SHAPING MINDS IN MOTION: INTEGRATING ARTIFICIAL INTELLIGENCE (AI) AND DIGITAL TRANSFORMATION IN CDIO-BASED ENGINEERING EDUCATION

CHUYỂN ĐỔI CHƯƠNG TRÌNH ĐÀO TẠO ĐẠI HỌC GIẢNG DẠY CÁC HỌC PHẦN CHUYÊN MÔN BẰNG TIẾNG ANH CHO KHỐI NGÀNH KỸ THUẬT THEO MÔ HÌNH CDIO TRONG BỐI CẢNH TÍCH HỢP TRÍ TUỆ NHÂN TẠO VÀ CHUYỂN ĐỔI SỐ

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(Received: March 20, 2026; Revised: June 10, 2026; Accepted: June 29, 2026)

DOI: 10.31130/ud-jst.2026.24(7A).167E

Abstract - In the context of Industry 4.0, higher education institutions are required to redesign training programs to equip graduates with both technical competence and digital adaptability. This paper analyzes key components of CDIO (Conceive-Design-Implement-Operate), highlighting the role of AI-driven and digital tools in enhancing teaching and learning effectiveness. Furthermore, the paper critically discusses the implementation of outcome-based education aligned with societal and labour market demands. Special attention is given to the radical challenges of delivering specialized engineering courses in English, along with proposed optimal solutions to improve student engagement, learning efficiency, and professional readiness in a digitally transformed and globally connected workforce.

Keywords - Curriculum development; CDIO; Learning outcomes; English language teaching; Technical education

Tóm tắt - Trong bối cảnh Cách mạng Công nghiệp 4.0, các trường đại học cần tái thiết kế chương trình đào tạo nhằm trang bị cho người học không chỉ năng lực chuyên môn kỹ thuật mà còn khả năng thích ứng trong môi trường số. Bài báo phân tích các thành tố cốt lõi trong phát triển chương trình đào tạo theo CDIO (Hình thành ý tưởng - Thiết kế - Triển khai - Vận hành), đồng thời làm nổi bật vai trò của các công cụ số và ứng dụng AI nâng cao hiệu quả dạy và học. Bên cạnh đó, bài báo thảo luận việc triển khai giáo dục dựa trên chuẩn đầu ra, bảo đảm sự phù hợp với nhu cầu của xã hội và thị trường lao động. Đặc biệt, bài báo đề cập đến những thách thức trong giảng dạy các học phần chuyên ngành kỹ thuật bằng tiếng Anh, đồng thời đề xuất các giải pháp nhằm nâng cao mức độ tham gia của sinh viên, hiệu quả học tập và năng lực nghề nghiệp, đáp ứng yêu cầu của lực lượng lao động toàn cầu trong bối cảnh chuyển đổi số.

Từ khóa - Phát triển chương trình đào tạo; CDIO; chuẩn đầu ra; giảng dạy bằng tiếng Anh; giáo dục kỹ thuật

1. Introduction

Curriculum development plays a pivotal role in determining the quality of teaching and learning outcomes in higher education institutions. The design and continuous improvement of undergraduate curricula represent a strategic, long-term process that reflects the transformation of educational models - from knowledge transmission approaches to competency-based, learner-centered education. In the context of rapid globalization and digital transformation, higher education systems are increasingly required to develop outcome-based curricula that integrate theoretical knowledge with practical application, ensuring that graduates are well prepared to meet the evolving demands of the labour market.

Despite ongoing reform efforts, existing studies and national education strategies continue to highlight persistent limitations in higher education curricula, particularly in engineering and technology disciplines. Many programs remain predominantly theory-oriented, lack strong connections with real-world practice, and have yet to fully foster students' creativity, problem-solving abilities, and professional competencies. In addition, insufficient collaboration between universities and industry, together with limited expertise in curriculum innovation, has contributed to a mismatch between graduates' competencies and labour market requirements, thereby affecting training quality and employability outcomes.

In response to these challenges, recent research has increasingly explored the application of the CDIO framework, Artificial Intelligence (AI), and English-Medium Instruction (EMI) as separate approaches to enhancing curriculum quality. The CDIO model has been widely recognized for promoting practice-oriented and competency-based education, while AI and digital technologies have been shown to support personalized learning and data-driven assessment. Similarly, EMI has been identified as a key strategy for improving students' academic English proficiency and global integration capacity.

However, a critical gap remains in the literature. Existing studies tend to examine CDIO, AI, and EMI in isolation, with limited attention to how these elements can be systematically integrated into a coherent curriculum development framework. There is a lack of research that explicitly conceptualizes the interplay between outcome-based education, CDIO principles, AI-driven digital transformation, and EMI within a unified model. As a result, current approaches often fail to provide comprehensive guidance for institutions seeking to simultaneously enhance technical competencies, digital skills, and global communication abilities in the context of Industry 4.0.

Addressing this gap, the present study adopts a systematic literature review approach to examine how CDIO, AI, and EMI can be integrated into a unified framework for curriculum development. The study analyzes the relationships among societal needs, professional competency requirements, and learning outcomes, while emphasizing the role of digital technologies and EMI in shaping modern engineering education.

This study contributes to the literature by proposing an AI-integrated CDIO framework for Engineering Education. Based on this analysis, the paper proposes an integrated conceptual framework that combines CDIO-based curriculum design, AI-supported teaching and assessment, and EMI implementation. This framework aims to enhance curriculum relevance, effectiveness, and sustainability, while equipping engineering students with the technical, digital, and communicative competencies required to succeed in a highly competitive and rapidly evolving global labour market.

2. Methods

This study adopts a systematic literature review approach to synthesize and critically evaluate existing research on curriculum development in Engineering Education, with a particular focus on the integration of AI and digital transformation within the CDIO framework. The review aims to identify emerging trends, key challenges, and effective practices in this field.

To ensure methodological rigor and transparency, the review follows a structured protocol adapted from Hallinger's framework, consisting of five stages: (1) formulation of research questions; (2) development of a conceptual framework; (3) systematic literature search; (4) screening and selection of studies; and (5) data extraction and synthesis [1].

Furthermore, this study applies the quality-based selection criteria of Daoud et al. [2], ensuring that only high-impact and methodologically robust studies are included, thereby enhancing the reliability, validity, and practical relevance of the synthesized findings for informing AI-integrated CDIO curriculum development in the context of the Fourth Industrial Revolution.

The literature search was conducted across major academic databases, including Scopus, Google Scholar, JSTOR, and ScholarGPS. The search covered publications from 2020 to 2026, ensuring the inclusion of recent developments in AI and digital transformation in education. A combination of keywords and Boolean operators was used, such as "CDIO", "engineering education", "curriculum development", "AI", and "digital transformation".

All retrieved records were exported and managed systematically. The initial database search identified 102 records. After removing 29 duplicate records, 102 unique records remained for screening. Titles and abstracts were then reviewed, resulting in the exclusion of 30 records that did not meet the inclusion criteria. Consequently, 72 articles were retained for full-text assessment.

During the full-text review stage, 32 articles were excluded because they did not provide sufficient relevance to AI-integrated CDIO curriculum development, lacked empirical or theoretical contributions, or did not meet the established quality criteria. As a result, 40 studies were considered eligible. Following a final quality appraisal based on the criteria proposed by Daoud et al. [2], 23 additional studies were excluded, leaving 17 studies for inclusion in the qualitative synthesis.

The inclusion criteria required studies to: (i) focus on curriculum development in engineering education; (ii) incorporate CDIO, AI, or digital transformation; and (iii) provide theoretical or empirical contributions. Studies that were not relevant, lacked academic rigor, or were non-scholarly sources were excluded.

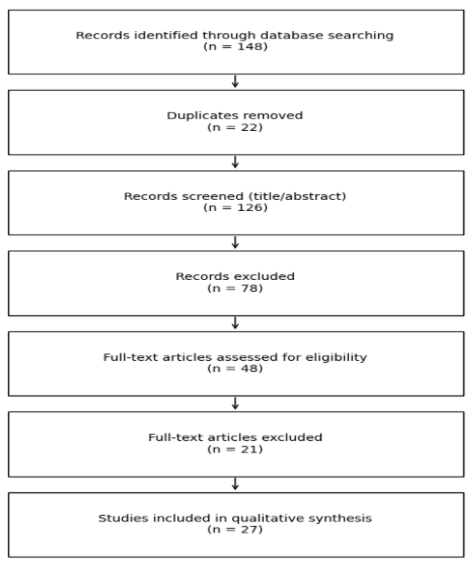

Figure 1. *PRISMA flow diagram showing the identification, screening, eligibility assessment, and inclusion of studies in the systematic literature review*

Figure 1 presents the PRISMA-based study selection process. The review procedure ensured transparency and reproducibility by documenting the number of records identified, screened, assessed for eligibility, excluded at each stage, and finally included in the synthesis.

Data extraction was conducted using a structured coding scheme, focusing on research design, technological applications, curriculum models, and learning outcomes. A qualitative content analysis approach was employed to identify key themes and patterns across the selected studies.

3. Higher Education Curriculum and Curriculum Development

3.1. The Concept of Higher Education Curriculum

The concept of a curriculum reflects diverse perspectives and understandings across different countries. In developed nations, curricula tend to be more flexible and elective-based, allowing students to select courses according to their interests and individual career orientations. This approach reflects an education system that encourages student autonomy and creativity in shaping their own learning pathways.

However, in developing countries such as Vietnam, curricula are typically more structured and regulated, consisting of a set of courses that students must complete in order to obtain a degree. While this structure may limit students' flexibility and autonomy in course selection, it ensures that all students acquire the fundamental and essential knowledge required for their future professions.

In Vietnam, higher education curricula today extend beyond formal academic courses to include additional requirements such as foreign language and information technology certificates, aiming to ensure the comprehensive development of students. The acquisition of these additional certifications enhances students' competitiveness in the labor market and helps meet societal demands.

P. T. Huyen emphasized that a curriculum is not merely a collection of courses but rather a comprehensive set of educational activities designed to develop students' knowledge, skills, and attitudes [3]. Particularly in the context of digital transformation in education and increasing demands for skill development, curricula must be flexible and responsive to the practical needs of the labor market. Curriculum design should therefore be based on clearly defined learning outcomes, ensuring that graduates possess not only theoretical knowledge but also practical skills and the capacity to adapt to change.

In the field of curriculum studies, diverse perspectives exist not only in Vietnam but also internationally. These perspectives reflect not only different definitions of curriculum but also distinct educational philosophies. In general, a curriculum can be understood as follows: A curriculum is an overall design, systematically structured for an educational and training process of a program within a given period of time, including four key components: (1) clearly defined educational objectives expressed through expected learning outcomes; (2) the content and duration of each course within the program; (3) the processes and methods used to implement the curriculum in order to achieve the stated objectives; and (4) methods for assessing learning outcomes [4]. It can therefore be observed that the concept of curriculum is dynamic and continues to evolve in response to socio-economic development as well as advances in science, technology, and information technology. To meet labor market demands at different stages of societal development, curricula must be continuously managed, developed, and updated.

Higher education curricula in Vietnam are formally defined in the Education Law, Article 41, and the Higher Education Law [5], [6]. According to these regulations, a higher education curriculum reflects the objectives of higher education; specifies knowledge and skill standards, the scope and structure of educational content, teaching methods and forms of training, as well as methods for assessing learning outcomes for each course, discipline, and level of higher education; and ensures articulation with other educational programs [3], [7].

A typical university curriculum usually consists of four to five knowledge blocks, each playing an important role in equipping students with the necessary knowledge and competencies. The general knowledge block provides foundational knowledge that enables students to develop a broad understanding across disciplines and cultivate comprehensive thinking. The basic disciplinary knowledge block establishes the foundational principles shared across related fields, helping students understand the fundamental concepts within their academic domain. The discipline foundation block focuses on providing core professional knowledge and theoretical foundations of the field. The specialized knowledge block represents the stage of advanced training, equipping students with the knowledge and skills necessary to address specific professional problems. Finally, the professional practice block emphasizes applied learning and practical experience, enabling students to develop workplace competencies essential for their careers after graduation. The clear structuring of these knowledge blocks not only ensures a comprehensive educational experience but also strengthens the connection between theory and practice, thereby producing graduates capable of meeting the workforce demands of modern society.

The concept of higher education curriculum development is not limited to a single definition but encompasses various interpretations, resulting in diverse curriculum development models. Curriculum development is generally viewed as a continuous process aimed at improving existing programs through ongoing revision and enhancement. The term "development" is often preferred over "design" or "construction" because it implies continuous adaptation and adjustment to societal needs and labor market demands. Current research on curriculum development in Vietnam can generally be categorized into three main areas: theoretical foundations, development approaches, and applied models, among which the CDIO framework has gained increasing attention.

The CDIO model, originally developed at the Massachusetts Institute of Technology (MIT) in the United States, is an educational approach designed to enhance the quality of training, particularly in engineering education, although it has since been expanded to other disciplines such as economics and business administration. This model helps universities align their training programs with the practical expectations of employers, thereby reducing the gap between education and labor market needs. One of the major benefits of the CDIO model is its ability to support the holistic development of students, enabling them to adapt more quickly to continuously evolving workplace environments.

Curriculum development therefore extends beyond the initial design of academic programs and requires continuous adjustments to meet the changing demands of society and the labor market. According to N. T. Nhi et al., CDIO can be applied to various training fields beyond engineering because it provides a comprehensive framework of knowledge and skills, such as in economics and business administration [8]. The CDIO framework plays an important role in connecting education with practice through clearly defined learning outcomes, which then serve as the basis for designing appropriate training programs. This approach allows students not only to acquire knowledge but also to develop the competencies necessary for effective performance in real-world environments. The adoption of the CDIO model in Vietnamese universities reflects the broader trend of educational reform and international integration, equipping students with both theoretical knowledge and practical skills, thereby enhancing their competitiveness in the labor market.

3.2. Curriculum Development in the Context of Digital Transformation

The concept of higher education curriculum development has undergone significant changes alongside transformations in socio-economic conditions and the rapid advancement of science and technology. In developed countries, university curricula are typically designed with a high degree of flexibility, allowing learners to personalize their learning pathways according to their interests, abilities, and career aspirations. This approach promotes learner autonomy, creativity, and interdisciplinary competencies - factors that are increasingly important in the digital economy.

In contrast, in developing countries, including Vietnam, traditional curricula tend to be more structured and predetermined, consisting of a system of compulsory courses designed to meet graduation requirements. While this model ensures that students acquire the foundational knowledge of their discipline, it may limit flexibility and the ability to adapt to emerging technological trends. Nevertheless, in recent years, higher education curricula in Vietnam have gradually expanded beyond core academic courses to include additional requirements such as foreign language proficiency, digital skills, and information technology certifications, reflecting the increasing demands of the labour market.

Many previous studies emphasize that higher education curricula should not be viewed merely as a collection of separate courses but rather as an integrated system of educational activities aimed at developing learners' knowledge, skills, and professional attitudes in a holistic manner. In the context of digital transformation and the rapid development of AI, curricula need to be designed based on clearly defined learning outcomes, with greater flexibility and stronger connections to professional practice. This requires a systematic shift from content-based teaching models toward competency-based education, ensuring that graduates not only master theoretical knowledge but also possess practical digital skills, critical thinking abilities, and the capacity to adapt to technological change.

From a broader perspective, a higher education curriculum can be understood as a structured educational blueprint consisting of four core components: (1) clearly defined learning outcomes, (2) curriculum content and workload distribution, (3) teaching and learning strategies, and (4) assessment and evaluation methods. This structural framework is dynamic and continuously adjusted to keep pace with developments in science, engineering, and digital technology. As labour market demands increasingly shift toward AI-related and data-driven professions, the continuous updating and innovation of curricula have become essential.

In Vietnam, the legal framework governing higher education curricula emphasizes alignment with national educational objectives, learning outcomes, teaching methodologies, and assessment mechanisms, while also ensuring articulation and coherence with other levels of the education system. University curricula are typically structured into several knowledge blocks, including general education, foundational disciplinary knowledge, core disciplinary knowledge, specialized knowledge, and practical or internship components. This structure provides a robust pedagogical foundation for embedding AI and digital transformation throughout the learning process, thereby bridging theoretical knowledge and authentic professional practice.

4. Outcome-Based Curriculum Development within the CDIO Framework

Curriculum development in higher education encompasses both the initial design of academic programs and the continuous process of improvement and refinement. Rather than being a one-time activity, curriculum development is an iterative process that requires regular review, feedback collection, and systematic adjustment. A fundamental principle of modern curriculum development is the strong alignment with clearly defined learning outcomes, which reflect the knowledge, skills, and competencies that students are expected to achieve upon graduation.

Outcome-Based Education (OBE) plays a crucial role in ensuring the relevance and quality of academic programs, particularly in engineering and technology disciplines. Learning outcomes should be formulated in a specific, measurable, transparent, and achievable manner and closely linked to employment positions and labour market requirements. In multidisciplinary higher education institutions, learning outcomes generally comprise two complementary domains: generic competencies and discipline-specific competencies. The former includes transferable skills and attributes such as ethical responsibility, communication, teamwork, foreign language proficiency, and digital literacy, whereas the latter focuses on professional knowledge, analytical thinking, problem-solving abilities, and specialized competencies associated with a particular discipline.

The CDIO framework provides an effective approach to ensuring alignment among learning outcomes, curriculum structure, and teaching-learning strategies. Within the CDIO framework, curriculum development emphasizes a balanced integration between theoretical knowledge acquisition and practical experience through real-world problem solving. This approach enables educational institutions to narrow the gap between academic training and labour market expectations by clearly mapping learning outcomes to professional competencies.

The process of outcome-based curriculum development within the CDIO framework is cyclical and data-driven. It requires continuous feedback from multiple stakeholders, including students, faculty members, employers, and industry partners, to ensure that academic programs remain responsive to technological advancements and societal needs. In the context of digital transformation, learning outcomes are increasingly expanded to include competencies related to AI, data analytics, automation, and digital system management, thereby enhancing graduates' professional adaptability in the era of the Fourth Industrial Revolution.

5. Integration of AI and Digital Technologies in CDIO-Based Curriculum Development

The research findings indicate that integrating AI and digital technologies into curricula developed under the CDIO framework significantly enhances both the relevance of academic programs and students' learning effectiveness. Outcome-based curriculum development enables a systematic classification of courses into core courses, elective courses, and extension courses. Courses that lack clearly defined learning outcomes are eliminated, thereby ensuring consistency, transparency, and accountability across the entire curriculum.

Within this framework, AI and digital tools can be integrated at both the course level and the program level. Learning outcomes serve as the foundation for designing assessment tools, including question banks and competency-based assessment tasks aligned with different cognitive levels. AI-assisted assessment systems enable adaptive testing, real-time feedback, and personalized learning pathways, which support the development of higher-order thinking skills such as analysis, evaluation, and innovation [9], [10], [11].

At the program level, learning outcomes are mapped across each academic year, enabling students to develop competencies progressively while allowing institutions to assess students' readiness for the labour market at different stages of their educational journey. This pathway-based approach facilitates the creation of flexible learning trajectories and enhances transparency regarding students' professional competencies.

The CDIO framework plays a central role in promoting the integration of AI and digital transformation within academic programs. In the Conceive and Design stages, students can utilize AI-powered tools to support idea generation, simulation, and solution optimization. During the Implement stage, students work with real-world data, digital platforms, and AI-enabled systems to develop and test solutions. In the Operate stage, learners focus on system management, performance evaluation, and continuous improvement based on data analysis.

Furthermore, the integration of AI contributes to innovation in teaching and learning by enabling personalized learning experiences, adaptive learning environments, and data-informed pedagogical decision-making. These innovations are particularly beneficial for specialized engineering courses taught in English, where AI-supported learning platforms help improve comprehension, student engagement, and learning outcomes [12] - [17].

Overall, the findings confirm that CDIO-based curriculum development, when combined with AI and digital transformation, provides an effective mechanism for aligning higher education with the demands of the Fourth Industrial Revolution. This approach not only strengthens students' disciplinary knowledge and professional competencies but also enhances their adaptability, lifelong learning capacity, and global competitiveness.

6. A Five-Step Integrative Framework for CDIO-Based Curriculum Development in the AI and Digital Transformation Era

Curriculum development based on the CDIO framework has been widely recognized as an effective approach to bridging the gap between higher education and labour market demands by emphasizing practice-oriented and competency-based learning. However, existing CDIO and OBE models primarily focus on disciplinary competencies and structured learning outcomes, with limited integration of AI, digital transformation, and data-driven continuous improvement mechanisms. As a result, these models often lack the flexibility and technological responsiveness required in the context of the Fourth Industrial Revolution.

To address this gap, the present study proposes a five-step integrative framework that extends traditional CDIO and OBE approaches by systematically embedding AI-driven tools, digital learning environments, and data-informed feedback loops into the curriculum development process. Unlike conventional models, this framework not only aligns learning outcomes with industry needs but also incorporates digital competencies, AI-supported teaching and assessment, and continuous curriculum optimization based on real-time data. This integrative perspective represents the key contribution of the study.

Step 1: *Needs Analysis in the Context of AI and Digital Transformation*

The first step involves conducting a systematic analysis of the existing curriculum in relation to the CDIO framework, with particular attention to competencies associated with digital transformation and AI. Traditional curricula often define learning outcomes as separate bodies of knowledge and skills, whereas the CDIO approach emphasizes integrated professional competencies connected to real-world engineering processes. Research findings indicate that CDIO learning outcomes are structured around the full lifecycle of professional activities-from conceiving ideas, designing solutions, implementing systems, to optimizing operations.

Since the CDIO framework was originally developed for engineering education, contextual adaptation is necessary to ensure its relevance across different engineering and management disciplines. Consultation with institutions that have implemented CDIO suggests that aligning learning outcomes with industry demands, digital skill requirements, and emerging AI applications forms the foundation for curriculum innovation in the digital era.

This step expands beyond traditional needs analysis in CDIO/OBE models by explicitly incorporating digital transformation trends and AI-related competencies. It emphasizes aligning learning outcomes not only with industry expectations but also with emerging technological requirements, thereby ensuring that curricula remain future-oriented and adaptable.

Step 2: *Digitally Enhanced CDIO Cycle with Data-Driven Continuous Improvement*

During implementation, the study found that the first three stages of CDIO - Conceive, Design, and Implement - are highly applicable to engineering disciplines, while the Operate stage requires adaptation to fit digitally driven environments. In AI-based systems, operational processes are closely linked with data analytics, system monitoring, and continuous optimization. Therefore, the study proposes a digitally enhanced CDIO model that emphasizes evaluation and continuous improvement following the principles of the PDCA cycle (Plan - Do - Check - Act). The adapted framework consists of four interconnected stages: Conceive - identifying problems and generating ideas with the support of digital and AI-based tools; Design - modeling and simulating systems with AI-supported optimization techniques; Implement - applying and testing solutions in digital or hybrid environments; Evaluate and Improve - conducting data-driven evaluation and continuous refinement.

While the conventional CDIO model follows the Conceive-Design-Implement-Operate cycle, this study reconceptualizes the final stage by integrating AI-supported evaluation and continuous improvement mechanisms. The proposed model incorporates a PDCA-informed loop, enabling real-time feedback, learning analytics, and iterative curriculum refinement - features that are largely absent in traditional CDIO implementations.

Step 3: *Outcome-Based Curriculum Alignment with Digital and AI Competencies*

The third step focuses on analyzing the curriculum development process in order to identify key factors that determine program quality. The findings highlight two critical elements that directly influence training effectiveness: (1) The accurate formulation of learning outcomes, integrating professional competencies, digital skills, and AI-related capabilities; (2) The strong alignment between curriculum structure and detailed course syllabi with these defined learning outcomes.

The course syllabus plays a central role in translating program-level learning outcomes into concrete teaching and learning activities, instructional materials, and assessment methods. In a digitally enhanced CDIO framework, course syllabi should clearly specify the role of AI tools, digital platforms, and hands-on activities in achieving the program's learning outcomes.

In contrast to standard OBE approaches, which often treat learning outcomes as static targets, this framework emphasizes dynamic alignment between program outcomes, course design, and AI-supported learning activities. It highlights the integration of digital tools and platforms as essential components in achieving both disciplinary and transversal competencies.

Step 4: *Transformation of Course Syllabi through AI-Integrated Pedagogy and Assessment*

A comparative analysis between traditional course syllabi and CDIO-based syllabi reveals significant differences in both structure and pedagogical orientation. CDIO-oriented syllabi go beyond describing course content by clearly specifying learning outcomes, competency levels, and measurable performance indicators. Teaching and learning activities are explicitly designed to support the achievement of these outcomes while leveraging digital technologies and AI tools.

Assessment methods in CDIO-based syllabi are aligned with the intended learning outcomes and evaluate not only disciplinary knowledge but also higher-order competencies such as problem-solving, collaboration, and innovation. The integration of AI-assisted assessment tools enables more comprehensive measurement of learning outcomes, enhances transparency, and increases accountability for both instructors and students.

Unlike traditional syllabi that primarily describe content and teaching methods, the proposed framework introduces AI-assisted instructional design and assessment strategies, enabling more personalized learning experiences and more accurate measurement of higher-order competencies such as problem-solving, collaboration, and innovation.

Step 5: *Implementation for Lifelong Learning and Global Competence Development*

The final step involves implementing the revised curriculum and fostering students' lifelong learning competencies within a digital and multicultural learning environment. One of the key learning outcomes of CDIO-based curricula in the digital era is the ability for self-directed learning and continuous knowledge updating, enabling students to adapt to the rapid pace of technological change. Foreign language proficiency - particularly English for Specific Purposes (ESP) - plays a crucial role in supporting this objective. It enables students to access global knowledge resources, participate in international professional communities, and effectively utilize AI-supported learning platforms. Through the integration of digital technologies, smart learning environments, and the CDIO approach, the curriculum ensures that graduates possess the competencies necessary to adapt, innovate, and work effectively in global and technology-driven labour markets.

This step extends beyond conventional CDIO outcomes by emphasizing self-directed learning, digital literacy, and global communication skills, particularly through the integration of EMI. The framework highlights the role of AI-supported learning environments in fostering continuous learning and adaptability in rapidly changing professional contexts.

7. Discussion and Theoretical Contributions

The findings of this study underscore the need for an integrated approach to curriculum development that responds to rapid advances in AI and digital transformation. While the CDIO framework continues to be effective in promoting practice-oriented learning, this study shows that traditional implementations are insufficient for addressing the demands of the digital era, particularly in enabling continuous adaptation and AI integration. This finding is consistent with recent studies on digital transformation in higher education, which argue that conventional curriculum models often struggle to respond to rapidly changing technological and workforce requirements [18], [19]. The review further suggests that although CDIO remains highly relevant for engineering education, its effectiveness may be constrained when digital technologies and AI-related competencies are not explicitly embedded within curriculum design.

By combining CDIO principles with AI-driven tools, digital transformation strategies, and EMI, the proposed framework offers a more comprehensive and adaptive model. Unlike prior studies that treat CDIO, AI, or EMI in isolation, this study conceptualizes their interrelationships within a unified, data-driven system. This synthesis extends previous research by highlighting that curriculum innovation is not simply a matter of adding new technologies but requires the alignment of pedagogy, assessment, language policy, and institutional strategy [20]. The literature reviewed indicates that fragmented implementation of AI or EMI often produces limited educational impact, whereas integrated approaches are more likely to support sustainable curriculum transformation. The integration of AI enables real-time feedback, learning analytics, and continuous improvement, thereby extending CDIO from a process-oriented approach to a dynamic and responsive framework.

From a theoretical perspective, this study contributes to both CDIO and OBE by reconceptualizing learning outcomes as dynamic, technology-mediated competencies that incorporate AI literacy, digital skills, and global communication capabilities. In addition, it establishes a conceptual bridge between engineering education, digital transformation, and language policy, highlighting the importance of interdisciplinary integration in contemporary curriculum design. More importantly, the review findings suggest that future curriculum frameworks may need to move beyond discipline-specific competence models toward more integrated ecosystems that combine technical expertise, digital competence, and intercultural communication [21]. This perspective expands current discussions in both CDIO and OBE literature, where these domains are frequently examined separately.

Practically, the findings provide actionable guidance for redesigning curricula through AI-integrated syllabi, competency-based assessment, and alignment between pedagogy, technology, and institutional strategy. However, implementation may be constrained by institutional readiness, infrastructure limitations, and faculty expertise, indicating the need for targeted capacity building and stronger university-industry collaboration. The review also reveals that successful implementation depends not only on technological investment but also on organizational culture, leadership commitment, and continuous professional development. These findings are consistent with studies emphasizing that digital transformation in higher education is primarily an institutional change process rather than a purely technological one [22], [23].

Overall, this study advances the understanding of how CDIO-based curriculum development can evolve into a more adaptive, data-driven, and globally relevant model for Engineering Education in the era of the Fourth Industrial Revolution. By synthesizing evidence across AI, digital transformation, CDIO, and EMI research, the study provides a broader conceptual perspective on curriculum innovation and identifies key areas for future empirical investigation, including the effectiveness of AI-enhanced CDIO implementation, the development of AI-related learning outcomes, and the role of EMI in supporting global engineering competencies.

While the proposed five-step framework offers a structured approach for integrating AI into CDIO-based curriculum development, it should be acknowledged that the framework remains primarily conceptual at this stage. The framework was derived from a systematic synthesis of recent literature and aims to consolidate existing knowledge into a coherent model for educational practice. However, no empirical validation, expert panel evaluation, or institutional case study was conducted within the scope of the present study.

Therefore, the findings should be interpreted as a theoretical contribution that provides a foundation for future implementation rather than as evidence of proven effectiveness. Future research should focus on validating the framework through expert reviews, Delphi studies, pilot implementations, and longitudinal case studies in engineering education programs. Empirical investigations involving curriculum designers, faculty members, industry stakeholders, and students would provide valuable insights into the practicality, scalability, and educational impact of the proposed framework.

Despite this limitation, the study contributes to the emerging discourse on AI-integrated curriculum innovation by identifying key dimensions, implementation considerations, and strategic directions that can guide future research and practice in CDIO-based engineering education.

As a systematic literature review, the primary objective of this study is theory building and framework development rather than framework testing. Consequently, empirical validation is intentionally positioned as the next phase of the research agenda.

8. Conclusion

In the context of rapid digital transformation, this review highlights the need to integrate AI, digital technologies, and global competencies into the CDIO framework to support adaptive and outcome-based curriculum development. The findings complement previous research on CLO attainment and outcome-based assessment [24] by extending the discussion to AI-enabled curriculum design, EMI integration, and continuous quality enhancement. This study provides a conceptual reference for universities seeking to modernize engineering and technology education in response to the demands of the digital era.

The proposed AI-integrated CDIO framework offers both theoretical and practical value by conceptualizing curriculum development as a dynamic, iterative, and data-driven process. In particular, the inclusion of AI-supported feedback mechanisms and EMI within a unified system contributes to a more comprehensive and future-oriented model of engineering education.

However, this study has several limitations. Firstly, as a systematic literature review, it is inherently dependent on the scope and quality of existing studies, which may limit the generalizability of the findings. Secondly, the proposed framework has not yet been empirically validated in specific institutional contexts. Thirdly, variations in institutional readiness, digital infrastructure, and students' language proficiency may influence the feasibility and effectiveness of implementation.

Future research should therefore focus on empirically testing the proposed framework in diverse educational settings, particularly through case studies and experimental designs. Further studies could also explore the effectiveness of specific AI tools in supporting CDIO-based learning, as well as strategies for optimizing EMI in technology-enhanced environments. In addition, longitudinal research is needed to examine the long-term impact of AI-integrated and EMI-supported curricula on students' competencies, employability, and adaptability in the evolving labor market.

Overall, this study contributes to advancing a more adaptive, data-driven, and globally relevant model for curriculum development, offering meaningful implications for both researchers and practitioners in Engineering Education.

Acknowledgements: This research was funded by Ho Chi Minh City University of Foreign Languages - Information Technology (HUFLIT), Vietnam, under research project code H2024-10.

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