SIMULATION-DRIVEN RESILIENCE: FROM CDIO TO CDI'S' ASSESSMENTS TO OUTSMART AI SHORTCUTS

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ABSTRACT

The Conceive–Design–Implement–Operate (CDIO) framework has played a central role in aligning engineering education with professional practice through authentic, project-based learning and outcome-oriented assessment. By embedding learning within realistic workflows, CDIO has shifted emphasis from content delivery to demonstrated competence. However, in management-oriented engineering domains such as supply chain management, operations strategy, and complex project environments, the Operate phase presents structural limitations. Real operational systems cannot be physically enacted in educational contexts due to constraints of scale, cost, risk, time, and ethical responsibility, often leading to simplified case-based or report-driven approximations that weaken experiential authenticity. At the same time, higher education faces growing challenges related to assessment integrity arising from the widespread availability of generative artificial intelligence. Traditional written assessments, including those embedded within CDIO projects, are increasingly vulnerable to AI-assisted production that obscures student reasoning and professional judgement. This paper proposes CDIS (Conceive–Design–Implement–Simulate) as an extension of the CDIO framework in which simulation replaces physical operation as the primary mechanism for experiential learning and assessment. Simulation-based environments enable complexity, uncertainty, delayed feedback, and cross-functional decision-making without the risks of real-world replication. Using The Fresh Connection supply chain simulation as an illustrative implementation, the paper argues that CDIS supports authentic, data-driven, and AI-resilient assessment. By embedding learning within dynamic systems governed by real-time KPIs and iterative decision cycles, CDIS strengthens deep learning while preserves the epistemological intent of CDIO in complex engineering and management education contexts.

KEYWORDS

Simulation-based learning, CDIO framework, Authentic assessment, Supply chain education, Assessment integrity, Standards 1–3, 5–8 and 11.

INTRODUCTION

Over the past two decades, the Conceive–Design–Implement–Operate (CDIO) framework has become one of the most influential models in engineering education. By positioning the full lifecycle of products, processes, systems, and services as the context for learning, CDIO has strengthened alignment between engineering curricula, professional practice, and outcome-based accreditation (Crawley et al., 2007, 2014). Its emphasis on experiential and active learning has shifted assessment away from passive knowledge recall towards the demonstration of integrated technical, personal, and interpersonal competences (Biggs & Tang, 2011). As a result, CDIO has addressed long-standing critiques that engineering education is overly theoretical and insufficiently connected to real-world practice (Felder & Brent, 2016).

As engineering education increasingly extends into management-oriented and system-level domains such as supply chain management, operations strategy, and complex project environments, the assumptions underlying the Operate phase warrant closer examination. In these contexts, operational performance emerges from complex interactions across networks, organisations, and time horizons rather than from a single physical artefact that can be constructed and tested within a laboratory environment. Consequently, operational learning is often approximated through case studies or report-based analysis, which can weaken the experiential authenticity central to the CDIO approach (Kolb, 1984; Prince & Felder, 2006).

At the same time, the assessment landscape in higher education is being reshaped by the rapid adoption of generative artificial intelligence tools. While these technologies offer legitimate support for learning, reflection, and ideation, they also expose structural weaknesses in traditional assessment formats. Written reports, reflective narratives, and explanatory analyses can increasingly be produced with limited cognitive engagement, making it difficult to distinguish deep understanding from surface-level reproduction (Boud & Falchikov, 2007). This challenge is particularly pronounced in management-oriented engineering education, where assessment frequently prioritises narrative justification rather than observable system behaviour and performance.

Together, these developments raise a fundamental question for contemporary engineering education: how can experiential, authentic, and outcome-based learning be sustained in domains where physical operation is infeasible and conventional assessments are vulnerable to automation? Reverting to tightly controlled or exam-based assessment would undermine the pedagogical progress achieved through CDIO and constructive alignment (Biggs & Tang, 2011). Instead, what is required is a principled evolution that preserves CDIO's core values while adapting its mechanisms to the realities of complex, data-driven systems.

This paper proposes CDIS (Conceive–Design–Implement–Simulate) as such an extension. In CDIS, simulation replaces physical operation as the final integrative phase of learning and assessment. Simulation-based environments allow students to make consequential decisions under uncertainty, observe system-level outcomes, and iteratively refine strategies without real-world risk—an approach long established in engineering, operations, and systems education (Sitzmann, 2011). By embedding assessment within measurable system performance rather than narrative output, CDIS strengthens experiential authenticity, supports interdisciplinary collaboration, and enhances assessment integrity. Using The Fresh Connection supply chain simulation as an illustrative implementation, the paper demonstrates how CDIS preserves the spirit of CDIO while extending its applicability and robustness in contemporary engineering and management education (Kok & van Zyl-Cillié, 2024; García-Reyes, Maycotte-Felkel & Quijano-Dominguez, 2023).

BACKGROUND

CDIO, Authentic Assessment, and the Limits of Physical Operation

The Conceive–Design–Implement–Operate (CDIO) framework was developed to address critiques that engineering education is overly theoretical and insufficiently aligned with professional practice. By focusing on demonstrable competence, CDIO aligns with accreditation frameworks such as ABET and AHEP4, which emphasise applied knowledge, professional skills, and performance in complex contexts (ABET, 2025; Engineering Council, 2020). Grounded in experiential learning theory, it conceptualises learning as an active process integrating technical knowledge, teamwork, and systems thinking (Kolb, 1984b).

A key feature of CDIO is authentic assessment, where learning is evaluated through tasks resembling professional practice and requiring judgement and problem-solving under realistic constraints (Wiggins, 1998). Such approaches support deeper learning and stronger alignment with industry expectations (Kozanitis et al., 2009).

In many engineering disciplines, the Operate phase enables this through physical systems and prototypes. However, in management-oriented domains such as supply chain and operations, systems are large-scale, distributed, and socio-technical, making authentic physical operation difficult to reproduce. As a result, operational learning is often approximated through case studies or report-based assessments, which are typically static and retrospective, limiting opportunities for iteration and real-time feedback (Kozanitis et al., 2009).

These limitations are further amplified by generative artificial intelligence, which can produce coherent narratives with minimal engagement. This raises not only concerns about academic integrity but also epistemic validity, as assessments based primarily on written explanation may fail to capture genuine professional competence (Boud & Falchikov, 2007; Wiggins, 1998; Kozanitis et al., 2009).

Taken together, these considerations suggest that the purpose of the Operate phase lies in exposing students to the consequences of decisions within realistic systems rather than in physical deployment itself. In contemporary engineering practice, such consequences are often mediated through performance indicators and feedback loops. Simulation therefore provides a pedagogically robust extension, enabling realism, iteration, and measurable outcomes without the constraints of physical replication, forming the conceptual basis for CDIS. While simulation can already be integrated within CDIO implementations, CDIS should be understood not as a replacement, but as a pedagogical emphasis highlighting the central role of simulation in domains where physical operation is impractical.

Theoretical Positioning: CDIS in Relation to CDIO and Project-Based Learning

Project-Based Learning (PBL) has long been used in engineering education to promote active, contextualised problem solving. Rooted in constructivist and experiential learning theory, PBL emphasises learning through extended tasks that require inquiry, collaboration, and the production of tangible outputs (Kolb, 1984; Prince & Felder, 2006). While PBL is widely recognised for enhancing student engagement and motivation, it is often pedagogically under-specified at programme level. In particular, PBL implementations can vary substantially in terms of curricular coherence, assessment alignment, and progression, and projects frequently culminate in reports or presentations rather than observable system performance.

The CDIO framework can be understood as a structured evolution of PBL that addresses these limitations by situating projects within a clearly articulated lifecycle of professional engineering activity (Crawley et al., 2014). By linking learning outcomes to the stages of conceiving, designing, implementing, and operating systems, CDIO strengthens curricular coherence and supports authentic assessment through engagement with real or realistic systems. However, this approach is less readily applicable in domains where physical implementation and operation are infeasible.

CDIS (Conceive–Design–Implement–Simulate) is proposed as a domain-sensitive extension of CDIO. It preserves the lifecycle logic and experiential emphasis of CDIO while replacing physical operation with simulation in contexts characterised by scale, complexity, and systemic interdependence. Simulation-based environments enable students to engage with uncertainty, trade-offs, and system feedback through measurable outcomes over time. In this way, CDIS extends CDIO's theoretical foundations to complex socio-technical systems while maintaining its focus on authenticity, integration, and assessment integrity. Table 1 summarises the distinctions between PBL, CDIO, and CDIS across key dimensions.

Table 1: Comparison of Project-Based Learning (PBL), CDIO, and CDIS

DIMENSION	PROJECT-BASED LEARNING (PBL)	CDIO	CDIS
Theoretical foundation	Constructivist and experiential learning (Kolb, 1984)	Experiential learning with outcome-based accreditation alignment (Crawley et al., 2014)	Experiential learning extended through system simulation and performance-based assessment
Curricular structure	Loosely structured; varies by course and instructor	Explicit lifecycle structure: Conceive–Design–Implement–Operate	Lifecycle structure: Conceive–Design–Implement–Simulate
Primary learning focus	Engagement through projects	Development of professional engineering competencies	Strategic and system-level decision-making in complex systems
Nature of the project	Often artefact- or report-based	Product, process, or system development	Dynamic system management within a simulation environment
Final integrative phase	Project presentation or report	Physical operation of a product or system	System simulation with evolving outcomes
Assessment approach	Often summative and narrative-based	Authentic, performance-informed assessment	Data-driven, performance-based, and iterative assessment
Feedback mechanism	Instructor-led, often periodic	Iterative feedback linked to lifecycle stages	Continuous feedback through system-generated KPIs
Handling of complexity and uncertainty	Limited; often simplified	Moderate; constrained by physical feasibility	High; uncertainty, trade-offs, and time pressure embedded
Interdisciplinary collaboration	Optional or implicit	Explicit and structured	Mandatory and role-based (e.g., sales, supply chain, operations)
Scalability to large systems	Limited	Limited in management-intensive domains	High; suitable for large-scale socio-technical systems
Vulnerability to AI-generated work	High	Moderate	Low; performance depends on real-time decisions and outcomes
Typical application domains	Design courses, capstone projects	Product design, manufacturing, laboratory systems	Supply chain management, operations strategy, project environments

From Operate to Simulate: Conceptualising CDIS

The CDIS framework (Conceive–Design–Implement–Simulate) extends the CDIO lifecycle by adapting the final integrative phase to the characteristics of complex management-oriented engineering systems. Rather than relying on physical operation, CDIS positions simulation as the environment through which students experience consequences, evaluate performance, and demonstrate professional competence. In many contemporary engineering and managerial contexts, competence is evidenced through decision quality, system behaviour, and performance indicators rather than through direct operation of physical artefacts.

Within CDIS, the Conceive phase focuses on strategic framing, requiring students to interpret contexts, define objectives, and establish performance indicators that balance cost, service, sustainability, and resilience (Crawley et al., 2014). The Design phase translates these objectives into decision policies while considering system-wide trade-offs, consistent with principles of authentic assessment (Wiggins, 1998).During Implement, strategies are operationalised and refined through feedback, reflecting Kolb's experiential learning cycle (Kolb, 1984). Finally, the Simulate phase provides dynamic outcomes such as financial performance, service levels, and sustainability indicators that evolve over time, exposing students to uncertainty, nonlinearity, and delayed system effects.

From an assessment perspective, CDIS operationalises authentic assessment more robustly than traditional project-based approaches. Students are evaluated on their ability to interpret feedback, adapt strategies, and justify decisions in relation to observed outcomes rather than on narrative explanation alone (Kozanitis et al., 2009). Reflection remains central but is anchored in concrete performance trajectories and decision histories, significantly reducing the effectiveness of AI-generated submissions. Assessment integrity is thus achieved through pedagogical design rather than restriction.

Interdisciplinary collaboration is integral to CDIS implementations. Simulation environments such as The Fresh Connection require students to assume distinct functional roles (sales, supply chain, purchasing, and operations) each governed by competing objectives (García-Reyes, Maycotte-Felkel & Quijano-Dominguez, 2023; Akkatal, Barooti & Akkartal, 2019). System performance emerges from cross-functional coordination rather than individual optimisation, reflecting contemporary organisational practice and aligning with CDIO's emphasis on teamwork and communication (Crawley et al., 2014). Crucially, collaboration is consequential: misalignment between functions produces measurable degradation in system performance, reinforcing the necessity of integration and shared accountability.

Generative AI and the Fragility of Narrative-Based Assessment

The rapid and recent adoption of generative artificial intelligence has brought renewed attention to long-standing challenges in assessment design within higher education, particularly in disciplines that rely heavily on written explanation, reflection, and structured analysis. While generative AI tools can support learning when used transparently and ethically, their widespread availability has made visible structural vulnerabilities in assessment formats that prioritise narrative coherence over demonstrable engagement with disciplinary processes. These vulnerabilities are not new; assessment scholars have long argued that tasks focused primarily on textual articulation risk privileging presentation over performance and understanding (Boud & Falchikov, 2007; Wiggins, 1998).

In engineering and management education, this vulnerability is especially pronounced. Students are frequently assessed on their ability to justify decisions, interpret scenarios, or reflect on outcomes through textual artefacts. When such tasks are detached from observable system behaviour, acceptable submissions can be produced without sustained engagement with uncertainty, trade-offs, or decision consequences. This issue is not primarily one of academic misconduct, but of epistemic validity: as assessment scholars have long argued, evaluations that do not require students to *act within* and *respond to* a system cannot reliably measure professional competence (Wiggins, 1998; Boud & Falchikov, 2007; Kozanitis et al., 2009).

Within experiential frameworks such as CDIO, this issue represents a misalignment between pedagogical intent and assessment practice. CDIO emphasises competence demonstrated through action, integration, and consequence rather than symbolic representation alone (Crawley et al., 2014). When the Operate phase is approximated through reports or retrospective analyses, assessment risks reverting to surface-level indicators of learning, creating conditions in which AI-generated outputs can obscure genuine understanding. These developments highlight the need for assessment designs that embed evaluation within system behaviour itself, motivating exploration of simulation-based approaches capable of sustaining authenticity and integrity under contemporary conditions.

CASE STUDY: CDIS IMPLEMENTATION AT UNIVERSITY OF HERTFORDSHIRE

Module Context and Design

The CDIS framework was implemented as a pilot within the Successful Project Delivery course (referred to as a “module” in the UK higher education system), a postgraduate module focused on foundational concepts in project and operations management. The student cohort comprised individuals from diverse academic and professional backgrounds. To promote multidisciplinary perspectives and effective collaboration, students were organised into teams of four to five members. Team composition was informed by both disciplinary background and the results of a personality assessment, with the aim of achieving a balanced mix of skills, working styles, and perspectives within each team.

Based on their background and personality profile, students were advised on functional roles that might best suit them—specifically Operations, Sales, Purchasing, Supply Chain, or Chief Executive Officer—mirroring the functional interdependence characteristic of real-world organisations. Final role allocation, however, was determined collaboratively within each team to ensure shared ownership and alignment with individual preferences. This role-based structure supported interdisciplinary collaboration and reflected CDIO principles related to teamwork, communication, and system integration (Crawley et al., 2014). The pilot cohort consisted of 26 students, forming a total of six teams. The module was deliberately designed to integrate simulation-based experiential learning as a core pedagogical and assessment mechanism rather than as a supplementary activity. This design choice aimed to align learning activities more closely with professional practice in management-oriented engineering contexts, where decision-making under uncertainty, system integration, and cross-functional coordination are central competencies.

At the outset of the module, students received structured instruction on core supply chain and operations management principles, providing the conceptual scaffolding required for informed decision-making later in the course. This initial phase ensured alignment with constructive alignment principles, enabling subsequent experiential activities to build on a shared theoretical foundation (Biggs, Tang & Kennedy, 2022). The CDIS lifecycle was then progressively embedded, with simulation serving as the primary environment through which learning and assessment were enacted.

Embedding CDIS Through Simulation-Based Learning

From the third week of the module, students were introduced to *The Fresh Connection* (TFC), a commercial supply chain simulation developed by Inchainge (Akkatal, Barooti & Akkartal, 2019; Maisiri & Hattingh, 2022; Kok & van Zyl-Cillié, 2024; García-Reyes, Maycotte-Felkel & Quijano-Dominguez, 2023). The initial exposure to TFC consisted of a guided, whole-class practice round. This activity familiarised students with the simulation interface, clarified the meaning of key performance indicators (KPIs), and illustrated how local decisions influence overall system performance. Following this shared experience, teams proceeded to formal decision rounds in which they were required to conceive strategies, design coordinated policies, implement decisions, and observe outcomes through simulation-generated feedback. In total, six decision rounds were conducted, commencing in Unit 5 and concluding in Unit 10 of the module. This iterative cycle of decision-making, feedback, and reflection became the central mechanism for operationalising the CDIS framework within the module, enabling students to engage progressively with system complexity, uncertainty, and performance trade-offs.

Throughout the semester, structured simulation time was embedded into each teaching session. New concepts such as demand forecasting, capacity planning, inventory management, and risk mitigation were introduced on a just-in-time basis, allowing teams to apply them immediately within the simulation. As the module progressed, the time available for decision-making was deliberately reduced to introduce realistic time pressure and reinforce collaborative decision-making, reflecting authentic managerial constraints (Kolb, 1984).

CDIS and Assessment Integrity in the Presence of Generative AI

The CDIS implementation also provided a practical response to emerging challenges associated with generative artificial intelligence in assessment. In engineering and management education, assessment often relies on written explanation, reflection, or structured analysis—formats that AI systems can now generate convincingly with limited cognitive engagement. While such tools may support learning when used appropriately, their availability exposes structural weaknesses in assessment designs that prioritise narrative output over observable system performance (Khodadad, 2025).

Within CDIO-aligned curricula, this challenge represents a pedagogical misalignment rather than merely a risk of misconduct. CDIO emphasises competence demonstrated through action, integration, and consequences, rather than symbolic representation alone (Crawley et al., 2014). When operational learning is approximated through reports or retrospective analyses, assessment becomes detached from system behaviour, resulting in surface learning, in which rhetorical coherence outweighs disciplinary understanding. As Wiggins (1998) argues, assessments that do not require students to “do the work of the discipline” risk measuring presentation rather than proficiency.

In the CDIS implementation, assessment was grounded in simulation-generated system behaviour rather than static outputs. Students were evaluated on their ability to interpret empirical evidence, respond to feedback, and adapt strategies across iterative decision cycles. Generic or decontextualised responses became immediately visible through misalignment with system outcomes, rendering inappropriate uses of AI pedagogically ineffective. This approach aligns with design-based perspectives on academic integrity, which emphasise assessment structures that make misconduct unproductive rather than relying on detection or prohibition (Bretag et al., 2019).

Learning Outcomes and Observed Impact

The outcomes of the pilot implementation were positive across engagement, participation, and learning performance. Attendance rates during the simulation phase ranged between 70–80%, significantly higher than the approximately 40% typically observed in modules without embedded experiential requirements. Students reported sustained engagement, attributing their participation to the interactive, consequential, and competitive nature of the simulation-based learning environment.

To further examine the impact of this engagement, correlation analysis was conducted between simulation attendance and two outcome measures, final ROI and overall performance score, as illustrated in Figure 1. Results indicate a strong positive correlation with performance score (r = 0.84) and a moderate positive correlation with ROI (r = 0.67). Student performance was systematically captured through a structured observation instrument administered at key project checkpoints. The observation form evaluated individual contribution across four dimensions: role ownership (confidence and accountability), preparedness and engagement (attendance and proactive participation), collaboration and support (team contribution and knowledge sharing), and impact on group success. Each dimension was assessed using Likert-scale measures and supplemented with qualitative observations. This enabled the integration of attendance data with observed behavioural engagement, strengthening the analysis of the relationship between engagement and performance.

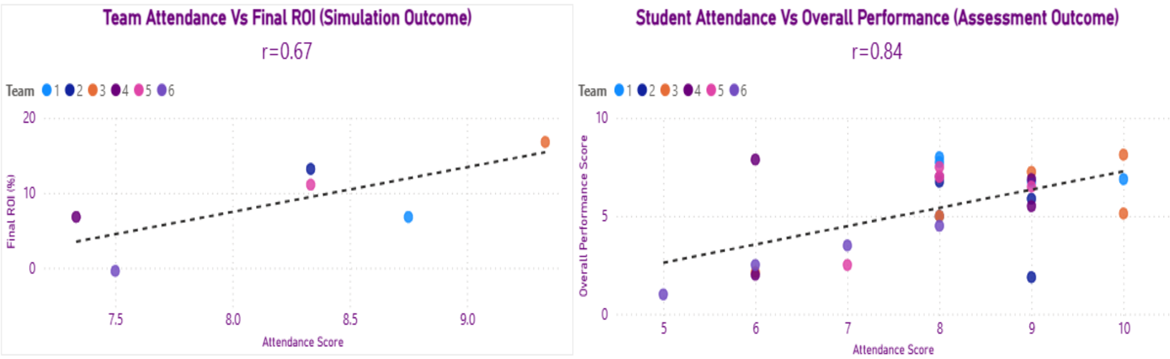

Figure 1: Relationship Between Simulation Attendance and Performance Outcomes at Team and Student Levels

While the relationship with performance score is partially influenced by the inclusion of engagement within assessment criteria, the correlation with ROI is moderate but meaningful, as ROI emerges from decision-making effectiveness within the simulation and is not directly graded. This suggests that sustained engagement contributes not only to academic performance but also the development of practical decision-making capability in complex systems.

Performance data generated by TFC simulation provided further evidence of learning progression. Most teams achieved improvements in key performance indicators, including Return on Investment (ROI), relative to their initial baseline performance, as shown in Figure 2. This upward trajectory suggests that students were not only able to understand core supply chain concepts, but also to apply them effectively within a complex, interdependent decision environment. The requirement to justify decisions in relation to observed outcomes further supported reflective learning grounded in evidence rather than abstraction (Kozanitis et al., 2009).

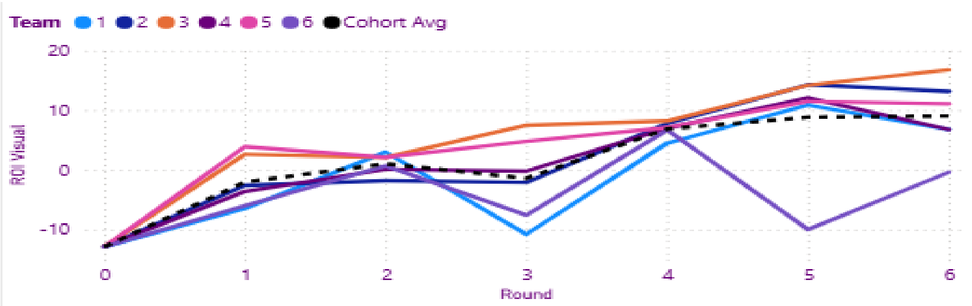

Figure 2: Return on Investment (ROI%) Performance Across Simulation Rounds

A notable pattern is observed in Team 6, whose performance fluctuated considerably across rounds. This instability is consistent with the broader trend shown in Figure 1, where lower and inconsistent attendance is associated with weaker performance. Informal observations indicated irregular participation during key decision rounds, suggesting that inconsistent engagement disrupted coordination and decision quality. This reinforces the dependence of simulation-based learning on sustained participation and effective collaboration to achieve stable system performance.

LIMITATIONS

As a conceptual paper, this work has several limitations that should be acknowledged. First, the CDIS framework is illustrated through a single institutional context and a single simulation platform, which may limit the immediate generalisability of the findings to other disciplinary domains, programme structures, or educational settings. While the case study provides rich descriptive insight into the implementation of CDIS, it does not constitute a controlled empirical evaluation. Further research is therefore required to examine learning outcomes systematically, including cognitive load, stress levels, long-term competence development, and comparative effectiveness relative to traditional CDIO or Project-Based Learning approaches.

In addition, although CDIS is positioned as resilient to AI-generated submissions through assessment-by-design, this claim remains conceptual and requires empirical verification. Future studies should investigate student behaviour, use of generative AI tools, and assessment performance under controlled or comparative conditions to substantiate this argument. These limitations do not diminish the conceptual contribution of the paper; rather, they identify clear directions for future research necessary to validate, refine, and extend the CDIS framework across contexts.

CONCLUSIONS

This paper has proposed CDIS (Conceive–Design–Implement–Simulate) as a conceptual extension of the CDIO framework for educational contexts in which physical operation is impractical. By positioning Simulation as the final integrative phase, CDIS preserves CDIO's experiential learning principles while adapting them to complex socio-technical systems such as supply chains and project-based organisational environments.

The analysis presented across the paper indicates that CDIS addresses several interrelated challenges facing contemporary higher education. First, it provides a coherent response to the limitations of physical replication in management-oriented engineering domains, where professional competence is expressed through decision-making, coordination, and interpretation of system performance rather than artefact operation alone. Second, CDIS strengthens authentic assessment by embedding evaluation within dynamic system behaviour, requiring students to engage with uncertainty, delayed feedback, and trade-offs over time. Third, by grounding assessment in system-generated data and decision histories, CDIS reduces the effectiveness of surface learning strategies and AI-generated shortcut behaviours not through restriction, but through resilient assessment design.

From a pedagogical perspective, CDIS reinforces interdisciplinary collaboration as a consequential rather than symbolic activity. The requirement for alignment across functional roles mirrors professional practice and makes visible the systemic consequences of miscoordination. At the same time, the framework supports scalability and fairness by providing common system conditions while allowing diverse strategies and performance trajectories.

While the paper is intentionally conceptual, it opens important directions for future research, including empirical studies on learning outcomes, student engagement, cognitive load, and long-term competence development within simulation-based environments. Quantitative analysis of performance trajectories, complemented by qualitative insights into student decision-making and reflective practices, would provide a stronger evidence base to validate, refine, and extend the CDIS framework across different disciplines and institutional contexts.

Future research should investigate learning outcomes, engagement, and competence development associated with simulation-based learning environments. Empirical studies examining performance trajectories and student decision-making could further refine the CDIS framework and evaluate its applicability across different disciplines and institutional contexts.

Finally, it is acknowledged that the choice of acronym “CDIS” may evolve in time to more accurately reflect the process. Indeed, during the development of this work, the letters “CDSO” as “Conceive Design Simulate Operate” may be more appropriate and reflective of the process. The authors acknowledge the concept as being a variation and evolution of the “CDIO” approach and envisage its potential use in the context of the CDIO organisation and would thus value the CDIO community’s input on this.

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