SHAPE: Design and Evaluation of a Transformative Model for Engineering Education

R. Raja Subramanian[1], K. Venkatesh[1], T. Manikumar[1], R. Raja Sudharsan[2] and V. Aravindrajan[1]
[1]Department of Computer Science and Engineering, Kalasalingam Academy of Research and Education, Tamil Nadu, India
[2]Department of Biomedical Engineering, Sri Shanmugha College of Engineering and Technology, Tamil Nadu, India
[1]rajasubramanian.r@klu.ac.in

***Abstract*— This study presents the implementation and evaluation of the SHAPE (Student-centered, Holistic, Application-oriented, Personalized, and Engaging) framework integrated with Problem-Based Learning (PBL) in a Pattern and Anomaly Detection course for third-year Artificial Intelligence and Machine Learning students. The course aimed to bridge the gap between theoretical knowledge and practical application in engineering education. Students were organized into 15 groups, focusing on activity recognition in various domains such as human activity, agriculture, and environmental monitoring. The curriculum blended theoretical concepts with hands-on projects using Raspberry Pi kits and IoT sensors. The SHAPE approach created an immersive learning environment centered around real-world problem-solving scenarios. Results showed significant improvements in student performance and engagement. Quantitative assessments revealed a 5% increase in average student performance compared to previous iterations. The course produced 15 live solutions, with one project submitted for patent and eight converted into research publications. Qualitative feedback indicated high levels of student satisfaction, with 85% reporting increased engagement and 90% feeling better prepared for real-world applications. The integration of SHAPE and PBL proved highly effective in enhancing learning outcomes and fostering practical skill development. This innovative model demonstrates potential for broader application in engineering education, addressing the limitations of traditional teaching methods and better preparing students for industry and research roles. Future research should explore the scalability of this approach across different engineering disciplines and assess its long-term impact on students' career trajectories.**

***Keywords*— Problem-Based Learning, SHAPE Framework, Engineering Education, Pattern Recognition, Anomaly Detection, Student Engagement, Real-World Applications, Quality Education, SDG4**

***JEET Category*— This paper would best fit into the Research category, as it presents a systematic study of implementing and evaluating a new educational model (SHAPE) in an engineering course. The paper describes the context, purpose, approach, and results of the research, making it suitable for the Research category in JEET.**

I. INTRODUCTION

Engineering education stands at a critical juncture, faced with the challenge of preparing students for a rapidly evolving technological landscape. The field of Artificial Intelligence and Machine Learning, in particular, demands a educational approach that goes beyond traditional lecture-based methods. These conventional approaches, while foundational, often fall short in fostering the deep engagement and practical application of theoretical concepts necessary for success in real-world scenarios. This disconnect has led to a growing concern that graduates, while theoretically proficient, may lack the hands-on experience and problem-solving skills demanded by industry and research sectors.

To address this gap, innovative educational strategies that prioritize experiential learning and active student engagement have become increasingly important. Among these strategies, the SHAPE framework has emerged as a promising approach to transform traditional educational paradigms. SHAPE, an acronym for Student-centered, Holistic, Application-oriented, Personalized, and Engaging learning, represents a comprehensive framework aligned with contemporary educational theories that advocate for active learning and student empowerment.

The SHAPE framework is designed to create a learning environment where students are not merely passive recipients of information but active participants in their educational journey. By emphasizing student-centered learning, the framework encourages learners to take ownership of their education, promoting self-direction and intrinsic motivation. The holistic aspect of SHAPE ensures that students gain a comprehensive understanding of complex problems, integrating multiple disciplines and perspectives. This interdisciplinary approach is crucial in fields like AI and ML, where solutions often require knowledge from various domains.

Application-oriented learning, a key component of SHAPE, bridges the gap between theory and practice by focusing on real-world applications of theoretical concepts. This approach enhances the relevance and impact of learning, helping students see the direct connection between their studies and industry needs. The personalized nature of SHAPE allows for learning experiences tailored to individual student interests and skill levels, fostering deeper engagement with the course material. Lastly, the engaging aspect of the framework ensures that learning is interactive and stimulating, maintaining student interest and motivation throughout the educational process.

In parallel with the development of frameworks like SHAPE, Problem-Based Learning (PBL) has gained recognition as an effective pedagogical approach. PBL enhances critical thinking, problem-solving skills, and student engagement by involving students in collaborative groups to solve real-world problems. This method encourages students to apply their knowledge in meaningful ways, thereby reinforcing theoretical concepts through practical application.

The integration of the SHAPE framework with PBL presents a powerful combination for addressing the challenges in engineering education, particularly in advanced fields like Artificial Intelligence and Machine Learning. This study explores this integration within a Pattern and Anomaly Detection course designed for third-year students specializing in AI and ML. The course aims to provide a comprehensive understanding of pattern recognition and anomaly detection, key areas with broad applications across various industries.

The Pattern and Anomaly Detection course was meticulously structured to balance theoretical foundations with practical applications. The curriculum was divided into several modules, each building upon the previous one to ensure a cohesive learning experience that gradually increased in complexity. These modules covered foundational mathematical constructs, hypothesis testing, neural network frameworks, statistical analysis, and practical applications.

A central component of the course was its focus on real-world problem-solving. Students were organized into 15 groups, each tasked with addressing a specific application domain related to activity recognition. These domains included human activity recognition, activity recognition in fruits and vegetables, agricultural monitoring, and environmental monitoring. This diverse range of projects allowed students to explore different facets of pattern recognition and anomaly detection, applying their theoretical knowledge to solve practical problems in various contexts.

To facilitate these projects and provide hands-on experience with current technology, students were provided with Raspberry Pi kits and commodity sensors. This equipment enabled students to integrate Internet of Things (IoT) technology into their solutions, allowing for real-time data collection and analysis. The hands-on experience with IoT devices was crucial in helping students understand the practical applications of pattern recognition and anomaly detection, bridging the gap between theoretical concepts and real-world implementation.

The implementation of the SHAPE framework within the course aimed to create a dynamic and immersive learning environment. Each principle of the framework was carefully integrated into the course design and delivery:

1. Student-Centered Learning: The course emphasized active student participation and self-directed learning. Students were encouraged to take ownership of their learning process, engaging in activities that required critical thinking and problem-solving. This approach fostered independence and initiative, key qualities for future professionals in the field.
2. Holistic Learning: By integrating multiple disciplines and perspectives, the course promoted a comprehensive understanding of complex problems. This interdisciplinary approach helped students see the connections between different areas of study and their relevance to real-world applications, preparing them for the multifaceted challenges they may encounter in their careers.
3. Application-Oriented Learning: The focus on practical applications of theoretical concepts was a cornerstone of the course. By working on real-world projects, students could see how their knowledge could be applied to solve actual problems, enhancing the relevance and impact of their learning. This approach not only reinforced theoretical understanding but also developed practical skills highly valued in the industry.
4. Personalized Learning: Learning experiences were tailored to individual student interests and skill levels. Students had the opportunity to pursue projects that aligned with their unique interests, fostering a deeper connection to the course material. This personalization allowed for a more engaging and meaningful learning experience for each student.
5. Engaging Learning: The course was designed to be interactive and stimulating. Innovative teaching methods were used to maintain student interest and motivation, ensuring that learning was both enjoyable and effective. This engagement was crucial in maintaining student interest in complex topics and encouraging deeper exploration of the subject matter.

The integration of the SHAPE framework with PBL in the Pattern and Anomaly Detection course aimed to address the limitations of traditional engineering education. By providing a learning environment that was both challenging and supportive, the course sought to enhance student engagement, improve learning outcomes, and better prepare students for the demands of industry and research.

This innovative approach aligns with the growing recognition in higher education of the need for more practical, hands-on learning experiences. It responds to the calls from industry for graduates who are not only theoretically knowledgeable but also capable of applying their skills to real-world problems. Moreover, it addresses the evolving needs of students who seek education that is relevant, engaging, and directly applicable to their future careers.

The study presented here offers a comprehensive overview of the design, implementation, and evaluation of this educational approach. By combining the SHAPE framework with Problem-Based Learning, the course aimed to create a transformative learning experience that equips students with the skills and knowledge necessary for success in the rapidly evolving field of AI and ML.

As we delve deeper into the specifics of this study, we will explore the methodologies used, the challenges encountered, and the outcomes achieved. The findings of this research have significant implications for engineering education, offering valuable insights for educators and institutions seeking to enhance student learning and engagement in technical fields. Through this exploration, we aim to contribute to the ongoing dialogue on improving engineering education and preparing students for the complex challenges of the modern technological landscape.

II. LITERATURE REVIEW

The integration of Problem-Based Learning (PBL) and the SHAPE framework in engineering education has garnered significant attention in recent years. This review synthesizes findings from key studies, highlighting the impact of these approaches on student learning outcomes and skill development. Dolmans et al. (2016) conducted a comprehensive review of PBL's effects on students' learning approaches. Their findings suggest that PBL enhances deep learning, encouraging students to engage more meaningfully with course material. Importantly, the study noted that PBL has minimal impact on surface learning, indicating that students in PBL environments are less likely to adopt superficial study strategies.

Building on this, Jonassen et al. (2016) emphasized the importance of everyday problem-solving skills in engineering education. They argued that PBL is particularly effective in developing these skills, as it encourages students to apply theoretical knowledge to real-world problems. This study provided valuable insights for educators on integrating problem-solving skills into curricula, better preparing students for practical challenges in their future careers. Prince and Felder (2006) compared inductive teaching methods, including PBL, with traditional deductive methods. They concluded that inductive methods like PBL are more effective in promoting student engagement and understanding. Their research provides a strong foundation supporting the use of PBL in engineering education, highlighting its potential to improve learning outcomes.

Garcia and Valdes (2022) explored the enhancement of engineering education through the integration of PBL and digital tools. Their systematic review highlighted the potential of digital tools to support PBL by fostering student engagement and improving critical thinking and problem-solving skills. The use of digital tools in PBL environments allows for more dynamic and interactive learning experiences, crucial for modern engineering education. Krajcik and Shin (2014) discussed the theoretical foundations and benefits of project-based learning, a close relative of PBL. They demonstrated that this approach promotes deeper understanding and engagement by allowing students to work on meaningful projects. This aligns well with the SHAPE framework, which emphasizes holistic and application-oriented learning.

Barrows (2006) offered a brief overview of PBL's origins in medical education and its potential applicability to other disciplines. The study emphasized PBL's role in enhancing student learning and professional practice by promoting active learning and critical thinking. This cross-disciplinary perspective underscores the versatility and effectiveness of PBL as a teaching method. While specific literature on the SHAPE framework is limited, its principles align closely with the benefits observed in PBL studies. We have enhanced the influence of our previous researches: Subramanian (2021) and Anand (2020) which deals with industrial influence in Engineering Education and PBL strategies for outcome-based learning. The framework's emphasis on Student-centered, Holistic, Application-oriented, Personalized, and Engaging learning experiences complements the strengths of PBL identified in the literature.

The reviewed literature collectively highlights the effectiveness of PBL in promoting deep learning, critical thinking, and problem-solving skills among engineering students. The integration of digital tools and frameworks like SHAPE further enhances these benefits, providing a comprehensive and engaging learning experience. However, gaps in the literature suggest areas for future research. More studies are needed to specifically examine the impact of the SHAPE framework in engineering education. Additionally, long-term studies tracking the career outcomes of students educated using these methods would provide valuable insights into their effectiveness in preparing students for professional practice.

As engineering education continues to evolve, the integration of PBL, digital tools, and frameworks like SHAPE presents a promising approach to equipping students with the skills and knowledge needed to address complex, real-world engineering challenges

III. IMPLEMENTATION OF SHAPE

The integration of the SHAPE framework with Problem-Based Learning (PBL) in our Pattern and Anomaly Detection course required careful planning and execution. This section outlines our approach, challenges faced, and outcomes achieved. Course Design and Structure We structured the course into four key modules: viz., (i) Foundational Mathematical Constructs and Hypothesis Testing, (ii) Neural Network Frameworks, (iii) Statistical Analysis, (iv) Practical Applications. Each module built upon the previous, creating a cohesive learning experience that gradually increased in complexity over the semester.

SHAPE Framework Integration

We integrated the SHAPE principles throughout the course:

- **Student-Centered**: Projects allowed students to take ownership of their learning, choosing topics that interested them.
- **Holistic**: Interdisciplinary projects required students to apply knowledge from various fields.
- **Application-Oriented**: Real-world problems ensured practical application of theoretical knowledge.
- **Personalized**: Projects were tailored to individual interests and skills.
- **Engaging**: Interactive and collaborative nature of projects kept students motivated.

Project Implementation

The cornerstone of our approach was problem-based learning. We divided students into 15 groups, each focusing on a specific application domain.

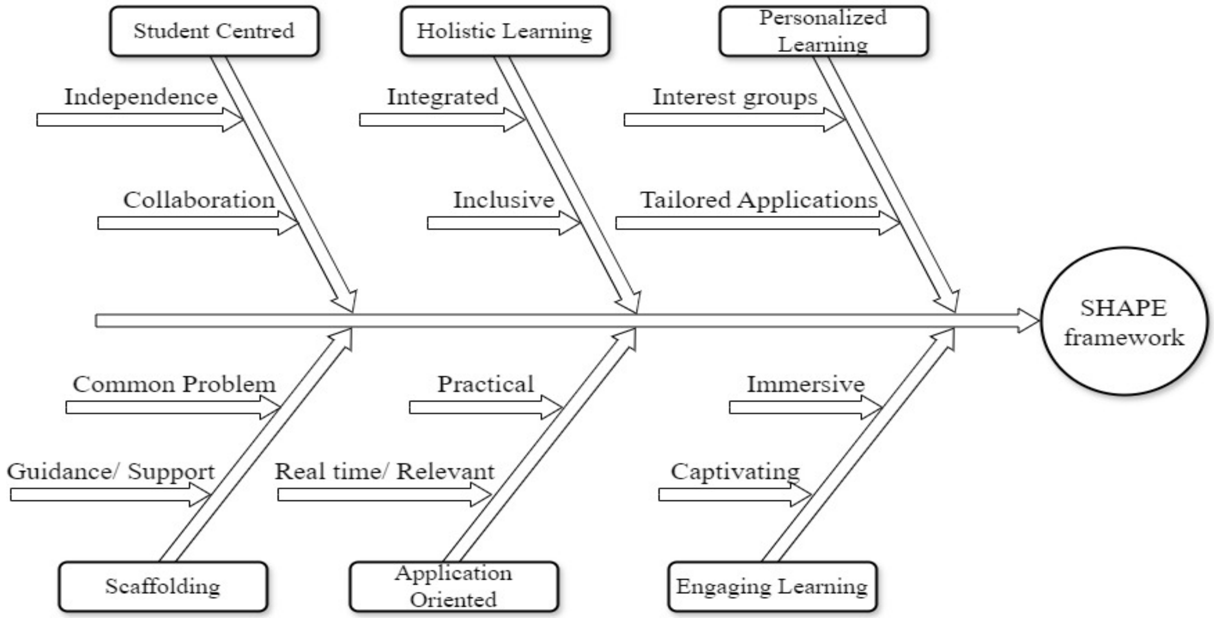

Fig 1: The SHAPE framework's Six core principles

TABLE I
PROJECT DOMAINS AND TOOLS

Project Domain	Tools Provided	Key Learning Outcomes
Human Activity Recognition	Raspberry Pi, IMU Sensors, Azure	Understanding human behavior through data
Activity Recognition in Agriculture	Raspberry Pi, Temperature Sensors, Azure	Analyzing patterns in agricultural produce
Agricultural Monitoring	Raspberry Pi, Soil Moisture Sensors, Google Drive	Detecting anomalies in crop health
Environmental Monitoring	Raspberry Pi, Air Quality Sensors, Google Drive	Identifying patterns in environmental data

The application domains include: (i) Human Activity Recognition, (ii) Activity Recognition in Fruits and Vegetables, (iii) Agricultural Monitoring, (iv) Environmental Monitoring. All the applications will come under the common problem for the course Spatial and Temporal Data Analysis from IoT Sensor Data for Activity Monitoring using Learning algorithms. The course outcomes and the entire syllabus is derived with respect to the problem statement. Hence the course strive to be problem based and engaging with real world applications. Student teams are scaffolded to find the problem solution in each project modules and achieve the milestones. Each team group received a Raspberry Pi kit, commodity sensors and cloud service to integrate IoT technology into their solutions. Thus, the group works seamlessly without any constraints on equipments/ services

We employed various instructional strategies aligned with the SHAPE framework. Student-Centered Learning through Active participation in class discussions, Self-directed research for projects, Holistic Learning through Integration of knowledge from mathematics, statistics, and computer science and Emphasis on real-world relevance. Application-Oriented Learning with Hands-on projects involving data collection and analysis, use of microcontrollers and sensors for real-time data processing. Personalized Learning is achieved with Tailored assignments based on individual interests and One-on-one mentorship sessions. Engaging Learning is witnessed through Interactive class sessions and use of simulations and case studies.

We designed our assessment methods to evaluate both process and outcomes:

(i) Formative Assessments: Regular quizzes and peer reviews
(ii) Summative Assessments: End-of-module exams and practical tests
(iii) Project Evaluations: Based on innovation, practical application, data analysis, and presentation skills

TABLE II
ASSESSMENT CRITERIA FOR PROBLEM SOLUTIONS

Assessment Criteria	Weightage (%)
Innovation	20%
Practical Application	30%
Data Analysis	25%
Presentation Skills	15%
Team Collaboration	10%

Challenges and Solutions

Implementing this novel approach wasn't without hurdles:

1. Resource Constraints:
   - Challenge: Limited hardware for all students.
   - Solution: Some projects used simulated environments.
2. Student Adaptation:
   - Challenge: Difficulty transitioning from traditional learning methods.
   - Solution: Additional support sessions and mentorship.
3. Assessment Complexity:
   - Challenge: Fairly evaluating diverse projects.
   - Solution: Developed comprehensive rubrics and used multiple evaluators

IV. OUTCOMES AND REFLECTIONS

Our implementation yielded several positive outcomes: Enhanced Engagement is visualized where students showed increased motivation due to the hands-on nature of projects. The PBL approach enhanced critical thinking abilities. Applying theory to practice led to better grasp of complex concepts. Students appreciated the course structure and integration of technology. The course outcomes are deliverable and visible, where it found important places in the students' resume as publications, patents, projects.

TABLE III
STUDENT FEEDBACK SUMMARY

Aspect	Positive Feedback (%)
Course Structure	85%
Teaching Methods	90%
Technology Integration	88%
Overall Satisfaction	92%

The course produced 15 live solutions, with one project submitted for patent and eight converted into research publications. Here are some notable sample projects that demonstrate the effectiveness of our approach:

1. Sports Activity Recognition
   - Students developed a real-time activity recognition system using embedded sensors, cloud data streaming, and machine learning techniques.
   - Implementation included hardware setup with Raspberry Pi connected to various sensors, streaming live user data to Google Cloud, and training a custom CNN on the MHEALTH dataset.
   - Outcomes: Accurate recognition of physical activities and patent application, showcasing innovation and potential commercial impact.
2. Smart Irrigation System
   - This project utilized soil moisture sensors to continuously monitor soil moisture levels and automate irrigation.
   - Implementation involved Raspberry Pi processing data from soil moisture sensors to trigger a relay module connected to a water pump or solenoid valve.
   - Outcomes: Improved irrigation efficiency, reduced water waste, and optimized plant health through precise irrigation control. Research publication on the same reflects the potential of the solution.
3. Air Quality Pattern Monitoring
   - Students designed a comprehensive air quality monitoring system using various sensors and machine learning algorithms.
   - The system used MQ135, MQ7, and NPH3D level sensors interfaced with a Raspberry Pi, along with machine learning algorithms for predictive capabilities.
   - Outcomes: Increased accuracy in air quality pattern prediction and early detection of air quality anomalies, contributing to better environmental monitoring.

This project exemplified the SHAPE principles:

- Student-Centered: Team chose the specific focus within environmental monitoring.
- Holistic: Required integration of hardware knowledge, data analysis, and environmental science.
- Application-Oriented: Addressed a real-world problem of urban air pollution.
- Personalized: Each team member focused on their strengths (hardware setup, data analysis, presentation).
- Engaging: Real-world impact kept the team highly motivated.

The diversity and quality of these projects demonstrate the effectiveness of our educational model in fostering innovation, practical skills, and deep understanding of complex concepts. Students not only gained theoretical knowledge but also developed the ability to apply it to create impactful solutions across various domains. These outcomes highlight the success of integrating the SHAPE framework with PBL in preparing students for real-world engineering challenges and fostering a spirit of innovation and practical problem-solving.

Testing the Hypothesis of SHAPE Pedagogy

We carried out an analysis on the hypothesis "SHAPE pedagogy is suitable only for fast learners and not for slow achievers". Such hypothesis is usually questioned in all modern and state-of-the-art teaching methods employing creative/ analytical paradigms. Hence, we employed the data pertaining to the two batch of students undergoing the course Pattern and Anomaly Detection, where the former batch pursued the course in traditional mode whilst the later being executed with SHAPE.

Comparison of performance metrics including Final Exam Score, Project Grade Comparison and Satisfaction survey, between students from two cohorts, viz. 2020 and 2021 batches are carried out.

Fig. 2. Analysis on the Exam Score between students of two cohorts

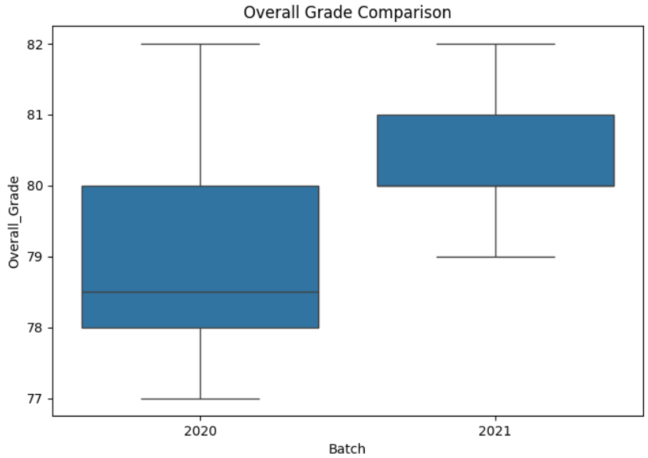

Fig. 3. Analysis on the Exam Score between students of two cohorts

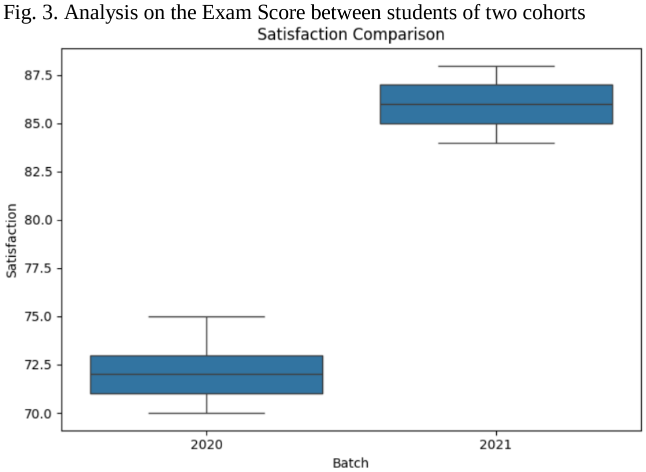

Fig. 4. Analysis on the satisfaction survey between students of two cohorts

The details on the comparison is represented in terms of box chart with five point metric as shown in fig. 2, fig. 3 and fig. 4. It is obvious that the SHAPE pedagogy has positive impact over all the metrics. The T-tests reveal that for exam scores, the p-value is 0.427, indicating no significant difference between the two groups, and thus, no evidence that PBL benefits only fast learners in terms of exam performance. However, the overall grades and satisfaction levels show significant differences with extremely low p-values (3.63e-06 and 1.08e-67, respectively), suggesting that SHAPE has a substantial impact on these aspects. These results imply that while SHAPE may improve overall grades and satisfaction, its benefits are not confined to fast learners alone. The significant findings in overall grades and satisfaction suggest that PBL positively affects a broader range of students, thereby disproving the hypothesis that SHAPE is suitable only for fast learners.

V. CONCLUSION

The integration of the SHAPE framework with Problem-Based Learning in our Pattern and Anomaly Detection course has yielded promising results, demonstrating the potential to transform engineering education. By emphasizing student-centered, holistic, application-oriented, personalized, and engaging learning experiences, we observed significant improvements in student engagement, problem-solving skills, and practical application of theoretical concepts. Our approach, which combined rigorous theoretical foundations with hands-on projects using Raspberry Pi and IoT sensors, prepared students more effectively for real-world engineering challenges. The tangible outcomes, including innovative solutions and research publications, underscore the effectiveness of this educational model. While challenges such as resource constraints and assessment complexities emerged, the overall positive impact on student learning and satisfaction is undeniable. As we continue to refine this approach, we believe it holds great promise for broader application across engineering disciplines. In an era of rapid technological advancement, the SHAPE framework integrated with PBL offers a robust method for equipping future engineers with the skills and knowledge needed to tackle complex, real-world problems. This study contributes valuable insights to the ongoing dialogue on innovation in engineering education.

VI. REFERENCES

Dolmans, D. H. J. M., Loyens, S. M. M., Marcq, H., & Gijbels, D. (2016). Deep and Surface Learning in Problem-Based Learning: A Review of the Literature. Advances in Health Sciences Education, 21(5), 1087-1112.

Garcia, M. A., & Valdes, A. R. (2022). Enhancing Engineering Education Through PBL and Digital Tools: A Systematic Review. Education and Information Technologies

Jonassen, D. H., Strobel, J., & Lee, C. B. (2016). Everyday Problem Solving in Engineering: Lessons for Engineering Educators. Journal of Engineering Education.

Krajcik, J. S., & Shin, N. (2014). Project-Based Learning. In R. K. Sawyer (Ed.), The Cambridge Handbook of the Learning Sciences (pp. 275-297).

Prince, M. J., & Felder, R. M. (2006). Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases. Journal of Engineering Education, 95(2), 123-138.

Barrows, H. S. (2006). Problem-Based Learning in Medicine and Beyond: A Brief Overview. New Directions for Teaching and Learning, 68, 3-12.

Raja Subramanian, R.; Sivapragasam, C.. A Case Study on the Student Centric Course in Engineering Programme Leveraging PBL. Journal of Engineering Education Transformations, [S.l.], vol. 35, p. 27-41, 2021. ISSN 2394-1707.

Shashi Anand, S., Francis Saviour Devaraj, A., Kanniga Devi, R., Bala Subramanian, C., Raja Subramanian, R., Nagaraj, P., Effective Design and Implementation of B.Tech (CSE) Curriculum with Industry Tie-Ups. Journal of Engineering Education Transformations, vol. 34, [S.l.], p. 191-200, 2020.

Kaushik, Scaffolding Models in a Project-Based Learning Course- A Case Study, Journal of Engineering Education Transformations, vol. 37, [S.1.], p. 796-803, Jan. 2024.

Rachana, Using STAD as an Assessment for Learning (AfL) in Mathematics, Journal of Engineering Education Transformations, vol. 37, [S.1.], p. 796-803, Jan. 2024.