose of the study by Čubela et al. (2023) was to determine the combination of problem-based learning, gamification, and data-driven strategies in engineering education following a course in Geoinformatics and Surveying GeoGovernment 1. The study used student centered framework that involves real world problem solving, spatial data analysis, as well as GIS technology to involve the learners in resolving ATM burglary cases in Germany. This strategy helped students develop better analytical, technical and self-directed learning as well as become more motivated and employable in the STEM subjects. Yet, some of the challenges were the changing nature of the role of the instructor to a facilitator, the possible lack of focus because of competitive aspects, and the necessity of the structured feedback loops to guarantee the same learning outcomes and an equal balance of engagement.

The Integrated Learning Stream (ILS) was the study by Paul et al. (2023) into how PBL, and critical reflection in engineering can be integrated into engineering education, resulting in meaningful learning experiences, but without requiring more course time or course work. The approach included the establishment of learners-focused classroom communities, the key to critical reflection, and the focus on the whole student development. The qualitative content analysis of the reflections, comments, and course artifacts of the students indicated the increased effectiveness of learning, the better ability to apply the knowledge to real-life problems, and the beneficial effects on the students in terms of the habits, well-being, and engagement. The primary weakness was the limited sample size that limited the richness of individual experiences being studied. Further studies ought to increase the amount of data and investigate more qualitative information.

Wijnia et al. (2024) performed a meta-analysis to investigate how problem-driven learning models, such as PBL, PjBL and Case-Based Learning, impact the motivation of students when compared to the conventional lecture-oriented learning. A small to moderate positive effect ($d = 0.498$) of STEM and healthcare on the beliefs, task value, and attitudes of students was observed by the authors in the analysis of 139 subsamples with 132 studies. The analysis has found that individual course applications have more potent motivational effects compared to curriculum-wide applications. Nevertheless, the review has shown mixing in the findings, which means that the benefits of motivation are highly related to the academic setting, the level of implementation, and the effects of novelty which restrict the extrapolation of results to other fields as well as long-term results.

Sukackė et al. (2022) utilized a systematic literature review of 177 studies to examine the utilization of active learning strategies, i.e. PBL, PjBL, and CBL in engineering learning. The study examined the way these pedagogies could help foster sustainability, collaboration, and communication skills in future engineers using the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). The review found that CBL is most appropriate to incorporate sustainability and multidisciplinary cooperation and foster an alignment with Sustainable Development Goals (SDGs). Nonetheless, it was found that significant implementation challenges that include differences in teacher expertise, time, institutional, and technological support, and the inability of the students to adjust to the self-directed learning conditions occurred.

3.2 Project Based Learning

Lavado-Anguera et al. (2024) carried out a systematic literature review in order to investigate the functioning of PjBL as an experiential pedagogy as a method of acquiring real-world skills in engineering education. They searched two databases, 54 studies were included in the analysis during 24 years, and PjBL was evaluated in terms of its contribution to seven pillars of an integrated approach to pedagogy, such as technology, sustainability, and multidisciplinary integration. It was found in the review that PjBL is an efficient method of improving the student competencies and helps in designing a holistic curriculum. Nevertheless, there remain areas to apply PBL to multidisciplinary and technological settings, and there is a shortage of open-access articles and a lack of evidence about the practitioner and simulation-based learning setting, which implies that further empirical research is required.

Zhang et al. (2024) carried out a meta-analysis to assess whether PjBL influences the improvement of computational thinking in students in different levels of education. The review indicated that PjBL has a significant positive effect on the innovation, collaboration, critical thinking, algorithmic reasoning, and problem-solving skills of learners by synthesizing the results of 31 experimental and quasi-experimental studies quantitatively. The research also identified age-related impacts as younger students had superiority in collaboration and old students in critical reasoning. The results are however based on statistical inference as opposed to causal evidence and the sample size is limited and this can limit extrapolation. Also, the issue of teacher influence and background of the learners were not explored and therefore the surrounding could be explored further.

Hariharasakthisudhan et al. (2025) developed a hybrid model of Design Thinking (DT), Conceive-Design-Implement-Operate (CDIO) model, and Root Assessment (RA) to improve PjBL in engineering education. The framework was meant to address traditional PBL constraints through the synthesis of empathic ideation, systematic engineering design and evaluation. Applied in the creation of a Seed Injecting Machine, it allowed students to use the principles of sustainability-focused decision-making, prototyping in a loop, and involving the stakeholders. The methodology was successful in connecting conceptual knowledge to practical innovation, and interdisciplinary problem-solving and critical thinking. The limitation however of the study is that it was used in only one case and that it has to be tested further with many situations in the field of engineering to determine its scalability and generalization.

Crespi et al. (2022) used a quasi-experimental study to investigate the efficacy of the PjBL to enhance interpersonal communication and teamwork abilities of university students. The researchers used a questionnaire of personal competencies, which had undergone a test before in a previous study, and applied it to an experimental group (387 students) and a control group (223 students) of Madrid universities to use pre-test/post-test design. Findings affirmed that PjBL was significant in developing transversal skills in students, which fostered collaboration and communication needed in the globalized professional environment. The paper has emphasized the role of PBL in the development of holistic competence-based education. The drawbacks, however, are possible contextual bias because of the regional sample and the scarcity of generalization to the transversal topics or a short-term learning effect.

The purpose of the work by Rio et al. (2022) was to assess the usefulness of PjBL in promoting the knowledge and interest of students in Mechanical Design courses in Mechanical and Chemical Engineering studies. PjBL labs were used in the study with the use of 3D printing and Digital Image Correlation (DIC), supplemented by online instructional videos and student survey to assess the experiment. The results showed enhanced theoretical and practical knowledge integration, increased design and problem-solving, and student satisfaction. PjBL was a successful approach to learning and enthusiasm. Nevertheless, the method was time-consuming and to some extent difficult to some students, implying that fine tuning of the lab design and its application in a wider range of engineering programs to validate the same.

Guaya et al. (2025) suggested the vertically integrated model to bridge between postgraduate and undergraduate programmes of Applied Chemistry and Agricultural Engineering, in conjunction with PjBL and Community-Based Learning. The research design also entailed the synthesis of zeolite materials to extract nutrients by the postgraduate students, which were utilized by the undergraduates in field trials involving rural communities in the study which were assessed through rubrics, surveys, focus groups, and reflective journals. The research proved that technical, communication, and critical thinking skills have been improved, and the importance of the connection between theory and practice has been highlighted, as well as the social impact has been. Asynchronous cohort participation, undergraduate training in science communication, and logistical considerations in production of materials were some of the limitations, which suggested that it is better coordinated, the interdisciplinary training is broader, and the implementation can be scaled.

3.3 Collaborative Based Learning

In their article, Chang et al. (2022) explore the potential of using PBL and collaborative learning techniques in a flipped classroom in promoting learning motivation and outcomes in a C# programming course. The experimental and control group was comprised of ninety-six first-year students, where the performance and motivation were measured through pre- and post-tests and questionnaires. Findings revealed that heterogeneous grouping of the experimental group enhanced educational success in the low-scoring students, enhanced interaction and satisfaction with flipped classes and project-based learning, as well as collaborative learning. The study was however constrained by the single department sample used, limits in teaching content, interpersonal dynamics were not investigated, and no qualitative insights were made, thereby limiting the external generalizability and depth of the study.

Beemt et al. (2023) studied the effect of the active learning pedagogy on student engagement in remote laboratories in the higher engineering education. The research took a case study methodology in two systems and control courses where data were gathered in form of digital traces, interviews, observations, and course assessments. The results showed that open-ended laboratory assignments, teamwork and systematic feedback played a critical role in enhancing the engagement and subsuming theoretical knowledge to practice. Students appreciated the convenience and access of remote labs but needed more support in the direction of the processes and software utilization. Remote labs generated profound learning and self-regulation, but also required a lot of preparation, coordination and teacher intervention, which brings up issues of scalability and implementation needs to make such a lab more widespread.

The authors of the article by Doulougeri et al. (2024) used a systematic review to uncover the implementation of CBL in engineering education and discovered the challenges and lessons learned. They reviewed 48 studies of empirical data published in 2010-2021 based on the curricular spider-web framework. The results showed that there was a great difference in CBL implementation, between course-level to project-level activity with more focus on open-ended and real-life challenges that improve student engagement and transversal skills. Nevertheless, the challenge design, stakeholder engagement, and multidisciplinary were observed to have inconsistencies. The review has pointed to the possibilities of CBL to match education with societal problems, as well as its constraints i.e., its inconsistent definitions, variability in methodological usage and lack of evidence on its long-term educational effectiveness.

Du et al. (2022) sought to understand the way engineering students perceive and implement learner agency in PBL and PjBL set-ups. Q methodology (a combination of qualitative and quantitative analysis) was used to rank 40 statements about learner agency with 39 civil engineering Qatar-based students. The study found eight different perspectives, which represent various perceptions of agency on the intrapersonal, behavioural, and environmental dimensions. Findings indicated that students appreciated self-directed learning but most of them continued to be dependent on instructor-guided learning. The article provided theoretical information about learner agency in PBL, but its small sample size, the choice of the specific context, and the absence of in-depth qualitative studies like interviews were its weaknesses.

Erp et al. (2022) suggested a research-based, project based, and case-based teaching model that would help prepare manufacturing engineering students to handle complex innovation projects. The framework has been implemented and tested during a master course taught at the University of Southern Denmark through a proof-of-concept strategy. Student self-assessment results revealed that there was much improvement in research, design, and project management competencies, which verified that the framework is effective in connecting the theory with practice. Nevertheless, the research has such limitations as being based on self-reports, not having been longitudinally validated and lacks scalability across fields. It was proposed that further research is necessary to make the framework more refined and ensure a prolonged research quality design.

The aim of the study by Miranda et al. (2021) was to investigate the topic of Education 4.0 in higher education concerning the identification of essential elements and tracing its development in correlation with four industrial revolutions. The proposed study involved a framework that included competencies, learning methods, information and communication technologies, and infrastructure. Three engineering education case studies were reviewed to demonstrate how these elements can be put into practice. The findings demonstrated that the results are positive, with improved knowledge generation, transfer of information with peers, innovative solutions, and effective utilization of technological resources. The research is however limited in that it applies case studies that limit the generalizability. Further studies may be extended by conducting experimental research and examining its use not only in formal higher education but in a wider educational setting.

The authors of the study by Vodovozov et al. (2021) started with the purpose to investigate the effect of active learning (AL) on the students of engineering specialisation with a diverse background and knowledge level with the aim to determine the factors that have an effect on the engagement and success. The research involved four groups of learners in regards to individual involvement and performance, and examined the performance of student-focused methods in various levels of skills. It was found out that strong students had full advantage of AL whereas weaker students frequently needed extra guidance of teachers and working in small groups as well as in individual instructions in order to succeed. It was pointed out in the study that AL alone is not always effective and that it has to be supported by systematic orientation and support. One of the limitations is its attention to generalized AL activities and does not investigate specific interventions that would suit each type of learner.

Cho et al. (2021) examined the application of the flipped classroom in the field of mechanical engineering to solve the problem of big lecture-oriented courses. The research was to determine the efficacies of the use of flipped classrooms in academic performance and learning experiences of learners. The procedure was to compare the level of success of students in the flipped and traditional lecture systems with the addition of the open-ended survey feedback analysis to discuss the perceptions and experiences. Findings showed that the students of the flipped classroom were better performers, enjoyed pre-week online lectures, and claimed they were more engaged, self-regulated and autonomous. One of the limitations is that the research was conducted on a course and department and this might limit their extrapolation to other fields or even a larger group.

4. Research Gap

Although the active learning strategies are increasingly being adopted in engineering learning, there are still a number of gaps. To begin with, a comparative study between PBL, PjBL, and CL is not done so much concerning their effectiveness in particular areas of learning outcomes, including problem-solving, innovation, and collaboration skills. Second, the majority of research is either individual course or program, there is no evidence on how the curriculum can be implemented and scaled on a large scale. Third, little has been done to identify how these active learning strategies are influenced by technological tools, online platforms, and blended learning environments. Also, the problem of instructor readiness, institutional assistance, and student adaptation to self-directed learning is inconsistently discussed. Lastly, the longitudinal studies of the long-term effects of such approaches on the professional skills and employability of students are few, which is why more complex, multi-contextual research is required.

4.1 Research Questions and Results

1. How are Problem-Based Learning, Project-Based Learning, and Collaborative Learning implemented across different engineering courses?

PBL is applied to real-life problems, which are open-ended and require teamwork and critical thinking. PjBL concentrates on the design and implementation of projects that combine theory with practice and frequently uses labs, prototyping or simulations. The main principle of CL is the emphasis on collaborative activities in courses (peer instruction, group assignments, and collaborative problem solving) to increase engagement, communication, and knowledge integration in a heterogeneous group of students.

2. What strategies are used by educators to facilitate active learning in PBL, PjBL, and CL?

Teachers use scaffolding, guided inquiry and guided feedback in PBL. Project milestones, prototyping support, and stakeholder involvement are all incorporated in PjBL by the instructors. The CL approaches are the heterogeneous grouping, peer evaluation and collaborative online tools. In all approaches, the role of the teacher is transformed into facilitation, where the teacher gives the student the resources and follows the progress and encourages the learners to be self-directed and reflective.

3. How do learning environments and tools support the implementation of active learning?

Online platforms, flexible classes, and virtual laboratories improve the interaction and access of resources. The hands-on experiences, experimentation, and data analysis are supported by such tools as simulation software, 3D printing, GIS, and collaborative platforms. Such environments promote interaction, dialogue and self-directed learning besides allowing one to track the progress made, deliver immediate feedback and offer practical real-life context on how to solve problems, carry out projects and collaborate with others.

5. Findings and Analysis

In the Findings and Analysis section, more specific details are presented about the existing situation in sufficient research on active learning methods like problem-based, project-based, and collaborative learning in higher education. The new articles issued have suggested the viability of these techniques in developing the engagement, critical thinking, teamwork, and problem-solving skills of students. The potentials and obstacles of applying these strategies in different academic fields are also mentioned in this section. Results show that active learning enhances self-directed learning and increases academic and inter-personal competencies. But the issues of different student backgrounds, teacher readiness and complexities of assessment are also important obstacles. All in all, the analysis shows that although active learning models are very effective in facilitating meaningful learning experiences, their effective implementation needs to be guided by structures, continuous feedback, and institutional support in order to make it uniform and inclusive in various learning settings.

4.1 Overview of Findings

The summary of research shows that active learning approaches, especially PBL, PjBL, and CL, play an important role in transforming the traditional education into student-centred and experiential one. All of the reviewed articles written between 2021 and 2025 prove that the methods are effective in terms of developing the skills that help students to think analytically, work in a team, communicate, and self-direct their learning. PBL promotes the application of real-world issues in learning and enhancing the ability of learners to integrate theory with practice. On the contrary, PjBL encourages innovation and creativity by organizing projects, enhancing a profound comprehension and long-term remembrance of knowledge. Team learning enhances interaction and shared responsibility among peers and enhances interpersonal and social skills necessary in professional development. Although there are these benefits, there were identified challenges such as the differences in motivational levels among the students, learning styles and the willingness of the instructors to adjust to the active methodologies. A number of the studies noted that good implementation would need meticulous curriculum design, continuous mentorship and evaluation plans in consonance with the learning objectives. The use of technology, including digital platforms and game-based tools, was also observed to boost the interaction and involvement. In addition, reflective practices and learning through feedback loops were identified to have a positive effect on learning outcomes. To conclude, the results confirm active learning strategies provide the solution to the gap between the theoretical teaching and practical one, transforming the education process and making it more active, inclusive, and corresponding to the 21st-century skills demands.

4.2 Synthesis of Findings

The synthesis of results underlines the fact that recent studies in the field of engineering education use varied methods, including systematic reviews, meta-analyses, case studies, and mixed-method designs. All of these methods show that active learning models, such as PBL, PjBL, and CL, increase the level of engagement, collaboration, and critical thinking among learners. Quantitative methods gave objective changes to academic performance whereas qualitative analysis gave more insight into learner motivation and reflection. Nonetheless, research revealed limitations such as poor scalability, variation in methods and dependence on context also. In general, the synthesis highlights the complementarity of empirical and reflective inquiry to enhance the results of active learning.

Table 2. Critical Comparison of Methods and Tools

Methodology	Techniques	Strengths	Weaknesses
Systematic Literature Review	PRISMA, Thematic Coding	Comprehensive, evidence-based	Time-consuming, subjective inclusion
Meta-Analysis	Statistical Synthesis	Quantitative validation	Requires homogenous datasets
Case Study	Observation, Reflection	In-depth insights	Limited generalizability
Quasi-Experimental	Pre/Post-Test, Surveys	Measurable outcomes	Often lacks qualitative depth
Mixed-Method	Surveys + Interviews	Balanced perspectives	Resource intensive

Table 2 shows a methodological synopsis that compares the key research approaches and techniques chosen in the studies reviewed. The following table will attempt to summarize the methodological rigor and the diversity of the existing research arena on active learning. Having classified the studies based on their main methodological orientation it makes visible the most common tools, procedures, and analytical frameworks applied in the measurement of active learning outcomes. The purpose behind this table is to illustrate the strength and weaknesses of the methodology of various designs that can assist in getting grounded on the evidence that has been produced and tested out in the sector.

5.3 Comparative Analysis of Active Learning Approaches in Engineering Education

The comparative analysis of the studies reviewed proves the fact that PBL, PjBL, and CL are all the problems contributing to the engineering education outcomes in a different way. The key areas of PBL are effective specifically in the development of critical thinking, conceptual and self-directed learning, which were reported in the research of Ramos-Mejia et al. (2025) and Paul et al. (2023). PjBL, such as Lavado-Anguera et al. (2024) and Crespi et al. (2022) is good at developing useful skills, interdisciplinary integration, and teamwork with tangible projects, though it can be quite time-consuming to implement and can need a lot of instructor effort. Similar to the methods investigated by Chang et al. (2022) and Beemt et al. (2023), CL strategies encourage interaction, sharing of knowledge and learning among peers, and they are especially effective within heterogeneous teaching groups and online education.

The methodological domains of these studies include qualitative, quasi-experimental, meta-analytical and systematic reviews, that is, a variety of techniques used to evaluate learning outcomes, motivation and skill development. Contextually, variations can be observed at the undergraduate and postgraduate levels, disciplinary, and course formats, where STEM-oriented interventions frequently incorporate the elements of technology, gamification, and a flipped classroom. Although all of the active learning strategies contribute to improved engagement and practical competence, PBL and PjBL are better applicable to structured problem-solving and application, whereas CL is ideal in the context of social learning, collaboration, and motivation. This synthesis shows the supportive aspect of these methods and implies that the combination of PBL, PjBL, and CL can be the best learning outcomes in engineering education in various situations in the hybrid or modular framework.

Table 4. Pedagogical Criteria Comparison

No.	Description	PBL	PjBL	CL
1	Theoretical Perspective	Constructivist, student-centered	Experiential, constructivist	Social constructivist, interaction-focused
2	Teacher Role	Facilitator, guide, mentor	Facilitator, project supervisor	Coordinator, mediator, supporter
3	Knowledge Level	Conceptual understanding, critical thinking	Applied knowledge, practical problem-solving	Shared knowledge, collective understanding
4	Skills	Critical thinking, problem-solving	Technical, interdisciplinary, project management	Communication, teamwork, collaboration
5	Confidence Level	Moderate to high	High (through tangible project outcomes)	Moderate to high (peer support)
6	Motivation	High (real-world relevance)	High (ownership of projects)	Moderate to high (social engagement)
7	Performance	Improved individual learning and application	Enhanced integration of theory and practice	Improved group performance and engagement
8	Learner's Outcomes	Enhanced conceptual and transferable skills	Improved employability, holistic competencies	Enhanced teamwork, peer learning, and engagement

Table 4 gives an ordered comparison of the main pedagogical requirements of three main approaches to active learning in engineering education: PBL, PjBL, and CL. It is used to bring out the conceptual differences and instructional plans of each model, which regards the theoretical views, the role of the teacher, the level of knowledge, the development of the skills, the confidence of the learners, motivations, performance, and the overall results. The table is meant to provide the reader with a succinct insight into the differences between these active learning approaches in terms of how they encourage engagement among the students, their effectiveness in learning, and their ability to acquire competencies. With the help of this comparative framework, the table helps comprehend the pedagogical justification of each of the models and allows critically examine their applicability and effectiveness in educational environments in engineering.

5.4 Challenges and Research Limitations in Active Learning Implementation

The critical review of the analysed research shows that there are a number of notable weaknesses of the implementation and assessment of active learning methods in teaching engineering. First, in the majority of the studies, the research was done in one institution or even in a department, which constrained the extrapolation of the research to other learning settings. Small sample sizes were also frequent particularly in qualitative studies, limiting the capacity to make statistically significant inferences. Secondly, the longitudinal study evaluating the long-term effectiveness of such methods as PBL, PjBL, and CL in the context of long-term skill retention and career readiness is evidently missing.

The other important limitation is the inconsistencies in the methods. Other research papers partly relied on self-reported questionnaires and thought processes, which are subjective and might not reflect real learning results. Besides, differences in instructional design, expertise of instructor and support of the institution presented differences in the implementation of these methods, making it hard to compare studies across different studies. The metrics of assessment were also rather varied; some were based on academic results, there were those that measured it on qualitative reflections or observations of behaviour and made it hard to standardize.

Moreover, the lack of resources and technical preparation was also an obstacle to the adoption of such innovative models as flipped classrooms, gamified learning, and virtual labs. Other studies noted that weaker students found it difficult to deal with self-directed learning implying that active learning is not always effective and needs adequate scaffolding and teacher guidance. Lastly, there was a paucity of literature on equity and inclusiveness, which has left research gaps in the way different groups of students engage in active learning practices.

5.5 Emerging Directions and Pedagogical Trends in Engineering Education

The critical review reveals that there are some changing trends and innovations that are defining the future of engineering education using active learning. The fact that digital technology and virtual platforms have been integrated to facilitate interactive, flexible, and remote learning settings is also a major trend. Online collaborative tools like simulation software, online collaborative tools, and digital feedback systems are making lesson delivery to students more engaging and efficient in terms of instructor evaluation.

The other new phenomenon is the paradigm shift of teacher to learner and placing an emphasis upon autonomy, collaboration and learning by doing. Solutions that integrate Design Thinking (DT), Conceive-Design-Implement-Operate (CDIO) and Root Assessment (RA) are becoming popular to bring theory closer to practical and real-world problem solving.

The trend toward interdisciplinary and sustainability-oriented learning is also powerful, which is consistent with the SDGs of the world. Students are being engaged more in projects that focus on environment, social and economic issues thus making them think holistically, ethically and innovatively.

In addition, the management of motivation and performance in engineering education is being changed by the use of gamification and data-driven instruction. The strategic implementation of competitive aspects, performance analytics, and feedback loops is meant to make learning more personalized.

Lastly, there is an increased focus on collaborative and community-based models, with a linkage between the universities and industries as well as the people surrounding them. This tendency highlights the necessity of lifelong learning, flexibility, and practicality, which implies a shift of paradigm towards active meaningful and purpose-based learning in the engineering discipline.

6. Conclusion

This critical review has discussed the modern application of active learning practices, which are PBL, PjBL, and CL in engineering education. These pedagogical methods prove to change the paradigm of learning process, which is teacher-centred to a student-centred one, resulting in engagement, critical thinking, creativity, and problem-solving. In the 20 studies reviewed, PBL was found to be especially useful in developing conceptual learning, collaboration, and real-world problem-solving skills, but it needed substantial facilitation by instructors and a tight selection of challenges. PjBL enabled experiential learning because it combined real-world projects with technological tools and interdisciplinary teamwork, which led to the emergence of transferable skills (innovation, communication, and project management). Teamwork, motivation, and learner autonomy were also strengthened with the help of CL strategies such as flipped classes, peer collaborations, and challenge-based learning, but they required systematic organization and adequate scaffolding to make sure that every student has the same benefits.

The review also reflects on the most important trends regarding implementing active learning. We can also see the trend towards incorporating technology, gamification and digital mediums to improve interaction and self-directed learning. The importance of real-world problem contexts, interdisciplinary projects, and stakeholder engagement has also been growing in popularity, as an indication of the increasing demand to equip engineering students with what they will need in the complex professional settings of practice. Also, systematic feedback, iterative reflection, and student-centred scaffolding became the key elements to successful implementation. Nonetheless, there are still several shortcomings. In most studies, there is a shortage of sample population, single course scenarios, or even a region, which can restrict the generalizability. Difficulties in the areas of instructor preparedness, institutional backing, scalability, and optimization to self-directed learning were always witnessed. Further, there is limited longitudinal data regarding the effectiveness of active learning strategies in the long term in terms of professional competencies and employability.

This review highlights the possibilities of active learning strategies to change the paradigm of engineering education through facilitating meaningful learning, engagement, and overall skill development. The results recommend more systematic, comparative, and longitudinal studies, which assess various learning conditions, technological solutions, and implementation of curricula. The identified gaps can be used to advise educators, curriculum designers, and policymakers on the best methods of active learning and train engineering students to meet the needs of the current professional practice.

References

1. Adigun, Olufemi Timothy, Nhlanhla Mpofu, and Mncedisi Christian Maphalala. 2025. “Fostering Self-Directed Learning in Blended Learning Environments: A Constructivist Perspective in Higher Education.” Higher Education Quarterly 79 (1): e12572.
2. Ang, Karyne CS, Fatima Afzal, and Lynn Heather Crawford. 2021. “Transitioning from Passive to Active Learning: Preparing Future Project Leaders.” Project Leadership and Society 2: 100016.
3. Aqlan, Faisal, and Richard Zhao. 2021. “Assessment of Collaborative Problem Solving in Engineering Students through Hands-on Simulations.” IEEE Transactions on Education 65 (1): 9–17.
4. Asad, Muhammad Mujtaba, Aisha Naz, Prathamesh Churi, and Mohammad Mehdi Tahanzadeh. 2021. “Virtual Reality as Pedagogical Tool to Enhance Experiential Learning: A Systematic Literature Review.” Education Research International 2021 (1): 7061623.
5. Capone, Roberto. 2022. “Blended Learning and Student-Centered Active Learning Environment: A Case Study with STEM Undergraduate Students.” Canadian Journal of Science, Mathematics and Technology Education 22 (1): 210–36.
6. Chang, Yi-Hsing, Yin-Chen Yan, and You-Te Lu. 2022. “Effects of Combining Different Collaborative Learning Strategies with Problem-Based Learning in a Flipped Classroom on Program Language Learning.” Sustainability 14 (9): 5282.
7. Chen, Chin-Sung, and Jing-Wen Lin. 2021. “An Action Research on the Long-Term Implementation of an Engineering-Centered PjBL of Sustainable Energy in a Rural Middle School.” Sustainability 13 (19): 10626.
8. Chidthachack, Sousada, Mark A Schulte, Forster D Ntow, Jia-Ling Lin, and Tamara J Moore. 2021. “Engineering Students Learn ABET Professional Skills: A Comparative Study of Project-Based-Learning (PBL) versus Traditional Students.” 2013 North Midwest Section Meeting.
9. Cho, Hyun Jin, Kejie Zhao, Cho Rong Lee, Debra Runshe, and Chuck Krousgrill. 2021. “Active Learning through Flipped Classroom in Mechanical Engineering: Improving Students’ Perception of Learning and Performance.” International Journal of STEM Education 8 (1): 46.
10. Coronado, José M, Amparo Moyano, Vicente Romero, Rita Ruiz, and Javier Rodríguez. 2021. “Student Long-Term Perception of Project-Based Learning in Civil Engineering Education: An 18-Year Ex-Post Assessment.” Sustainability 13 (4): 1949.
11. Crespí, Paula, José Manuel García-Ramos, and Marián Queiruga-Dios. 2022. “Project-Based Learning (PBL) and Its Impact on the Development of Interpersonal Competences in Higher Education.” Journal of New Approaches in Educational Research 11 (2): 259–76.
12. Čubela, Dino, Alexander Rossner, and Pascal Neis. 2023. “Using Problem-Based Learning and Gamification as a Catalyst for Student Engagement in Data-Driven Engineering Education: A Report.” Education Sciences 13 (12): 1223.

13. Doulougeri, Karolina, Jan D Vermunt, Gunter Bombaerts, and Michael Bots. 2024. "Challenge-Based Learning Implementation in Engineering Education: A Systematic Literature Review." Journal of Engineering Education 113 (4): 1076–106.
14. Du, Xiangyun, Adrian Lundberg, Mohamed A Ayari, Khalid K Naji, and Alaa Hawari. 2022. "Examining Engineering Students' Perceptions of Learner Agency Enactment in Problem-and Project-Based Learning Using Q Methodology." Journal of Engineering Education 111 (1): 111–36.
15. Elaby, Mohammed F, Hesham M Elwishy, Saeed F Moatamed, Mahmoud A Abdelwahed, and Ahmed E Rashiedy. 2022. "Does Design-Build Concept Improve Problem-Solving Skills? An Analysis of First-Year Engineering Students." Ain Shams Engineering Journal 13 (6): 101780.
16. Erp, Tim van. 2022. "Combining Research-, Project-, and Case-Based Learning in Higher Manufacturing Engineering Education." Global Conference on Sustainable Manufacturing, 1016–24.
17. Gomez-del Rio, T, and J Rodriguez. 2022. "Design and Assessment of a Project-Based Learning in a Laboratory for Integrating Knowledge and Improving Engineering Design Skills." Education for Chemical Engineers 40: 17–28.
18. Guaya, Diana, Juan Carlos Romero-Benavides, Natasha Fierro, and Leticia Jiménez. 2025. "Integrating Project-Based and Community Learning for Cross-Disciplinary Competency Development in Nutrient Recovery." Sustainability 17 (19): 8820.
19. Hadibarata, Tony, Topik Hidayat, and James Kwabena. 2023. "Problem Based Learning in Engineering Course in Malaysia." Acta Pedagogia Asiana 2 (2): 95–105.
20. Hariharasakthisudhan, P, K Logesh, K Sathickbasha, and Sathish Kannan. 2025. "Enhancing Project-Based Learning in Engineering Education: A Hybrid DT-CDIO-RA Framework for Sustainable Product Design." Discover Education 4 (1): 138.
21. Joshi, Kapil, Rajesh Kumar, Salil Bharany, et al. 2024. "Exploring the Connectivity between Education 4.0 and Classroom 4.0: Technologies, Student Perspectives, and Engagement in the Digital Era." IEEE Access 12: 24179–204.
22. Kozanitis, Anastassis, and Lucian Nenciovici. 2023. "Effect of Active Learning versus Traditional Lecturing on the Learning Achievement of College Students in Humanities and Social Sciences: A Meta-Analysis." Higher Education 86 (6): 1377–94.
23. Kumar, Vinod Vijay, Deborah Carberry, Christian Beenfeldt, Martin Peter Andersson, Seyed Soheil Mansouri, and Fausto Gallucci. 2021. "Virtual Reality in Chemical and Biochemical Engineering Education and Training." Education for Chemical Engineers 36: 143–53.
24. Lavado-Anguera, Silvia, Paloma-Julia Velasco-Quintana, and María-José Terrón-López. 2024. "Project-Based Learning (PBL) as an Experiential Pedagogical Methodology in Engineering Education: A Review of the Literature." Education Sciences 14 (6): 617.
25. Marcinauskas, Liutauras, Aleksandras Iljinas, Jurgita Čyvienė, and Vytautas Stankus. 2024. "Problem-Based Learning versus Traditional Learning in Physics Education for Engineering Program Students." Education Sciences 14 (2): 154.
26. Marley, Sarah A, Alessandro Siani, and Stuart Sims. 2022. "Real-Life Research Projects Improve Student Engagement and Provide Reliable Data for Academics." Ecology and Evolution 12 (12): e9593.
27. Marougkas, Andreas, Christos Troussas, Akrivi Krouska, and Cleo Sgouropoulou. 2023. "Virtual Reality in Education: A Review of Learning Theories, Approaches and Methodologies for the Last Decade." Electronics 12 (13): 2832.
28. Marra, Rose M, Douglas J Hacker, and Carolyn Plumb. 2022. "Metacognition and the Development of Self-Directed Learning in a Problem-Based Engineering Curriculum." Journal of Engineering Education 111 (1): 137–61.
29. Miranda, Jhonattan, Christelle Navarrete, Julieta Noguez, et al. 2021. "The Core Components of Education 4.0 in Higher Education: Three Case Studies in Engineering Education." Computers & Electrical Engineering 93: 107278.
30. Monrat, Natthanon, Mingkhuan Phaksunchai, and Ratchanikorn Chonchaiya. 2022. "Developing Students' Mathematical Critical Thinking Skills Using Open-Ended Questions and Activities Based on Student Learning Preferences." Education Research International 2022 (1): 3300363.
31. Neves, Renato Martins, Rui M Lima, and Diana Mesquita. 2021. "Teacher Competences for Active Learning in Engineering Education." Sustainability 13 (16): 9231.
32. Nguyen, Kevin A, Maura Borrego, Cynthia J Finelli, et al. 2021. "Instructor Strategies to Aid Implementation of Active Learning: A Systematic Literature Review." International Journal of STEM Education 8 (1): 9.

33. Nilimaa, Jonny. 2023. "New Examination Approach for Real-World Creativity and Problem-Solving Skills in Mathematics." Trends in Higher Education 2 (3): 477–95.
34. Oseni, Rukayat Ejide, Prisca Adejumo, and IO Kolawole. 2022. "Conceptual Analysis of Student-Centred Learning." International Journal of Medicine, Nursing & Health Sciences, 15–28.
35. Patiño, Azeneth, María Soledad Ramírez-Montoya, and Mariana Buenestado-Fernández. 2023. "Active Learning and Education 4.0 for Complex Thinking Training: Analysis of Two Case Studies in Open Education." Smart Learning Environments 10 (1): 8.
36. Paul, Robyn Mae, Yani Jazayeri, Laleh Behjat, and Michael Potter. 2023. "Design of an Integrated Project-Based Learning Curriculum: Analysis through Fink's Taxonomy of Significant Learning." IEEE Transactions on Education 66 (5): 457–67.
37. Ramos-Mejía, Aurora, and Kira Padilla. 2025. "A Problem-Based Learning Electrochemistry Course for Undergraduate Students to Develop Complex Thinking." Education Sciences 15 (3): 320.
38. Roy, Mousumi, and Abhijit Roy. 2021. "The Rise of Interdisciplinarity in Engineering Education in the Era of Industry 4.0: Implications for Management Practice." IEEE Engineering Management Review 49 (3): 56–70.
39. Silva, Rita, Cláudio Farias, and Isabel Mesquita. 2021. "Cooperative Learning Contribution to Student Social Learning and Active Role in the Class." Sustainability 13 (15): 8644.
40. Sukackė, Vilma, Aida Olivia Pereira de Carvalho Guerra, Dorothea Ellinger, et al. 2022. "Towards Active Evidence-Based Learning in Engineering Education: A Systematic Literature Review of PBL, PjBL, and CBL." Sustainability 14 (21): 13955.
41. Tharwat, Alaa, and Wolfram Schenck. 2023. "A Survey on Active Learning: State-of-the-Art, Practical Challenges and Research Directions." Mathematics 11 (4): 820.
42. Torrijo, Francisco Javier, Julio Garzón-Roca, Guillermo Cobos, and Miguel Ángel Eguibar. 2021. "Combining Project Based Learning and Cooperative Learning Strategies in a Geotechnical Engineering Course." Education Sciences 11 (9): 467.
43. Van den Beemt, Antoine, Suzanne Groothuijsen, Leyla Ozkan, and Will Hendrix. 2023. "Remote Labs in Higher Engineering Education: Engaging Students with Active Learning Pedagogy." Journal of Computing in Higher Education 35 (2): 320–40.
44. Vodovozov, Valery, Zoja Raud, and Eduard Petlenkov. 2021. "Challenges of Active Learning in a View of Integrated Engineering Education." Education Sciences 11 (2): 43.
45. Welsen, Sherif. 2023. "Fostering Self-Directed Learning in Engineering Undergraduates: A Collaborative Approach." International Conference on Interactive Collaborative Learning, 12–19.
46. Wijnia, Lisette, Gera Noordzij, Lidia R Arends, Remigius MJP Rikers, and Sofie MM Loyens. 2024. "The Effects of Problem-Based, Project-Based, and Case-Based Learning on Students' Motivation: A Meta-Analysis." Educational Psychology Review 36 (1): 29.
47. Xu, Zhihong, Xuan Zhou, John Watts, and Ashlynn Kogut. 2023. "The Effect of Student Engagement Strategies in Online Instruction for Data Management Skills." Education and Information Technologies 28 (8): 10267–84.
48. Zamiri, Majid, and Ali Esmaeili. 2024. "Strategies, Methods, and Supports for Developing Skills within Learning Communities: A Systematic Review of the Literature." Administrative Sciences 14 (9): 231.
49. Zappatore, Marco. 2024. "Incorporating Collaborative and Active Learning Strategies in the Design and Deployment of a Master Course on Computer-Assisted Scientific Translation." Technology, Knowledge and Learning 29 (1): 253–308.
50. Zhang, Wuwen, Yurong Guan, and Zhihua Hu. 2024. "The Efficacy of Project-Based Learning in Enhancing Computational Thinking among Students: A Meta-Analysis of 31 Experiments and Quasi-Experiments." Education and Information Technologies 29 (11): 14513–45.