Empowering Engineering Ethics: Integrating Project-Based Learning for Holistic Student Development in VLSI Education

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***Abstract*— Integrating value education into Electronics and communication engineering program and Electrical and Electronics engineering program is essential for developing students' ethical, social, and emotional maturity, enabling them tonavigate personal and professional scenarios with integrity and empathy. This paper incorporates the PBL into VLSI courses within a value educational framework, that offers a comprehensive approach to student development. It is not only enhances technical proficiency but also cultivates essential life skills and values, promoting engaged learning and holistic growth.Project-Based Learning (PBL) is an effective strategy for achieving this integration, transforming the educational landscape by fostering both technical skills and essential life principles. PBL engages students in hands-on projects that simulate real-world challenges, requiring collaboration, critical thinking, and innovative problem-solving, particularly in the field of VLSI. Thisactive learning approach shifts the educational experience from passive reception to active engagement, allowing students to take control of their learning journey. This approach ultimately prepares socially responsible engineers ready to make positive contributions to society. Engineering ethics plays a crucial role in ensuring that technological advancements benefit society and minimize harm. In VLSI, ethical considerations can affect safety, privacy, and environmental sustainability. Integrating ethics into engineering education equips students to navigate these challengesresponsibly.**

***Keywords*— Integration; Project Based Learning (PBL); Realtime projects; VLSI;**

I. INTRODUCTION

The integration of engineering ethics into VLSI education through PBL can be achieved using a structured approach. Thisprocess begins with forming diverse, interdisciplinary teams to encourage collaboration and a variety of perspectives. Teams define a problem statement that addresses both technical and ethical challenges relevant to VLSI (Patil, R.,2020). They conduct research and develop a project plan that outlines their technical and ethical approaches. During the design and simulation phase, teams use appropriate tools to create their projects while adhering to ethical standards, regularly reviewing progress to ensure both technical accuracy and ethical compliance. In the evaluation phase, teams validate their designs against technical and ethical benchmarks through testing and peer reviews, refining their work based on feedback.

The final steps involve preparing comprehensive documentation and presentations that highlight the project's technical and ethical aspects, followed by a reflective phase where students discuss their learning experiences and the impact of integrating ethics into their work. This method provides students with a holistic education, combiningtechnical expertise in VLSI with a solid foundation in engineering ethics, preparing them for the complex challenges of their future careers. (Lison, C, 2015)

To implement PBL (Problem-Based Learning) in Very Large Scale Integration (VLSI) for 3rd-year students, the following pedagogies can also be incorporated to create enthusiasm and interest in the topic.

Flipped Classroom: Faculty will share pre-recorded VLSI design tutorials, simulations, and theoretical materials with the students that can be studied outsideof class. In-class time can be dedicated to working on projects, labs, and collaborative problem-solving withthe knowledge acquired from the tutorials. (Uma, M. 2016)

Case-Based Learning (CBL): Students will analyze the real-world VLSI design failures and successes canhelp students understand practical applications and implications of theoretical knowledge.

Collaborative Learning: Group projects where students collaborate on VLSI design projects, simulations, and troubleshooting can enhance learning through peer interaction and knowledge sharing.

Simulation-Based Learning: Students can adopt VLSIdesign tools and simulators such as SPICE, ModelSim,and Visual TCAD to create virtual labs. These labs allow them to experiment and learn through trial and error in a controlled environment.

Competency-Based Learning: Tailoring VLSI courses to ensure students to develop key competencies in areas like digital design, analog circuits, FPGA programming and ASIC design.

Gamification: Faculty in VLSI domain created few challenges, competitions, and assessments related to VLSI design using online tools that makes learning more interactive and enjoyable for students.

II.LITERATURE SURVEY

We, as a team first considered incorporating Problem-Based Learning (PBL) into VLSI design course, We drew heavily from the insights offered by key scholarly works. Each paper provided valuable guidance on how to design an engaging, challenging, and effective PBL experience tailored to the needs of our students. Then our journey began with Bédard and Lison's (2015) emphasis on the importance of student engagement and relevance. We knew that for PBL to work in the complex and technical field of VLSI design, students had to see the direct connection between the classroom problems and real-world industry challenges. Inspired by this, We crafted problems that mirrored the design issues faced by professionals in the semiconductor industry, such as optimizing chip performance and minimizing energy consumption in circuit designs. These were not just academic exercises but real problems that allowed students to dive into the nuances of VLSI design while maintaining motivation through their direct applicability to future careers.

Mills and Treagust's (2003) distinction between PBL and project-based learning (PjBL) further informed our approach. We have recognized the need to balance the problem-solving focus of PBL with the hands-on project work characteristic of PjBL. While PBL sharpened our students' critical thinking by confronting them with open-ended questions like designing efficient circuits, integrated with PjBL for the larger, more structured VLSI projects that required them to design and simulate entire systems. This dual approach, rooted in the comparison outlined in the paper, allowed students to build both theoretical understanding and practical skills.

The nuanced perspective presented by Savin-Baden (2000) helped us to appreciate the broader learning outcomes of PBL that could achieve beyond just technical knowledge. I understood that PBL was not just about getting students to solve problems but about helping them develop resilience, teamwork, and self-directed learning skills. This inspired us to give students more autonomy in the learning process. Rather than offering immediate solutions, We have encouraged them to explore, make mistakes, and learn from their failures, just as they would in a real-world design environment. These experiences allowed students to build confidence and adaptability, essential traits in the ever-evolving field of VLSI.

Kolmos and Holgaard’s (2010) work on curriculum change was instrumental, when we sought to align PBL course with industry needs. The VLSI field moves quickly with rapid advancements in technology and design methodologies. So, we have focused on ensuring our students to work on reflected current industry trends, such as the push for energy-efficient and high-speed integrated circuits. We also collaborated with industry professionals to provide feedback on the curriculum, making sure that the skills students developed through problem-solving, design thinking matches with the companies were looking for.

Finally, Prince and Felder’s (2006) review on inductive teaching methods gave us a broader perspective on how to implement PBL effectively. Their emphasis on the importance of quality implementation helped us for fine-tuning of our approach. We worked to create problems that were complex enough to be challenging but also structured to provide clear learning outcomes. Their call for more empirical research inspired us to regularly assess the effectiveness of our approach, gathering feedback from students and making adjustments to improve their learning experiences.

In implementing PBL in VLSI design course, we leaned on the lessons from these foundational papers to create a learning environment where students could engage deeply with challenging problems, collaborate effectively, and prepare themselves for the real-world demands of the VLSI industry. Moving forward, we have planned to continue evaluating the impact of PBL on student learning and refining the approach to ensure that it stays aligned with both educational goals and industry trends.

III METHODOLOGY

Implementing Problem-Based Learning (PBL) for 3rd-year students in VLSI (Very Large Scale Integration) requires a structured approach to ensure effective learning outcomes. In this method, faculty members serve as facilitators and mentors,guiding students through the PBL process without giving direct solutions. They provide continuous support, feedback, and additional resources as needed. This approach ensures thatstudents engage deeply with the subject matter, developing problem-solving skills and independent learning abilities:

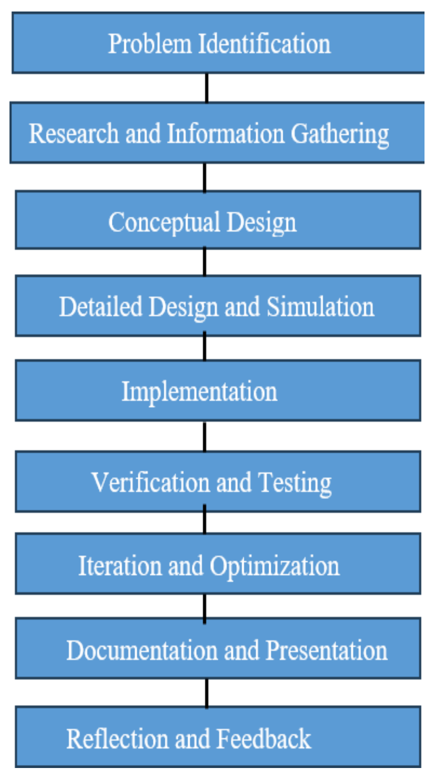

Fig. 1. PBL Design Flow

Problem Identification: In the initial stage, Form Student Groups plays a critical role in fostering collaboration. Small groups with a mix of skill levels are formed to promote balanced teamwork, allowing students to tackle complex VLSI design problems collectively. Each group begins by assessing curriculum needs, consulting faculty, and interacting with industry experts to identify Learning Objectives relevant to VLSI education for 3rd-year students. These objectives include essential knowledge and skills in areas like digital and analog design, FPGA programming, and ASIC design.

Research and Information Gathering: Once the Problem Statement is defined, students embark on the Research and Inquiry phase. They gather information on current industry trends and cutting-edge VLSI challenges. A typical problem might involve designing a low-power, high-performance circuit for wearable technology, balancing constraints like power consumption, size, and cost. Tools such as SPICE and ModelSim, provided by the institution, are vital resources during this research phase. Faculty facilitate brainstorming sessions and discussions, encouraging students to explore various theoretical and practical solutions.

Conceptual Design: At this point, students work within their groups to develop Real-World Problems based on their findings. Faculty ensures these problems are complex, open-ended, and closely aligned with industry trends. This stage emphasizes collaboration and critical thinking, requiring students to design circuits that address real-world challenges. By promoting Research and Inquiry, students are encouraged to ask questions, test assumptions, and conceptualize potential solutions.

Detailed Design and Simulation: Students use the design tools provided by the institution, including SPICE, ModelSim, and Visual TCAD, to translate their conceptual designs into detailed simulations. During this phase, Experimentation is crucial as students apply their theoretical knowledge and begin testing the performance of their designs. They refine their solutions based on experimental results, iterating to improve efficiency and functionality.

Implementation: Once the design is validated through simulation, students proceed to the Implementation phase. Here, they translate their designs into physical prototypes, if feasible, or prepare detailed documentation of the implementation. This stage ensures that students gain hands-on experience with real-world VLSI design tools and processes, enhancing their practical understanding of circuit implementation.

Verification and Testing: At this stage, students verify the accuracy and efficiency of their designs, aligning with Formative Assessment techniques. Faculty conducts regular check-ins and provides constructive feedback, guiding students as they assess their designs against predefined benchmarks. The designs are tested for performance under various conditions to ensure reliability and functionality.

Iteration and Optimization: Based on the results from verification and testing, students engage in Iteration and Optimization. They revisit their designs, making necessary adjustments to optimize performance. This iterative process mirrors real-world VLSI development, where designs are constantly refined based on testing outcomes. Faculty feedback plays a critical role here, helping students identify areas of improvement and refine their approaches.

Documentation and Presentation: In this phase, students document their entire design process, from concept to implementation. Clear communication of their findings is essential, as it mirrors industry requirements for presenting technical work. This stage also serves as a Summative Assessment, where faculty evaluates the final solutions based on structured rubrics, taking into account creativity, technical accuracy, and practicality.

Reflection and Feedback: Finally, students participate in a Reflection phase, where they discuss their learning experiences with peers and faculty. They reflect on the challenges they encountered, the skills they developed, and how they applied theoretical concepts to real-world problems. Faculty also gathers student feedback on the PBL process in the Iterate and Improve stage, using this feedback to refine future implementations of PBL in VLSI education.

TABLE I
WEEK WISE PLAN FOLLOWED IN IMPLEMENTING THE PBL

Week 1-2	Introduction to VLSI concepts and tools. Forming groups and presenting the problem statements
Week 3-4	Research phase- Students gather information and begin brainstorming solutions.
Week 5-6	Experimentation phase. Students use simulators to test and refine their solutions.
Week 7	Presentation phase. Groups present their solutions and receive feedback.
Week 8	Reflection and assessment. Students reflect on their learning and the overall process.

Table 1shown above provides a comprehensive week-by-week schedule for the PBL implementation.

IV EVALUATION OF PBL ON VLSI

After the Project-Based Learning (PBL) module on Very- Large-Scale Integration (VLSI) is implemented, students will participate in a series of assessments. This section provides a comprehensive overview of the evaluation process, including the rubrics used to assess the students' projects and the criteria for awarding individual marks. (Baden, M., 2000)

Additionally, it includes details about the formation and composition of the student batches shown in the Table 2.

TABLE II
DETAILS OF BATCHES

Number of Batches from III Year ECE & EEE	No. of Batches optedfor PBL in VLSI	Size of the batch	Total No. of Students	Number of Papers published in UGC/ Conferences
25	10	4	40	7

The process for forming structured rubrics involved several steps to ensure comprehensive and fair evaluation for the students. Initially identified the key performance areas relevant to the VLSI project such as technical knowledge, design implementation, teamwork, problem-solving, and presentation skills. Next, developed some specific measurable indicators foreach performance clearly to define expectations form the students.

Problem Identification and Definition (10M): In this category, students are evaluated on their ability to clearly identify and define the problem. For an excellent rating, the student must demonstrate a thorough understanding of the problem with a well-defined and precise scope. A good rating is given when the problem is identified and understood, but with slightly less depth. A satisfactory performance indicates that the student has a basic understanding, but the scope of the problem may be vague or incomplete. When the definition is unclear or lacks completeness, the student falls under the "Needs Improvement" category. Failure to identify the problem properly results in a poor rating.

Research and Information Gathering (10M): This category assesses the student's ability to conduct relevant research using credible sources. An excellent performance involves thorough research with a variety of credible sources, while a good rating indicates adequate research but with less depth. A satisfactory rating shows that basic research was conducted with a limited range of sources. If the research lacks relevance or depth, it falls under "Needs Improvement." A poor rating is given when the student fails to gather adequate information or conduct proper research.

Conceptual Design (10M): Conceptual design is evaluated based on the student's ability to develop innovative and well-structured design concepts, including a clear system architecture. An excellent rating is given when both design innovation and clarity are demonstrated. A good rating reflects solid design concepts but with some limitations in clarity. A satisfactory performance indicates basic design concepts that may lack clarity in certain aspects. When design concepts are underdeveloped or unclear, they fall under "Needs Improvement." A poor rating is given if the student fails to develop coherent design concepts at all.

Detailed Design and Simulation (15M): This category looks at the student's ability to produce detailed designs and run accurate simulations using appropriate tools. For an excellent rating, the designs and simulations must meet all specifications and be executed with high precision. A good rating reflects some minor errors in design or simulation but meets most of the required specifications. A satisfactory performance shows basic designs and simulations that meet only some of the specifications. When the designs or simulations are incomplete or inaccurate, they fall under "Needs Improvement." A poor rating is given if the student fails to produce adequate designs or simulations.

Implementation (10M): Students are assessed on how effectively they implement their designs into manufacturable layouts. An excellent rating indicates that the implementation was done without issues, translating into practical, manufacturable designs. A good rating is given when there are minor issues but the designs are mostly manufacturable. A satisfactory performance reflects basic designs with some issues in manufacturability. If the implementation is incomplete or has significant issues, it falls under "Needs Improvement." A poor rating means that the student failed to implement the designs properly.

Verification and Testing (15M): In this category, students are evaluated on how well they test their designs and resolve any issues. An excellent rating is given when thorough testing is conducted, with all issues identified and resolved. A good rating reflects minor issues that were resolved effectively. A satisfactory rating indicates basic testing, with only some problems resolved. If testing is incomplete or ineffective in resolving issues, it falls under "Needs Improvement." A poor rating is given when the student fails to conduct proper testing or resolve issues.

Documentation and Presentation (10M): This category assesses the clarity and comprehensiveness of documentation and the effectiveness of the presentation. An excellent rating reflects clear, comprehensive documentation, and an effective presentation of the findings. A good rating indicates that the documentation and presentation were well done but with some room for improvement. A satisfactory performance shows basic documentation with an adequate presentation. If the documentation or presentation is incomplete or unclear, it falls under "Needs Improvement." A poor rating is given when the student fails to produce adequate documentation or deliver a clear presentation.

Reflection and Feedback (5M): Reflection and feedback are evaluated based on the student's ability to reflect meaningfully on their learning experiences, challenges, and skill development. An excellent rating indicates a deep and thorough reflection, while a good rating reflects well on the experiences, though not as in-depth. A satisfactory performance indicates some reflection but may lack insight or depth. If the reflection is superficial or incomplete, it falls under "Needs Improvement." A poor rating is given when the student fails to meaningfully reflect on their experiences.

Collaboration and Teamwork (5M): This category assesses the student's ability to work collaboratively with peers and contribute to the team's success. An excellent rating is given when the student works actively and significantly contributes to the team's objectives. A good rating reflects adequate collaboration and contribution to the team's work. A satisfactory performance indicates that the student works with peers but makes minimal contributions. If collaboration is limited or ineffective, the student falls under "Needs Improvement." A poor rating is given when the student fails to collaborate with the team at all.

These indicators are then weighted according to their importance in the overall project assessment. The rubric is refined through iterative reviews, incorporating feedback from colleagues and industry experts to ensure relevance and clarity. Finally, the rubric is tested with a sample group of students to validate its effectiveness and make necessary adjustments before starting the implementation. In Table 3, the structured rubrics for assessment are given for each stage of PBL.

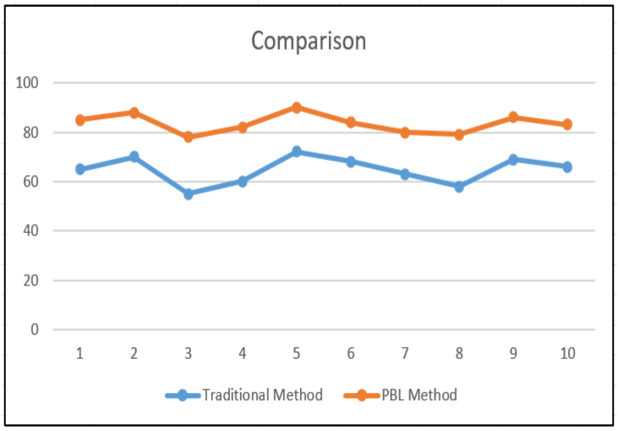

Fig. 2. Comparison between Traditional and PBL approach

The graph compares student performance in VLSI design across 10 batches before and after the implementation of Project-Based Learning (PBL). It shows that the PBL method consistently results in higher average marks, ranging from 80 to 90, with minimal fluctuation, indicating more stable performance. In contrast, the traditional teaching method produces lower and more variable scores, averaging between 60 and 70, suggesting less predictability and effectiveness in student outcomes.

Overall, the graph highlights the benefits of PBL, demonstrating an upward trend in student performance. The PBL approach fosters deeper comprehension, practical skills, and collaborative abilities, contributing to better results.

Proof of Activities: Below are few pictures captured during the implementation ofprojects in VLSI through PBL.

Fig. 3. Demonstration and Practicing of PBL

Feedback Survey :

Out of 40 students 36 submitted the feedback on PBL implementation as shown in below table:

Question	Extremely useful (5)	Helpful (4)	Don't know (3)	Not useful (2)	Not required (1)
Do you think PBL is useful for your learning experience? Rate between 1 to 5. 5 being more useful and 1 being less useful	30	6	0	0	0
Do you think rubrics for PBL shared is useful for your learning experience? Rate between 1 to 5. 5 being more useful and 1 being less useful	29	6	1	0	0

Challenges faced during implementation: The implementationof Project-Based Learning (PBL) in VLSI design faced several challenges. Initially, there was resistance from both studentsand faculty accustomed to traditional teaching methods,requiring significant effort to shift their mindsets. Coordinatingthe formation of diverse and balanced student batches was also complex, necessitating careful consideration of academicperformance and team dynamics. Additionally, developingcomprehensive and fair evaluation rubrics was time- consuming, involving multiple iterations and expert consultations. Technical issues, such as ensuring access tonecessary tools and resources, posed logistical challenges.Finally, maintaining consistent student engagement and collaboration throughout the project duration required continuous monitoring and support, highlighting the need for effective facilitation and mentoring.

CONCLUSION

This paper detailed the implementation of Problem-Based Learning (PBL) in VLSI design for third-year ECE and EEE students by their respective faculty, resulting in numerous positive outcomes. Through engaging with real-world challenges, students developed critical problem-solving skills and a deep understanding of VLSI concepts. This hands-on approach enhanced their technical proficiency with industry-standard tools and simulators while fostering collaboration, teamwork, and independent learning.

Additionally, students refined their documentation and presentation skills, essential for professional success. Reflecting on their experiences promoted continuous improvement, preparing them for the VLSI industry with a comprehensive practical and theoretical knowledge base. Integrating PBL into VLSI education has proven to be transformative, encouraging active learning, critical thinking, and ethical decision-making. Overcoming implementation challenges through strategic planning and collaboration led to significant improvements in student performance and engagement. Ultimately, PBL offers a dynamic and effective educational framework that prepares students to address the complexities and ethical challenges of the engineering profession, ensuring they are well-equipped forfuture success in VLSI.

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