IMPLEMENTING THE CDIO FRAMEWORK IN DATA-DRIVEN ENGINEERING CONTEXT: A COURSE-LEVEL CASE STUDY

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ABSTRACT

Engineering practice has been increasingly influenced and developed by digitalization, data availability, and advanced analytics using simulation, modelling, and Artificial Intelligence. As a result, modern engineers are expected not only to design and realize products, but also to use data to inform decisions across the entire product realization lifecycle from conception to operation and continuous improvement. This development creates new challenges and opportunities for CDIO-based engineering education. The CDIO framework aims to educate engineers capable of Conceiving, Designing, Implementing, and Operating complex systems in authentic contexts. CDIO Syllabus 3.0 reinforces this ambition by explicitly emphasizing digitalization, data-informed decision-making, sustainability, reflective learning, and systems thinking. However, many institutions still face difficulties in operationalizing these high-level learning outcomes into concrete, course-level implementations. Therefore, this paper aims to present a course-level case study of CDIO implementation through the course Data-Driven Product Realization, developed within the Chalmers initiative Tracks. The course is structured according to the Cross-Industry Standard for Process Mining model, which is an iterative and systematic approach for planning, executing, and deploying data analytics projects. It follows a project-based learning pedagogy, where diverse student teams engage in solving complex real-world industrial problems together with the companies. The paper contributes a detailed mapping between the course elements, CDIO Syllabus 3.0 outcomes, and CDIO Standards. Additionally, it proposes a reusable course design pattern that can support institutions seeking to implement CDIO Syllabus 3.0 in data-driven engineering contexts. Findings from course evaluation survey and student and teacher reflections demonstrate that the course effectively enhances integrated learning of technical and professional engineering competencies.

KEYWORDS

CDIO Implementation, CDIO Syllabus 3.0, Data-driven Engineering Course, Professional Skills Development, Project-Based Learning, Standards 1, 2, 7, 8, and11.

INTRODUCTION

Engineering practice has undergone a transformation driven by digitalization, increased data availability, and advances in simulation, modelling, and Artificial Intelligence (AI). In manufacturing industry, data-driven approaches are increasingly used to support decision-making across the entire product realization lifecycle, from early concept development to operation, maintenance, and continuous improvement (Wuest et al., 2016; Bokrantz et al., 2023). As a result, modern engineers are expected not only to design and realize products, but also to interpret, analyze, and apply data to inform engineering decisions in complex, socio-technical systems (Coskun et al., 2019; Li et al., 2021). A growing body of engineering education research emphasizes the increasing importance of interdisciplinary, digital, and professional competencies, including systems thinking and data-informed decision-making (Leles et al., 2024; Pacher et al., 2024). This aligns well with the Conceive Design Implement Operate (CDIO) framework that was developed to better align engineering education with professional engineering practice by emphasizing the integration of disciplinary knowledge with personal, interpersonal, and system-building skills in authentic contexts (Crawley, 2001; Berggren et al., 2003; Crawley et al., 2007). Since its introduction, the CDIO framework has been widely adopted internationally, with extensive implementation experiences reported in CDIO conference proceedings (Malmqvist et al., 2015).

The CDIO Syllabus 3.0 represents an evolution of the CDIO framework in response to emerging technological, societal, and industrial challenges identified by the CDIO community (Malmqvist et al., 2022). In addition to traditional engineering knowledge and skills, the updated syllabus explicitly emphasizes digitalization, data-informed decision-making, sustainability, ethics, reflective learning, interpersonal skills (e.g., teamwork and communications) and systems thinking. While the CDIO Syllabus 3.0 provides a comprehensive and future-oriented set of intended learning outcomes, it remains intentionally generic to support adaptation across disciplines and institutions, with programs expected to customize priorities based on their context and stakeholder needs (Malmqvist et al., 2022). A remaining challenge lies in translating syllabus-level ambitions into concrete, assessable, course-level elements particularly in emerging domains such as data-driven engineering, where professional practices and tools continue to evolve rapidly (Cheah & Leong, 2018). A recent review of CDIO practice also highlights persistent operational challenges in embedding CDIO principles consistently across courses (O'Connor et al., 2023). Addressing aforementioned challenges, this paper aims to present a course-level case study of CDIO implementation in the course Data-Driven Product Realization, developed within the Tracks Chalmers initiative (Enelund & Henricson Briggs, 2020).The paper contributes a detailed mapping between the course elements, CDIO Syllabus 3.0 outcomes, and selected CDIO Standards, thereby offering a practical and reusable course design pattern for implementing CDIO Syllabus 3.0 in data-driven engineering education.

BRIEF BACKGROUND

The CDIO framework conceptualizes engineering education around the full engineering lifecycle and positions this lifecycle as the authentic context for learning engineering practice (Crawley et al., 2007). Rather than prescribing specific curricula, CDIO provides a flexible educational framework that institutions adapt to disciplinary, institutional, and cultural contexts while maintaining a shared pedagogical foundation (Chuchalin, 2020). To support systematic implementation, the framework is operationalized through the CDIO Standards, which define best practices for curriculum design, teaching and learning activities, assessment, learning environments, and faculty competence (Crawley et al., 2014). The updated CDIO Standards

3.0 respond explicitly to changes in engineering practice, particularly related to sustainability and digitalization, and emphasize integrated learning experiences, active and experiential learning, and alignment between learning outcomes and assessment (Malmqvist et al., 2020). Complementing the standards, the CDIO Syllabus 3.0 provides a comprehensive and updated articulation of intended learning outcomes for engineering education in response to sustainability, digitalization, acceleration of change, and accumulated experience use in curriculum and course development (Malmqvist et al., 2022). Digitalization is treated as a cross-cutting theme, with digital and data-related competencies embedded across disciplinary knowledge, personal and professional skills, interpersonal skills, and CDIO lifecycle activities, rather than as a standalone competency area. The syllabus is intentionally formulated at a generic level to support broad applicability across engineering disciplines and institutional contexts. While this flexibility is a key strength of the CDIO framework, it also presents challenges when translating syllabus-level outcomes into concrete learning elements (e.g., teaching and learning activities and assessment tasks) at the course level, particularly in rapidly evolving domains influenced by digitalization and data-driven engineering practice (Malmqvist et al., 2022).

Within the CDIO community, this challenge is closely connected to the broader role of CDIO in engineering education research. CDIO has historically prioritized educational development, while increasingly positioning its conference and publications as spaces where usefulness for practice and scholarly rigor is jointly valued (Edström, 2020). Evidence from a systematic review of CDIO publications indicates that course-level and program-level implementation studies constitute the majority of CDIO publications and play a critical role in knowledge sharing within the community (O'Connor et al., 2023). At the same time, O'Connor et al. (2023) highlight a need for more analytically grounded studies that document not only how CDIO principles are implemented, but also how specific learning outcomes, especially those related to emerging professional practices are operationalized and assessed. Detailed course-level implementations therefore remain an important contribution to both CDIO practice and research; in this paper addressed through a course-level case study.

A COURSE-LEVEL CDIO IMPLEMENTATION

This section presents a course-level case study illustrating how CDIO Syllabus 3.0 and selected CDIO Standards are operationalized in practice within an advanced engineering course.

Context and course overview

Educational context: Tracks Chalmers

Tracks Chalmers is an educational initiative at Chalmers University of Technology aimed at providing flexible, challenge-driven, and industry-relevant learning pathways for students across engineering programs (Enelund & Henricson Briggs, 2020). The initiative emphasizes authentic engineering practice by integrating disciplinary knowledge with professional skills, interdisciplinary collaboration, and close interaction with industry partners (Bingerud et al., 2023). Courses within Tracks Chalmers are designed to address complex, real-world challenges and to prepare students for modern engineering roles characterized by digitalization, sustainability demands, and rapid technological change. An example of a course within the Tracks initiative is Data-Driven Product Realization which is offered as an elective course within the theme Sustainable Production. It brings together students from different educational backgrounds to work collaboratively on data-driven industrial challenges provided by partner companies, thereby reflecting professional engineering practice.

Course objectives

The rapid advancement of digital technologies is currently reshaping the manufacturing industry. Above all, the recent developments in AI and Machine Learning (ML) open possibilities for improved decision-making towards sustainable manufacturing. The purpose of the course is therefore to enable data-driven and fact-based decisions in the industrial product realization process. The demand for future engineers with multi-disciplinary competencies in developing and applying AL/ML solutions in industry has been rising (Li et al., 2021: Bokrantz et al., 2023). Therefore, the course aims to provide students with fundamental knowledge about data science (including AI and ML) as well as skills in applying data science techniques for improving production systems and product development. The course is designed so students having completed the course should be able to:

- Apply data-driven methods, including analytics and modelling, to support decision-making in product development and production contexts.
- Integrate data analytics with engineering design and product realization activities across the lifecycle.
- Work effectively in multidisciplinary and culturally diverse teams.
- Experience and reflect on a full or partial CDIO lifecycle in a realistic, industry-connected project setting.

The detailed learning objectives of the course are given below:

- LO1. Critically and creatively identify and formulate data analytics problems
- LO2. Solve open-ended data analytics problems
- LO3. Lead and participate in data analytics projects
- LO4. Work in multidisciplinary analytics teams
- LO5. Work sensitively with cultural differences in analytics teams
- LO6. Assess the impact of data analytics solutions
- LO7. Identify and discuss ethical aspects of data analytics
- LO8. Present the results of data analytics project to various stakeholders

These objectives are aligned with the intended learning outcomes of CDIO Syllabus 3.0, with particular emphasis on data-informed decision-making, professional skills, and systems perspectives.

Course structure and pedagogy

The course applies project-based learning pedagogy (Thomas, 2000) and consists of a mix of teaching and learning activities as summarized below. Overall aim is to create individual, personal, and flexible study opportunities for reflection on both technical outcomes and professional skills, including teamwork, communication, and ethical considerations.

- Lecture: Theoretical knowledge, skills, and abilities needed for the project work.
- Community: Expert talks to get inspiration from real-world insights from AI/ML applications in product realization combined with paper seminars from the state-of-the-art, and self-paced learning modules on professional skills with associated group reflections.

- Project: Practical work focused on the achievement of data-driven and fact-based decisions in the industrial product realization process.
- Examination: Assessment activities that constitute the basis for the final grade.

Multidisciplinary student teams collaborate with partner companies to solve complex, open-ended industrial problems using real-world needs, requirements, and datasets provided by them. Students work under the joint guidance of an industry-connected supervisor and an academic supervisor, ensuring close collaboration that integrates practical industry insight with academic expertise throughout the project. The course structure follows the Cross-Industry Standard Process for Data Mining (CRISP-DM) (Wirth & Hipp, 2000), providing an iterative and systematic framework for planning, executing, evaluating, and deploying data analytics solutions within an engineering context. The course is organized into eight major phases with a mix of different teaching and learning activities, mapped to the CDIO lifecycle phases, as summarized in Table 1.

Table 1. Course phases mapped to the CDIO lifecycle phases

Course phase	Focus	Teaching and learning activities	CDIO phase
Phase 1 – Course & Project Introduction	Orientation and process framing	Course and project introduction (Lecture); Introduction to the CRISP-DM framework (Lecture)	Conceive
Phase 2 – Business Understanding	Problem framing and project planning	Project management (Lecture); Problem–solution mapping (Lecture); Expert talk & paper seminar #1	Conceive
Phase 3 – Data Understanding	Data exploration and contextual understanding	Data pre-processing methods (Lecture); Self-paced learning on intercultural communication	Design
Phase 4 – Data Preparation	Data readiness and quality	Data quality assessment (Lecture); Expert talk & paper seminar #2	Design
Phase 5 – Modeling	Analytics and model development	AI/ML modelling for industrial datasets (Lecture); Self-paced learning on ethics	Implement
Phase 6 – Evaluation	Performance and impact assessment	Model evaluation and assessment of business impact (Lecture)	Implement (Reflective)
Phase 7 – Deployment	Operational and lifecycle considerations	Model deployment, operation, and maintenance (Lecture); Expert talk & paper seminar #3	Operate (Reflective)
Phase 8 – Report & Presentation	Communication and reflection	Presentation seminar; Self-studies; Final project report and individual reflection submission	Operate (Reflective)

Mapping to CDIO Syllabus 3.0

This section presents how the course aligns with the CDIO Syllabus 3.0. Rather than aiming to cover all syllabus elements equally, the course focuses on a coherent subset that is particularly relevant for data-driven product realization and professional engineering practice.

Fundamental knowledge and reasoning (Syllabus section 1)

The course integrates disciplinary knowledge from product development, production systems, data analytics, and systems engineering. Students apply quantitative reasoning, data modelling, and validation techniques as central inputs to engineering decision-making. Through the CRISP-DM framework, students learn to structure and reason about complex, data-intensive engineering problems in a systematic manner.

Personal and professional skills and attributes (Syllabus section 2)

The course explicitly develops personal and professional skills relevant to data-driven engineering practice, including:

- Analytical reasoning and problem solving (2.1), through formulation and solution of open-ended analytics problems.
- Experimentation and knowledge discovery using data (2.2), supported by iterative modelling and evaluation activities.
- Ethics, equity, and other responsibilities (2.5), addressed through dedicated self-paced learning activities and reflective assignments.

Interpersonal skills: Collaboration, teamwork, and communication (Syllabus section 3)

Team-based project work is a core element of the course. Students practice:

- Teamwork and collaboration (3.1) in teams composed of students with different disciplinary backgrounds.
- Communications (3.2) through project report, presentation, and interaction with industrial partners.

Conceiving, designing, implementing, and operating systems in the enterprise, societal and environmental context – the innovation process (Syllabus section 4)

The course engages students in multiple phases of the CDIO lifecycle. Students:

- Conceive (4.3) data-informed product and production improvement concepts based on industrial needs (e.g., the students clarify the company's problem and translate a business issue into a data-driven engineering question).
- Design (4.4) solutions supported by data analysis, modelling, and systems thinking (e.g., the students decide what data to use, which models to apply, and how results will support decision and design an analytics workflow using CRISP-DM).
- Implement (4.5) analytics pipelines or decision-support tools (e.g., the students build data pipelines, AI/ML models, or dashboards).
- Operate (4.6) by reflecting on deployment including business impact and other considerations (e.g., students do not deploy the solution in the factory. Instead, they reflect on how the solution would be deployed, what maintenance, data quality, or organizational issues would arise, etc.).

This is a partial CDIO lifecycle especially in relation to Operate phase, but aligned with the CDIO intent the students still experience and reason about all phases

Alignment with CDIO standards

CDIO Standard 1: Context

The course is explicitly framed within the context of product realization across the CDIO lifecycle, with data analytics and digitalization serving as central enablers. Industrial project contexts provide authenticity and relevance, aligning learning activities with professional engineering practice.

CDIO Standard 2: Learning outcomes

Course learning objectives are derived from and mapped to the CDIO Syllabus 3.0, ensuring transparency and coherence, and the different levels of the Bloom's taxonomy (Krathwohl, 2002). Figure 1 presents a matrix illustrating the relationships between the learning objectives, teaching and learning activities, and the assessment tasks based on Constructive Alignment (Biggs, 1996). A summary mapping between the course elements, and the CDIO Syllabus 3.0 outcomes, and the CDIO Standards is provided in Table 2.

	Learning Objectives (LO)							
Teaching and Learning Activities (TLA)	**LO1**	**LO2**	**LO3**	**LO4**	**LO5**	**LO6**	**LO7**	**LO8**
CRISP-DM	X	X	X					
Project management			X	X	X			
Problem-solution mapping	X	X						
Self-paced learning (intercultural communication)					X			
Methods for pre-processing		X						
Data quality		X						
Self-paced learning (ethics)							X	
AI/ML modeling for industrial data sets			X		X			X
Model evaluation & business impact		X				X		X
Model deployment, operation, and maintenance		X				X		
Expert talks & paper seminars	X	X				X		X
Assessment Tasks (AT)								
Project report	X	X	X	X	X	X	X	X
Individual quiz	X	X						
Individual reflection			X	X	X			

Figure 1. The Constructive Alignment matrix

CDIO Standards 7 and 8: Integrated learning experiences and active learning

The course integrates disciplinary knowledge with professional skills through active, project-based learning. Students simultaneously develop technical competence, teamwork abilities, and professional judgment through continuous feedback, supervision by two main supervisors and reflection.

CDIO Standard 11: Learning assessment

Assessment is based on a combination of project presentation and report, individual quiz and reflection. These assessment tasks are aligned with the intended CDIO learning outcomes and provide both formative and summative feedback on students' technical and professional development.

DISCUSSION

This section presents evaluation and reflections from the course survey (i.e., sent out to all students that have attended the course to gather opinions about the course, which gives highly valuable input on how well it is succeeded in conveying the content of the course and how other aspects surrounding the course works) and the interviews conducted with the students to explore how students perceived and experienced the CDIO principles as intended. The course evaluation included 16 student responses from the two most recent course offerings with approximately 50% response rate. In addition, semi-structured interviews were conducted with two students.

Table 2. Mapping between the course elements, the CDIO Syllabus 3.0 outcomes, and the CDIO Standards

Course elements	Description	CDIO Syllabus 3.0 alignment	CDIO Standards alignment
Industrial project work	Multidisciplinary student teams solve real industrial product realization problems using data-driven methods in collaboration with industry partners	4.3 Conceiving systems; 4.4 Designing systems; 4.5 Implementing systems; 4.6 Operating systems; 3.1 Teamwork and collaboration	Standard 1; Standard 7; Standard 8
CRISP-DM framework	Iterative and structured process model for planning, executing, evaluating, and deploying data-driven engineering projects	1.2 Core engineering fundamental knowledge; 2.1 Analytical reasoning and problem solving; 2.2 Experimentation, investigation and knowledge discovery; 4.2 Designing systems	Standard 2; Standard 7
Use of real-industrial data sets	Analysis of real data sets provided by partner companies to support engineering decision-making	1.3 Advanced engineering fundamental knowledge, methods and tools; 2.2 Experimentation, investigation and knowledge discovery; 4.2 Designing systems	Standard 1; Standard 8
Lectures	Lectures providing theoretical foundations, methods, and tools to support project work	1.1 Knowledge of underlying mathematics and sciences; 1.2 Core engineering fundamental knowledge; 1.3 Advanced engineering fundamental knowledge, methods and tools	Standard 2
Community activities (e.g., expert talks and paper seminars)	Expert talks and paper seminars linking theory, research, and industrial practice through discussion and reflection	2.2 Experimentation, investigation and knowledge discovery; 2.4 Attitudes, thought and learning; 3.2 Communications	Standard 7; Standard 8
Self-paced learning modules	Professional learning modules addressing ethics and intercultural teamwork, combined with reflective discussion	2.5 Ethics, equity, and other responsibilities; 3.1 Teamwork and collaboration; 2.4 Attitudes, thought and learning	Standard 8
Project report	Documentation of technical results, engineering reasoning, and lifecycle considerations in a structured written format	3.2 Communications; 4.4 Designing systems; 4.5 Implementing systems; 4.6 Operating systems	Standard 2; Standard 11
Project presentation	Oral presentation of project outcomes to academic and industrial stakeholders	3.2 Communications; 2.4 Attitudes, thought and learning	Standard 8; Standard 11
Individual quiz	Assessment of foundational knowledge in data analytics, AI/ML, and product realization	1.1 Knowledge of underlying mathematics and sciences; 1.2 Core engineering fundamental knowledge	Standard 11
Individual reflection	Structured reflection on teamwork, ethics, learning process, and professional development	2.4 Attitudes, thought and learning; 2.5 Ethics, equity, and other responsibilities; 3.1 Teamwork and collaboration	Standard 11; Standard 8

To complement student perspectives, an interview was also conducted with the course examiner to reflect how the CDIO-based course design was realized in practice and how key pedagogical choices were experienced from a teaching perspective. Taking together, these multiple perspectives also allow the findings to be interpreted in relation to broader engineering education theory, particularly constructive alignment, experiential learning, and situated learning through authentic practice (Biggs, 1996; Kolb, 2014; Lave & Wenger, 1991).

Course evaluation and students' reflections

Overall course evaluation results indicate a generally positive student perception of the course structure, learning outcomes, teaching, and alignment between activities and intended learning outcomes. Students reported that learning outcomes were clearly communicated and that the course structure supported achievement of these outcomes. This perceived coherence between outcomes, activities, and assessment is consistent with constructive alignment principles, where transparent course design supports student engagement and achievement (Biggs, 1996).

Qualitative interviews provide insight into how students engaged with CDIO phases in practice. Students described the problem-framing phase as particularly influential, emphasizing how industrial partners helped shape realistic expectations and encouraged focus on learning processes rather than complete technical solutions. One student noted that early clarification that the problem was too complex to fully solve shifted the team's mindset toward iterative learning and reflection, aligning strongly with the Conceive phase of CDIO and with professional engineering practice. Such experiences also reflect experiential learning perspectives, where authentic challenges combined with reflection can deepen students' understanding of professional processes (Kolb, 2014). Students also highlighted how working with real industrial data changed their understanding of engineering practice. Challenges related to data quality, preprocessing, and contextual understanding were frequently mentioned, reinforcing the role of uncertainty and judgment in data-driven engineering. These experiences align with CDIO's emphasis on authentic contexts rather than deterministic problem-solving (Edström & Kolmos, 2014). They also resonate with situated learning theory, suggesting that professional competence develops more effectively when learning activities are embedded in realistic contexts (Lave & Wenger, 1991).

Teamwork and multidisciplinary collaboration emerged as central learning experiences. Interviewees described how differences in disciplinary background, academic level, and experience shaped role distribution and leadership within teams. Rather than formal role assignments, leadership emerged naturally, often influenced by prior experience. Students reported learning to adapt communication styles, balance technical and systems perspectives, and negotiate shared understanding and skills explicitly emphasized in CDIO Syllabus sections on teamwork and communication (Malmqvist et al., 2022).

Intercultural communication and ethics were also experienced as meaningful, though students suggested that these elements would have been even more effective if introduced earlier in the course. Reflections on data confidentiality and the potential societal impact of analytics solutions illustrate how ethical considerations were encountered as situated and practical rather than abstract. This supports the course design choice to embed ethics and professional skills within project work rather than treating them as standalone topics. This finding aligns with research indicating that professional skills are often learned more effectively when integrated into disciplinary practice rather than separated into isolated modules (Crawley et al., 2014; Malmqvist et al., 2022).

Students' reflections on CDIO lifecycle phases suggest differentiated engagement across teams and individuals. The "Conceive" and "Design" phases were most strongly experienced, while "Implement" activities were distributed unevenly within the team depending on prior technical skills.

Teacher reflections

From the teacher's perspective, students most strongly experienced the "Conceive" and "Design" phases of the CDIO lifecycle, as these are the phases that can be meaningfully addressed within the scope and timeframe of an eight-week course. Fully engaging with the "Implement" and "Operate" phases was neither expected nor feasible, given both the course duration and the practical limitations of deploying and operating solutions in real industrial settings. Instead, these later phases were addressed through application, reflection and discussion with industry stakeholders. While this was a pragmatic adaptation to the course context, it can also represent a limitation. Without full deployment and operational follow-up, students might have fewer opportunities to experience issues such as robustness, maintenance, user adoption, organizational constraints, and long-term system performance. As a result, the course may provide stronger preparation for early-stage engineering work than for later lifecycle responsibilities. This suggests that partial engagement with the CDIO lifecycle may need to be complemented elsewhere in the programme through follow-up courses, simulations, longer projects e.g., Industry-sponsored MSc thesis projects (Crawley et al., 2014; Malmqvist et al., 2022). The teacher emphasized that working with real industrial problems and data was central to the authenticity of the learning experience. Unlike curated datasets commonly used in academic settings, industrial data were described as messy, incomplete, and difficult to interpret, and these conditions that students must learn to navigate in professional practice. The teacher also noted that engagement levels were noticeably higher due to the presence of company stakeholders and the perception that student work could contribute to actual industrial improvement. This supports wider engineering education findings that authenticity, external relevance, and contact with stakeholders can strengthen motivation and perceived value of learning activities (Edström & Kolmos, 2014; Thomas, 2000).

Interdisciplinary and mixed-level student groups were described as a defining feature of the course, aligned with the broader Tracks Chalmers structure. The teacher observed clear benefits in terms of complementary competencies, role differentiation, and peer learning, with students drawing on diverse strengths in data analytics, domain knowledge, and communication. At the same time, common challenges related to workload distribution, communication styles, language barriers, and intercultural differences were acknowledged. Rather than being viewed as shortcomings, these tensions were framed as expected and educationally valuable aspects of interdisciplinary engineering practice. The use of embedded Professional Skills materials, particularly on intercultural communication and ethics, was highlighted as an important enabler of integrated learning.

The teacher reported that situating these materials within project-specific seminars helped students connect abstract concepts to their own team dynamics and project realities. Intercultural communication was perceived as especially effective, as students encountered such challenges continuously throughout the project. Ethical reasoning, while considered important, was described as more difficult for students to experience directly, given the absence of real-world consequences during the course.

Finally, the teacher reflected on the assessment tasks as they are constructively aligned with the other course elements, combining individual and group assessments to address different cognitive levels and has worked well. It was also noted that the rapid emergence of AI assisted tools poses a major challenge for the current assessment tasks and makes them obsolete. This concern was framed not as course-specific, but as a broader systemic issue facing engineering education and requiring future research on innovation in assessment formats. More broadly, this points to a growing need for assessment approaches that capture process competence, critical judgement, teamwork, and responsible use of AI, rather than relying primarily on traditional written outputs (Pacher et al., 2024).

Recommendations

Based on the insights gained from this case study, the following recommendations are suggested for CDIO implementers seeking to integrate data-driven engineering practice and professional skills at course level.

- **Integrate professional skills modules early and through active learning:**
  Institution-level professional skills resources (e.g., ethics and intercultural communication) can effectively support CDIO Standard 7 and 8 when embedded as active learning activities combined with reflection and relation to students' project discussion.
- **Clarify expectations and align lectures with project work:**
  In project-based, CDIO-aligned courses should explicitly communicate the intended level of technical depth and ensure strong alignment between lectures and evolving project needs in open-ended, data-driven contexts.
- **Use industry-academia collaboration as a learning context, not only a setting:**
  Industry-connected projects naturally expose students to communication, coordination, expectation, and management challenges typical of industry-academia and research collaborations and thereby reinforcing authentic professional learning beyond technical outcomes.

CONCLUSIONS

This paper presented a course-level case study illustrating how the CDIO Syllabus 3.0 and the selected CDIO Standards can be implemented in a data-driven engineering context. The mapping between course elements, CDIO Syllabus 3.0 outcomes, and CDIO Standards shows the operationalization of CDIO principles through a constructive alignment of teaching and learning activities and assessment tasks. Industrial project work, the CRISP-DM framework, lectures, and embedded professional skills activities together support the integrated development of interdisciplinary knowledge, professional skills, teamwork, and CDIO lifecycle competencies. Findings indicate that students experienced authentic CDIO-aligned learning, with the Conceive and Design phases most strongly emphasized the course duration and the practical limitations of deploying and operating solutions in real industrial settings. The Implement phase with was addressed through building the analytics pipeline while Operate phase was mostly on reflection and interaction with industry stakeholders rather than full deployment, illustrating a pragmatic approach to lifecycle implementation. As a single course-level case, the findings are illustrative rather than generalizable, however, it provides a transparent example for institutions seeking to operationalize the CDIO Syllabus 3.0.

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