IMPLEMENTING CDIO STANDARDS THROUGH CHALLENGE-BASED LEARNING: A CASE STUDY IN AI ENGINEERING EDUCATION

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ABSTRACT

We present our experience with Challenge-Based Learning (CBL) within an AI project in ESPRIT School of Engineering's 3rd and 4th-year AI engineering curriculum. Spanning two academic years, it examines how CBL, aligned with CDIO standards, melds practical skills and AI theory. The approach includes theoretical AI knowledge, hands-on AI application development, and integrates the UN's Sustainable Development Goals to promote a sense of global responsibility and ethical consciousness in our students. Additionally, CBL involves collaboration with local entities, enhancing students' real-world skills. The study highlights CBL's effectiveness in fostering teamwork, communication, intercultural awareness, and creativity. Initial feedback shows increased student engagement and a comprehensive understanding of AI's societal implications. The paper discusses CBL's role in meeting CDIO standards in AI education, enhancing technical and transversal competencies, and concludes with potential broader applications and future recommendations. This research adds to the dialogue on innovative AI and engineering education methods.

KEYWORDS

Challenge-Based Learning (CBL), Artificial Intelligence Education, CDIO Standards, Sustainable Development Goals (SDGs) Integration. Standards 2, 3, 5, 7, 8, 9, and 11

INTRODUCTION

This paper explores the implementation of Challenge-Based Learning (CBL) in AI engineering courses at ESPRIT School of Engineering, with a particular focus on the Conceive-Design-Implement-Operate (CDIO) Standards. CBL, as an experiential, student-centered approach, complements and enhances the CDIO framework, thus providing a comprehensive educational experience that combines technical skills with vital personal and interdisciplinary skills (Rådberg, 2020). The importance of CBL in AI engineering education lies in its ability to connect theoretical knowledge with practical applications, crucial for engineering programs Studies such as Gudoniene et al. (2021) have emphasized the positive impact of CBL in engineering education, especially when aligned with Sustainable Development Goals (SDGs), providing both learning pathways and practical skills. Similarly, Crichton et al. (2022) found

that interdisciplinary problem-based learning, akin to CBL, promotes increased awareness of diverse approaches and preparation for professional challenges in engineering students (Ikonen, 2009).

the adoption of CBL in AI engineering education, as illustrated in our case study at ESPRIT School of Engineering, signifies a substantial move towards preparing students for the multi-dimensional challenges of the future. This paper provides a detailed exploration of this approach, offering insights and guidelines for educators and institutions looking to enrich their engineering education programs.

MODULE OVERVIEW

Course Description

This module, titled "AI Project for Community Impact", or shortly “AI Project”, is integrated into the AI Engineering program targeting 3rd and 4th-year computer science students majoring in AI. Spanning 14 weeks with a 6-hour weekly commitment, the course adopts a Challenge-Based Learning (CBL) framework, guiding students through the Engage, Investigate, and Act phases. The curriculum is designed to deploy AI technologies to address real-world challenges that align with the United Nations Sustainable Development Goals (UN SDGs). Students work in teams to develop, implement, and refine AI solutions in collaboration with community or industrial partners, with a strong emphasis on ethical considerations and social impact.

Intended Learning Outcomes (ILOs)

- Develop AI Solutions: Students will be able to design and implement AI models aimed at solving identified community challenges, applying appropriate AI tools and technologies.
- Ethical Implementation: Students will demonstrate the ability to incorporate ethical considerations and responsible AI practices throughout the development and deployment of AI solutions.
- Engage Stakeholders: Students will effectively collaborate with community and industry partners, ensuring the AI solutions are responsive to the needs and feedback of those partners.
- Manage AI Projects: Students will apply project management principles tailored to the lifecycle of AI development, ensuring timely and successful implementation of AI solutions.
- Analyze Impact: Students will assess the social impact of their AI solutions, evaluating their contribution towards achieving specific UN SDGs.
- Communicate Outcomes: Students will competently communicate both the process and outcomes of their AI projects to a broad audience, utilizing both oral presentations and written documentation.

SURVEY ANALYSIS:

Our methodology for assessing the module incorporated a dual approach. Firstly, we documented weekly insights and remarks based on our supervision and leadership, focusing on the students' advancement and classroom interactions. Secondly, at the module's conclusion, we conducted a survey to gather broader feedback. The survey, completed by 28

of the 36 students in the class, was administered via Google Forms. It included a combination of Likert-scale and open-ended questions, allowing us to capture both quantitative and qualitative data on student experiences and perceptions.

Quantitative analysis:

Students rated various aspects of the program on a scale from 1 (worst evaluation) to 5 (best rating). These aspects include:

- Effectiveness of CBL in understanding and applying AI concepts.
- Helpfulness in developing skills for conceiving and designing AI solutions.
- Effectiveness in developing skills for implementing and operating AI solutions.
- Contribution of the program to the development of critical thinking and problem-solving skills.
- Overall satisfaction with the CBL approach in the program.

Table 1. summarizes the key statistical measures – mean and standard deviation - for each numerical question from the survey:

Table 1. The Key Statistical Measures – Mean and Standard Deviation

Question	**Mean**	**Standard Deviation**
Effectiveness in understanding and applying AI concepts	4.19	0.75
Developing skills in conceiving and designing AI solutions	4.24	0.62
Developing skills for implementing and operating AI solutions	4.05	0.74
Incorporation of ethical, societal, environmental, and economic aspects	4.43	0.68
Development in teamwork, communication, and leadership skills	4.48	0.60
Enhancement in critical thinking and problem-solving	4.48	0.60
Engagement and involvement during the program	4.33	0.73
Preparation for understanding global challenges	4.43	0.60
Overall effectiveness of CBL in AI education	4.14	0.73

Insights from the quantitative analysis:

- High Effectiveness in Teamwork, Communication, and Critical Thinking: The highest mean scores were observed in the development of teamwork, communication, and leadership skills (4.48) and enhancement in critical thinking and problem-solving (4.48). These scores suggest that the CBL approach is particularly effective in nurturing interpersonal skills and analytical abilities, which are crucial in modern AI education.

- Strong Incorporation of Broader Perspectives: The incorporation of ethical, societal, environmental, and economic aspects scored a high mean of 4.43, indicating that the CBL approach effectively integrates these essential perspectives into AI learning, aligning well with global educational trends and the CDIO Syllabus's emphasis on broader contextual understanding.

- Good Engagement and Preparation for Global Challenges: The program's ability to engage students and prepare them for understanding global challenges both received strong mean scores (4.33 and 4.43, respectively). This suggests that students felt actively involved and better equipped to tackle complex global issues through the program.

- Slightly Lower Scores in Implementing and Operating Skills: The lowest mean score was in developing skills for implementing and operating AI solutions (4.05). While still positive, this indicates a potential area for improvement, suggesting that the practical application and operation of AI solutions might require more focus in the CBL framework.

- Variability in Responses: The standard deviations, ranging from 0.60 to 0.75, reflect some variability in participant perceptions. This variability might be attributed to individual differences in learning styles, prior knowledge, or specific program implementations.

The quantitative data indicates a positive overall reception of the CBL approach in AI education, with particular strengths in promoting critical thinking, teamwork, and a broad understanding of societal and ethical implications. However, there appears to be room for enhancing aspects related to the practical implementation and operation of AI solutions, ensuring a better educational experience in line with the objectives of the CDIO Syllabus.

Qualitative analysis

In this analysis we include key themes and insights, supported by relevant quotes from the students.

Overall Appreciation of the CBL Approach

The first aspect of our qualitative analysis focuses on students' overall appreciation of the CBL approach.

- General Sentiment: The feedback indicates a strong endorsement of CBL's effectiveness in AI engineering education. Students appreciate the hands-on, practical nature of the approach, as evidenced by one student's remark: "I find the CBL approach in this program to be highly effective and engaging."
- Engagement and Practical Learning: The CBL approach is praised for its practicality and ability to engage students deeply in the subject matter. As another student notes, "The Challenge-Based Learning (CBL) approach is practically oriented, making learning more relatable."
- Pros:
    - High Engagement: Students are more engaged due to the practical, real-world applications of AI concepts.
    - Effective Learning: The approach facilitates a deeper understanding of AI, as it aligns well with the experiential learning style preferred by many engineering students.
- Cons:
    - Potential for Overwhelm: For some students, the intensity and hands-on nature of the CBL act phase might be overwhelming, especially for those who are accustomed to more traditional, structured learning environments.

Most Beneficial or Enjoyable Aspect of CBL

This aspect examines what students found most rewarding about the CBL approach.

- Real-World Relevance and Problem-Solving: Many students cited the real-world relevance of the projects as the most beneficial aspect. One student expressed, "I found the real-world relevance and problem-solving focus of CBL most beneficial."
- Freedom to Explore and Innovate: The liberty to explore different avenues within AI and come up with innovative solutions is highly valued. A student highlighted this by saying, "I like the fact that CBL gives you the freedom to explore your ideas."
- Pros:
    - Encourages Innovation: Students are encouraged to think creatively and innovate, which is vital in the field of AI.
    - Prepares for Real-World Challenges: By dealing with real-world problems, students are better prepared for the challenges they will face in their professional lives.
- Cons:
    - Lack of Guidance: While freedom is appreciated, some students may feel lost without clear guidance, impacting the learning experience.

Challenges and Less Effective Aspects of CBL

This item explores the challenges students faced with the CBL approach and aspects they found less effective.

- Resource and Time Management: Students encountered challenges related to resource availability and time constraints. One student noted, "While resources were provided, at times it felt like more could have been done to support our projects."
- Securing Sponsorships and Partnerships: Engaging with external entities like sponsors was a noted challenge. As one student shared, "Securing sponsors during the investigation phase was challenging and time-consuming."
- Pros:
    - Real-World Problem Solving: These challenges mimic real-world scenarios, preparing students for practical issues they might face in their careers.
    - Learning Resourcefulness: Dealing with resource constraints fosters creativity and resourcefulness.
- Cons:
    - Overwhelming for Some Students: The pressure to secure resources or sponsors can be overwhelming and detract from the learning experience.
    - Time Compression: The compressed timelines for certain phases, like the Act Phase, can limit the depth of exploration and learning.

Effectiveness in Raising Awareness about Global Challenges

This aspect assesses how effectively the CBL approach raised students' awareness of global challenges.

- Increased Awareness and Engagement: Many students felt that CBL effectively raised awareness about global issues. A student expressed: "The CBL approach proved highly effective in raising my awareness about global challenges."
- Pros:
    - Broadened Perspectives: CBL helps students understand and appreciate the broader implications of AI technologies in a global context.

    - Encourages Social Responsibility: Students are more likely to consider the societal and ethical dimensions of their work in AI.
- Cons:
    - Varied Impact on Awareness: The effectiveness in raising awareness may vary depending on the project's nature and the individual student's engagement level.

Suggestions for Improving the CBL Approach

This part of our analysis focuses on students' suggestions for enhancing the CBL approach in AI Engineering education, based on their experiences and insights.

- Extended Time for Phases: Several students suggested extending the duration of certain CBL phases, particularly the act phase. One student mentioned, "maybe giving more time to the act phase would be beneficial."
- Efficient Time Distribution: The need for a more efficient distribution of time across all phases of CBL was highlighted. As one student advised, "Distribute the time efficiently across all phases of CBL."
- Complementary Classes: The idea of having complementary classes to bolster the CBL experience was proposed. A student suggested, "a complementary class to help us gain skills that are not covered in CBL would be helpful."
- Pros:
    - Enhanced Learning Experience: These suggestions aim to deepen the learning experience by allowing more time for exploration and reducing time-related pressures.
    - Comprehensive Skill Development: Complementary classes could provide a more rounded educational experience, covering areas not extensively addressed in CBL.
- Cons:
    - Potential for Overextension: Extending phases or adding complementary classes could lead to an overextended curriculum, possibly overwhelming students.
    - Resource Implications: Implementing these suggestions could require additional resources, including time and faculty involvement.

Synthesis of qualitative Findings:

The analysis of the Challenge-Based Learning (CBL) approach in AI Engineering education provides a multifaceted view of its impact, challenges, and areas for improvement.

- Reception and Practical Application: The initial analysis highlights a highly positive reception of the CBL approach. Students value the practical, hands-on learning experience, which enhances engagement and deepens understanding of AI concepts. The opportunity to tackle real-world problems and the freedom to innovate are especially appreciated. However, there is a clear need for a balance between this freedom and structured guidance to cater to a diverse range of learning preferences. Ensuring this balance is crucial for maximizing the educational benefits of the CBL approach.
- Real-World Mimicry and Global Awareness: The approach is effective in mimicking real-world scenarios, fostering resourcefulness and practical skill development. Challenges such as resource constraints and time pressures are notable, with activities like securing sponsorships and managing project timelines offering practical experience but also proving overwhelming for some. CBL is successful in raising

awareness about global challenges, broadening students' perspectives, and encouraging social responsibility. However, the impact on global awareness varies among students, pointing to a need for more consistent integration of global challenges in CBL projects.

- Enhancement Suggestions: Students expressed a desire for an enhanced CBL experience that allows for deeper exploration and a more comprehensive skill set. Suggestions include extending certain phases and incorporating complementary classes, reflecting a need for a more balanced and holistic approach. While these suggestions aim to improve the learning experience, considerations regarding potential curriculum overextension and resource implications are crucial.

Overall Implications

Combining all these insights, it is evident that while the CBL approach in AI Engineering education is highly valued for its practicality and real-world relevance, there are areas that require attention and refinement. Balancing freedom with structured guidance, consistently integrating global challenges, and carefully considering curriculum enhancements are key to advancing the effectiveness of the CBL approach. These findings offer a roadmap for us to refine and optimize CBL methodologies, ensuring that we can meet the diverse needs and learning styles of students in AI engineering programs.

ALIGNMENT OF CBL IN AI PROJECT MODULE WITH CDIO STANDARDS: AN EMPIRICAL ANALYSIS

We examine in this section the alignment of an "AI project" module, conducted under the Challenge-Based Learning (CBL) pedagogical modality, with the Conceive-Design-Implement-Operate (CDIO) Standards. Through a mixed-methods approach involving the above quantitative surveys and qualitative feedback from students, the effectiveness of the CBL approach in an AI engineering context is evaluated against the CDIO framework. The findings reveal significant congruence with key CDIO Standards, notably in fostering teamwork, communication, critical thinking, and the integration of broader perspectives.

RESULTS AND DISCUSSION

Alignment with CDIO Standard 2 (Learning Outcomes)

The CBL approach in the AI module demonstrated high effectiveness in developing interpersonal skills, including teamwork, communication, and leadership, with a mean score of 4.48. This aligns strongly with CDIO Standard 2, which emphasizes personal and professional skills and attributes. The focus on practical, real-world problem-solving under CBL resonates with the experiential learning style preferred in engineering education, enhancing a deep understanding of AI concepts.

Alignment with CDIO Standard 3: Integrated Curriculum

- Technical and Non-Technical Integration: The high scores in areas such as the incorporation of ethical, societal, environmental, and economic aspects (mean score: 4.43) suggest that the module successfully integrates non-technical considerations with

technical AI engineering education. This integration is a key component of CDIO Standard 3, which calls for an interdisciplinary curriculum.

- Cohesive Learning Experience Across CDIO Spectrum: The module's CBL approach, particularly effective in enhancing critical thinking and problem-solving skills (mean score: 4.48), indicates a curriculum that spans across the conceive and design phases effectively. However, the relatively lower score in implementing and operating AI solutions (mean score: 4.05) points to a potential gap in the 'Implement' and 'Operate' phases of the CDIO spectrum. This suggests a need for the curriculum to more robustly address these latter stages.
- Student Feedback for Curriculum Enhancement: Qualitative feedback highlighting the need for extended phases and additional resources indicates room for improvement in the curriculum structure. Aligning with CDIO Standard 3, the curriculum could benefit from adjustments that allow students to spend more time in each phase of the CDIO cycle, ensuring a more thorough and integrated learning experience.

Congruence with CDIO Standard 7 (Integrated Learning Experiences)

The AI module's emphasis on the application of ethical, societal, environmental, and economic aspects in AI solutions, scoring a mean of 4.43, reflects a robust alignment with CDIO Standard 7. This standard highlights the importance of integrated learning experiences that encompass a broad range of engineering and professional issues. The CBL modality effectively translates these aspects into tangible learning experiences, reinforcing students' ability to integrate diverse considerations in AI engineering.

Areas for Enhancement: CDIO Standard 5 (Design-Implement Experiences)

While the feedback for the module was generally positive, the slightly lower score of 4.05 in developing skills for implementing and operating AI solutions, though still high, was lesser compared to other criteria. This suggests an opportunity for enhancement in alignment with CDIO Standard 5, which emphasizes design-implement experiences. Strengthening this aspect of the CBL approach could further improve hands-on operational skills in AI engineering.

Alignment of the "AI project" module with CDIO Standard 8: Active learning

Based on the survey results we can derive these insights:

- Student Engagement: The module received a high mean score (4.33) for engagement and involvement, indicating strong alignment with CDIO Standard 8. This standard underscores the importance of active student participation and learning through doing, which the module seems to effectively foster.
- Practical Learning Approach: The emphasis on Challenge-Based Learning (CBL), as reflected in student feedback, aligns with active learning principles. Students' appreciation for the practical, hands-on nature of the module suggests that the learning experiences are well-aligned with the active engagement ethos of CDIO Standard 8.

The alignment of the "AI project" module with CDIO Standard 9

CDIO standard 9, which pertains to Enhancing Faculty Teaching Competence, can be analyzed in the context of the training sessions attended by the teacher supervisors for conducting Challenge-Based Learning (CBL).

- Faculty Training in CBL Methodology: The training sessions for teacher supervisors, focusing on the conduct of CBL, the roles of students and supervisors, and the intervention strategies, directly support CDIO Standard 9. This standard emphasizes the need for faculty to be well-prepared in pedagogical methods that facilitate active and experiential learning, which is central to CBL.
- Guidance and Intervention Strategies: The training on when and how teachers should intervene in the CBL process aligns with the aspect of CDIO Standard 9 that stresses the importance of faculty understanding their role in guiding and facilitating student learning, rather than directing it.
- Assessment Modalities of CBL: Faculty training on assessment modalities aligns with CDIO Standard 9's emphasis on faculty competence in evaluating student learning and progress. This is crucial in CBL, where assessment often involves evaluating complex, project-based activities.

The alignment of the "AI project" module with CDIO Standard 11

CDIO Standard 11 emphasizes assessing student learning in various areas including personal and interpersonal skills, product, process, system, and service building skills, as well as disciplinary knowledge.

- Effectiveness in Specific Areas: High mean scores in areas such as teamwork, communication, and critical thinking (4.48), and ethical and societal aspects (4.43) suggest effective assessment practices in these domains. However, the slightly lower score in implementing and operating AI solutions (4.05) indicates room for improvement in assessing these specific skills.
- Assessment of Personal and Interpersonal Skills: The high scores in areas related to personal and interpersonal skills demonstrate effective assessment methods in these domains, in line with CDIO Standard 11's emphasis on assessing a broad range of skills beyond just disciplinary knowledge.

The "AI project" module's assessment practices show good alignment with CDIO Standard 11, particularly in assessing a wide range of skills and using diverse assessment methods. However, the module could benefit from refining its assessment methods in the areas of implementing and operating AI solutions to fully realize the objectives of CDIO Standard 11.

Student Feedback and Suggestions

Qualitative feedback suggested extending certain phases of the CBL approach, aligning with CDIO Standard 3 (Integrated Curriculum). The suggestions to enhance learning experience and skill development reflect a need for a more balanced curriculum that thoroughly addresses the CDIO lifecycle phases.

DISCUSSION AND LEARNED LESSONS

Our study on the Challenge-Based Learning (CBL) approach within the AI project module at ESPRIT School of Engineering demonstrates substantial alignment with key CDIO Standards. The methodology, involving a mix of quantitative surveys and qualitative feedback, revealed CBL's effectiveness in developing critical skills like teamwork, communication, and problem-solving, with notable success in integrating broader ethical and societal perspectives. However, the analysis also identified areas needing enhancement, particularly in the implementation and

operation of AI solutions, and in adapting to diverse student learning styles. These findings offer a roadmap for refining the CBL approach, highlighting the importance of balancing structured guidance with experiential learning, and ensuring a comprehensive curriculum that addresses all CDIO lifecycle phases. This study contributes to the discourse on innovative AI engineering education, providing insights for educators aiming to optimize CBL methodologies in line with CDIO standards.

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