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Institutionalizing entrepreneurship education in CDIO-based project courses: evidence from a fifteen-year longitudinal case

Magnus Klofsten
Department of Management and Engineering, PIE Division, Linköping University, Linköping, Sweden

Abstract

Purpose – This study examines how entrepreneurship education can be sustainably integrated into engineering programmes by analysing a fifteen-year case of a mandatory entrepreneurship component embedded in CDIO-based project courses at a Swedish university. It addresses the challenge that many entrepreneurship initiatives in engineering remain elective or poorly connected to technical studies.

Design/methodology/approach – A qualitative single case research design is used, combined with reflexive autoethnography. The analysis is triangulated with student evaluations, project materials, and programme documents from 2009 to 2025, covering more than three thousand students. The study traces the evolution of the component from early planning templates to a concise idea instrument focusing on need, user value, assumptions, uncertainties and short-term direction.

Findings – The study identifies several conditions that supported long-term institutionalisation: compulsory embedding at programme level, stable learning aims combined with flexible delivery, inquiry-based facilitation, and alignment with the rhythms and demands of CDIO project work. The entrepreneurship component became a consistent part of project practice without competing with technical learning.

Research limitations/implications – A key limitation is that the study focuses on a single programme, which may limit generalisability to other contexts or disciplines. Findings reflect specific project-based ecologies and repeated exposure, and outcomes could differ in less structured environments. Nevertheless, the case has clear implications: entrepreneurship education can be designed as a durable, integrated programme rather than isolated interventions. Recurrent exposure and alignment with project sequences support competence development, shared professional understanding, and programme coherence. This suggests that embedding entrepreneurship as durable practices across courses, rather than relying on individual modules, is critical for lasting educational impact.

Practical implications – For teachers, entrepreneurship is most effectively sustained when integrated into compulsory project courses where authentic uncertainty is central and structured planning supports continuity across academic cycles. Short early-stage idea assignments focusing on users, needs, value, and assumptions can be applied across diverse projects, enabling scale without losing relevance. Assessment should emphasise clarity of reasoning and reflective justification. Facilitation works best when it is question-driven, encourages comparison of alternatives, highlights uncertainty, and maintains student ownership. Framing entrepreneurship as early idea reasoning strengthens legitimacy, creates a shared vocabulary, and can be reinforced through visible progression, scheduled interactions, and curated exemplars.

Social implications – Embedding entrepreneurship education across project-based engineering programmes has broader societal implications. Through supporting competence in recognising opportunities, evaluating alternatives, and making decisions under uncertainty, students are better prepared to contribute to innovation, value creation, and organisational renewal in diverse sectors. Recurrent exposure and shared reasoning practices cultivate professional identity and collaboration skills, supporting workforce readiness for complex, uncertain environments. Framing entrepreneurship as widely applicable reasoning, not just start-up creation, equips graduates to address societal challenges, create sustainable solutions, and participate effectively in both established organisations and emerging ventures.

Originality/value – The paper contributes by explaining how entrepreneurial learning can be institutionalised within project intensive engineering curricula through sustained alignment between pedagogical practices and organisational arrangements. It reframes entrepreneurship as judgement under uncertainty rather than venture

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preparation and shows how this orientation can be meaningfully embedded and maintained at scale within CDIO based project environments. The process observed in this case may inform other programmes seeking durable integration, while remaining sensitive to local pedagogical and organisational conditions.

Keywords Entrepreneurship, Idea development, Coaching workshop, Design-build-test course, Project-based learning

Paper type Research article

1. Introduction

Entrepreneurship has gained importance in engineering education, reflecting expectations that engineers contribute not only to technical problem solving but also to innovation, value creation and organisational renewal (Gunnarsson *et al*., 2010; Norrman *et al*., 2014; National Academy of Engineering, 2004; Hadgraft and Kolmos, 2020). Within CDIO (Conceive–Design–Implement–Operate) oriented programmes, extended project courses create conditions of technological change, interdisciplinary collaboration and uncertainty. These environments encourage students to recognise opportunities and make decisions with incomplete information and are therefore well suited for entrepreneurial learning aligned with professional competences (Malmqvist *et al*., 2020; He, 2025; Cheah *et al*., 2025).

Research on entrepreneurship education in engineering has often concentrated on elective courses and short-term initiatives, which limits understanding of how entrepreneurship can be embedded and sustained at programme level across multiple cohorts and technical contexts (Carpenter and Wilson, 2022; Anubhav *et al*., 2024). This paper addresses that gap through a longitudinal case where entrepreneurship forms a mandatory element within CDIO based project courses. The stable course sequence makes it possible to examine arrangements that support continuity and how these arrangements relate to programme coherence. Two constructs guide the analysis. Durability refers to recurring presence of an educational practice across academic cycles, supported through stable aims, aligned assessment and organisational routines that remain intact despite staff changes and variation among cohorts. Programme coherence refers to cumulative effects that arise when students repeatedly encounter shared reasoning tasks across different technical settings, creating a cross-cutting vocabulary and capability line.

The study proceeds from competence oriented and practice-based perspectives. Entrepreneurship education is understood as experiential learning under uncertainty where capability develops through action and reflection, rather than as preparation for immediate venture creation (Gibb, 2002; Fayolle and Gailly, 2008; Sánchez, 2013; Politis, 2005). Situated learning explains how participation in communities of practice supports identity and judgement, while reflective practice highlights how learners work with ill-defined problems through iterative testing of emerging understandings (Lave and Wenger, 1991; Schön, 2017). Evidence also shows that entrepreneurship education strengthens transferable skills, perceived behavioural control and opportunity identification in engineering contexts where new ventures are not the primary aim (Karimi *et al*., 2016; Parker *et al*., 2025). The study addresses the following questions: (i) How can entrepreneurial learning be durably embedded within CDIO based project courses in engineering programmes? and (ii) How is such embedding reflected in programme coherence and student experiences?

The contribution lies in identifying design principles that support continuity at programme level, shifting attention from isolated activities toward institutional arrangements that align teaching, assessment and organisational structures. The case clarifies how entrepreneurship remains relevant for diverse engineering career paths, strengthening intrapreneurial and innovation-oriented competence through authentic project engagement (Gibb, 2002; Karimi *et al*., 2016; Klofsten *et al*., 2021, 2024).

The paper continues with a review of entrepreneurship education and CDIO-based pedagogical environments (Section 2), followed by methodology and data (Section 3), and the longitudinal case development (Section 4). Section 5 presents a discussion of how durability

and programme coherence emerge through an institutionalisation process across project-based courses, and Section 6 concludes with implications and directions for future research.

2. Entrepreneurship education and learning under uncertainty

Entrepreneurship education initially focused on preparing students for business creation, with early university courses built around opportunity analysis, venture planning and market entry, supported through practitioner involvement but with limited theoretical grounding and unclear intended outcomes (Gartner and Vesper, 1994; Solomon, 2007; Neck *et al*., 2021). As the field developed, research questioned the centrality of venture creation and redirected attention toward experiential learning and judgement under uncertainty, where knowledge evolves through action and reflection in changing situations (Politis, 2005; Rae and Wang, 2015).

Drawing on broader theories of professional practice, Schön's work explains how individuals handle ill-defined problems through cycles of testing and revision (Schön, 2017). This aligns with competence-oriented perspectives that position entrepreneurship education as capability development through experiential engagement with uncertainty rather than as training for firm creation (Fayolle and Gailly, 2008; Sánchez, 2013). Social learning theory offers a similar understanding, portraying learning as participation in communities of practice where identity and capability develop through involvement in shared activity (Lave and Wenger, 1991).

Empirical research supports this emphasis on competence formation. Studies show that entrepreneurship education strengthens transferable skills, perceived behavioural control and opportunity identification even when venture creation is not the primary aim (Sánchez, 2013; Karimi *et al*., 2016; Parker *et al*., 2025). Action oriented approaches demonstrate how authentic engagement with uncertain problem settings, supported through interaction with peers, mentors and external actors, encourages students to confront assumptions, reflect on outcomes and develop informed judgement (Hytti and O'Gorman, 2004; Rasmussen and Sørheim, 2006). Comparative work further shows that entrepreneurship education serves several purposes, including awareness, capability development and behavioural orientation, with outcomes shaped through clarity of educational intent and institutional context (Hytti and O'Gorman, 2004; Fayolle and Gailly, 2008; Blenker *et al*., 2014).

Across this body of work, entrepreneurship education appears as an educational field centred on learning under uncertainty. Experiential engagement, social interaction, and structured reflection function as processes through which students learn to articulate needs, assess alternatives, and reason about value and context. Studies also show that exposure to uncertainty and the possibility of failure can deepen learning, as these moments prompt adjustment of assumptions and refinement of understanding (Gibb, 2002; Rasmussen and Sørheim, 2006). The educational contribution is often described in terms of long-term competence development rather than rapid venture outcomes.

2.1 CDIO and institutional learning environments

Entrepreneurship education shares conceptual foundations with CDIO, emphasizing practice-based engagement where understanding develops through work with real problems and structured opportunities for application and feedback (Gunnarsson *et al*., 2010; Malmqvist *et al*., 2020; Norrman *et al*., 2014; He, 2025). Empirical studies show that extended project work, iterative exploration and systematic reflection support deep engagement with innovation capability when learning activities align with clear educational intentions (Malmqvist *et al*., 2020; Cheah *et al*., 2025).

Design oriented perspectives emphasise the need for clarity regarding pedagogical intention when approaches developed in one domain are applied in another, as shown in reviews of design thinking (Johansson Sköldberg *et al*., 2013). CDIO offers a widely recognised educational structure with its focus on progression, authentic tasks and integration

of professional competences with technical knowledge (Malmqvist *et al*., 2020). Studies also show how sustainability, innovation and entrepreneurship can be incorporated when supported through standards, feedback routines and organisational commitment that encourage consistent practice (Cheah *et al*., 2025).

Research further shows that CDIO frameworks extend into vocational and mixed institutional environments, supporting capability development and alignment with workplace expectations (He, 2025). Large scale institutional collaborations provide authentic contexts for learning, although their long-term functioning depends on coordination, governance and clear pedagogical intentions (Zhuang, 2026). Ecosystem perspectives clarify how resources, networks and staged arenas shape opportunities for testing emerging ideas over time (Wright *et al*., 2017). Within CDIO settings these ecosystem logics interact with project sequences through which students work with real problems and refine understanding through repeated cycles of application and reflection (Malmqvist *et al*., 2020).

Assessment and institutional conditions are also central. Evaluation models that focus on prediction or completeness may limit exploration in project courses, whereas CDIO oriented assessment emphasises clarity of reasoning, documentation and justification of decisions (Norrman *et al*., 2014; Malmqvist *et al*., 2020). Weak organisational structures or insufficient alignment between curriculum, intention and departmental routines can reduce the effect of entrepreneurship and innovation-oriented activities even when pedagogical potential is strong, highlighting the importance of coherence between intention, structure and educational design (Adamowicz, 2019; Hytti and O'Gorman, 2004).

3. Methodology and data

This study adopts a qualitative and exploratory single-case study design combined with a reflexive autoethnographic approach, as the author has been involved in the entrepreneurship component from its inception (Van de Ven, 2007). Autoethnography was used to analyse lived experience in relation to institutional practices, including teaching arrangements, student interactions, and iterative adjustments of the module (Hackley, 2020; Edwards, 2021). The case concerns a mandatory entrepreneurship component integrated into CDIO-based Design-Build-Test (DBT) courses across multiple engineering fields, reaching over three thousand students by 2025. Entrepreneurship is framed as competence in opportunity recognition, evaluation, and judgement under uncertainty, making this long-term context particularly suitable for studying durability and institutional development (Gabrielsson *et al*., 2025). Key materials include annual student evaluations (2009–2025), project assignments, reflective documents, and internal programme files (Gartner and Vesper, 1994; Hytti and O'Gorman, 2004; Shekhar *et al*., 2024).

Autoethnographic reflections were complemented with documentary data to support triangulation, consistent with calls for methodological pluralism in entrepreneurship education research (Blenker *et al*., 2014). Student evaluations were treated as indicators of perceived alignment between entrepreneurial learning and technical project work rather than as measures of effectiveness (Hytti and O'Gorman, 2004). Project assignments and reflective documents were used to explore how students articulate assumptions, alternatives, and uncertainty in their projects, focusing on sensemaking rather than performance outcomes (Rasmussen and Sørheim, 2006; Norrman *et al*., 2014). Programme documents, syllabi, and pedagogical reports provided additional insight into institutional arrangements and curriculum development (Gabrielsson *et al*., 2025).

Data were analysed through an iterative and more structured process than originally planned at the outset of the study, which initially relied on a more open-ended autoethnographic approach. Autoethnographic notes and documentary sources were first reviewed to identify analytically grounded categories related to compulsory integration, alignment with project-based pedagogy, approaches to uncertainty, and assessment routines, categories that capture key processes through which entrepreneurship education is durably

embedded and coherently connected across the programme (Hytti and O'Gorman, 2004; Rasmussen and Sørheim, 2006; Norrman *et al*., 2014). These categories were treated as intermediate analytical elements and were compared systematically across data sources to identify recurring patterns over time. Through repeated comparison across successive academic cycles, the categories were consolidated into broader analytical patterns reflecting stability, gradual change, and refinement of pedagogical and organisational arrangements (Blenker *et al*., 2014; Gabrielsson *et al*., 2025). Student evaluations and project artefacts were then examined to confirm, nuance, or challenge these patterns, strengthening interpretive validity and grounding the analysis in student experiences (Hytti and O'Gorman, 2004). Finally, discussions with colleagues involved in teaching and programme coordination functioned as an additional interpretive resource, helping to clarify how particular routines became institutionalised and gained stable organisational footing within the programme (Bienkowska and Klofsten, 2012; Zhuang, 2026). This analytical process resulted in two overarching analytical themes. Durability captures how the entrepreneurship component was maintained over time through stable tasks, assessment routines, and organisational anchoring. Programme coherence captures how repeated exposure to the same reasoning task across different CDIO-based project courses contributed to cumulative learning and the development of a shared analytical vocabulary across the programme. The analysis focuses on pedagogical design and institutional arrangements rather than personal experience, acknowledging challenges associated with long-term researcher involvement while aligning with competence-based and practice-oriented perspectives on entrepreneurship education (Hytti and O'Gorman, 2004; Rasmussen and Sørheim, 2006; Wright *et al*., 2017).

The combination of a longitudinal single-case design and reflexive autoethnography provides insight into durability, competence development, and institutionalisation, and helps identify design processes transferable to other compulsory, project-based engineering environments with large cohorts. (Hytti and O'Gorman, 2004; Wright *et al*., 2017; Zhuang, 2026). Limitations relate to the single-case design, which provides depth but limits generalisability (Thomas, 2011), and reliance on documented materials, which may overlook short-lived or informal changes. Student evaluations capture perceived coherence rather than competence development, while programme documents reflect administrative routines. These constraints position the findings as context-dependent insights intended to inform similar educational settings.

4. Case description, institutional programme context and course development

The engineering programmes at Linköping University, Sweden (LiU) have long emphasised learning through active engagement in realistic project settings. Project courses therefore constitute central learning arenas, characterised by open-ended assignments, teamwork, and student responsibility for progress (Gunnarsson *et al*., 2010; Linköping University, 2026). This pedagogical tradition has shaped how complementary components, including entrepreneurship, have been integrated into the curriculum. The CDIO framework is a structured approach to engineering education aimed at strengthening graduates' technical and professional skills, originally developed at the Massachusetts Institute of Technology and later formalised through the CDIO Initiative, which began 25 years ago as a collaboration among four universities and has since evolved into a global community of practice. CDIO is organised around the CDIO Syllabus, defining intended learning outcomes, and the CDIO Standards, specifying key programme components. LiU was one of the founding members of the Initiative and initially implemented CDIO within the Applied Physics and Electrical Engineering programme through design–build–test (DBT) courses integrating disciplinary knowledge with teamwork and communication skills.

Extensive project courses in areas such as automatic control, image and graphics, and applied physics have since served as platforms for embedding entrepreneurship directly into students' ongoing technical work. Learning develops through sustained group participation

and increasing expectations of independent problem solving. Many DBT courses span an entire term, carry twelve credits, and involve technically demanding, open-ended tasks that require iterative reasoning under uncertainty (Svensson and Gunnarsson, 2012). These conditions naturally raise questions of opportunity, users, value, and context, making entrepreneurship a coherent and recurring element of project-based learning across programmes and cohorts.

4.1 Scale and participation

The entrepreneurship component has been integrated into a wide range of project courses since 2009, giving it a stable and recurring presence across the programme. Because the courses differ in theme, scope and project structure, the component has reached students with varying technical backgrounds and professional orientations. Each year, several hundred students encounter the component as part of their project work, creating substantial engagement with early idea development alongside technical tasks. Although the courses span diverse areas, three project courses account for the largest share of student involvement: Automatic Control, Images and Graphics and Applied Physics. Their differing technical orientations and recurring nature ensure that the entrepreneurship component appears in multiple contexts and functions as a shared learning element across programme tracks.

Table 1 summarises participation from 2009 to 2025. The three largest courses alone contribute more than one third of all participating students, while smaller courses continue to provide steady involvement, ensuring programme-wide exposure to idea development linked to ongoing technical work.

This distribution shows how the entrepreneurship component has become part of routine project-based learning throughout the programme. Students work with early idea development in parallel with their technical tasks, irrespective of whether their projects concern algorithms, systems, design challenges or modelling. Despite substantial variation in course size and technical content, the component functions as a common learning experience that connects project work with questions of value, users and assumptions. Over time, this has created a broad and sustained presence within the project course structure.

4.2 Original course design

The entrepreneurship component, a 3 ECTS (European Credit Transfer and Accumulation System) module, was introduced to give engineering students hands-on experience in examining early ideas and assessing their potential. It supported reflection on users, contexts, and early development paths, while introducing core themes such as opportunity development, argumentation, and intellectual property. Early lectures framed entrepreneurship as an iterative

Table 1. Participation in project courses where the entrepreneurship component has been included, 2009–2025

Course/orientation	Total students 2009–2025
Automatic control	1,020
Images and graphics	595
Applied physics	435
Electrical engineering (incl. VLSI design)	425
Applied mathematics	238
Biomedical engineering	204
Signal processing, communications and networking	340
Total	*3,247*

and uncertain process, using models such as the Business Platform (Klofsten, 2002) to illustrate how ideas, teams, and ecosystems interact in the early stages of development.

The initial design centred on a business plan developed as a group assignment, submitted and presented at the end of the module, and explicitly linked to students' technically oriented project work. This connection was essential to ground entrepreneurial reasoning in authentic engineering problems, ensure relevance for technically focused students, and enable systematic reflection on use, value, and feasibility. The emphasis was on early reasoning, examining assumptions, alternatives, and forms of value, rather than venture creation. Teaching combined lectures with workshops where student groups explored their project ideas through guided discussion. Repeated delivery across eight project courses revealed patterns that informed adjustments to enhance clarity and provide consistent support across courses of different size and technical orientation.

4.3 Pedagogical evolution

Over time, the entrepreneurship component was revised through repeated delivery. The initial simplified business plan was phased out and replaced by a format explicitly designed for early-stage idea development, the IdeaPM. This shift redirected attention from venture planning to analysing emerging ideas. Student groups described their idea, its value, potential users, underlying rationale, key uncertainties, and possible directions for exploration. Built around the NABC model and a SWOT analysis, the format emphasised clarity regarding needs, user value, assumptions, and weaknesses. The change followed observations that the business plan encouraged premature predictions and poorly grounded market details, often leading to mechanical completion rather than exploration of assumptions or alternative processes. The IdeaPM aligned more closely with the exploratory nature of technical projects and supported deeper reasoning about early development choices. The NABC model provided a clear entry point, directing attention to need and value before detailed planning became relevant, and suited short, focused working periods.

The projects span a broad range of technological domains, including electronics, energy systems, robotics, materials science, digital services, and automotive technologies, and are summarised through representative examples developed within CDIO-based entrepreneurship courses (Table 2). The project ideas originate from engineering students working in extended,

Table 2. Examples of project ideas in CDIO entrepreneurship courses

Technology/Concept	Description
Low-power, highly reliable analogue-to-digital converter for infrared cameras	A specialised ADC engineered for IR imaging with low energy consumption and high signal fidelity
Ultra-efficient solar panels	Advanced photovoltaic panels designed to substantially increase renewable energy generation efficiency
Flexible, scalable drone swarm system	Coordinated drone platform for large-area surveying with interchangeable sensor modules
Modular software-based battery diagnostic system	Predictive tool that identifies battery faults at an early stage
High-throughput open-source materials simulation service	Computational platform supporting accelerated materials discovery
Smart bionic hand with force feedback	Robotic hand enabling precise remote surgical operations
Non-generative super-resolution photo-restoration app	Restores low-quality photos while avoiding AI-related artefacts
Non-generative image enhancement and colour restoration app	Upscales and restores colours in old photos without artificial artefacts
AI-powered packing optimisation tool	Uses computer vision to create efficient packing layouts
Digital vehicle-access solution	Smartphone-based digital key enabling unlocking, starting and personalisation of a car

project-oriented course settings where technical development is combined with considerations of user needs, value creation, and implementation constraints. While not intended as finished products, these ideas function as learning vehicles through which students explore opportunity identification, feasibility assessment, and design trade-offs under realistic conditions. The format functioned across diverse technical contexts. In larger courses, it supported system-level and design-oriented challenges; in analytical or implementation-focused settings, it facilitated examination of assumptions linked to technical tasks. Smaller, specialised courses used it to explore possibilities within narrow domains. Teaching practices were adjusted accordingly, with workshops emphasising comparison of alternatives and reflection rather than providing direct solutions, and digital sessions enabling teachers to meet multiple groups simultaneously. Over time, students developed a broader understanding of entrepreneurship as relevant beyond venture creation, encompassing issues central to engineering practice such as value, assumptions, context, and users. Throughout these developments, the component remained closely tied to technical project work while evolving routines that supported long-term coherence and relevance.

4.4 Student feedback

Students reported a wide range of experiences illustrating how the module influenced their project work. Some students initially described uncertainty about the role of entrepreneurship within the project courses, noting for instance that:

> At first, the entrepreneurship part felt disconnected from our technical project, and I wasn't sure why we had to spend time on it.

Others expressed that early expectations were unclear, as reflected in the comment:

> Some of the early workshops seemed repetitive, and it was hard to see how discussing value or users would affect our actual technical work.

As the course structure stabilised, many students articulated how discussions about potential users or contexts shifted their approach to technical tasks (c.f., Packham *et al*., 2010; Fayolle and Gailly, 2015). Activities prompting reflection on value, purpose or use scenarios helped them consider what a project might represent beyond its technical solution.

Workshops were highlighted as key occasions for refining early reasoning. Students described these sessions as opportunities to clarify assumptions, compare alternatives and strengthen arguments for chosen directions. One student explained that:

> The workshops really made us stop and think about who would actually use our solution, which changed the way we approached the technical parts of our project.

Another reflected that:

> At first, I didn't see how entrepreneurship related to our engineering work, but reflecting on value and purpose helped me understand how early decisions shape the whole project.

Staff questions, rather than direct advice, were often described as helpful in prompting careful examination of emerging ideas. As one student put it:

> Having staff ask questions rather than giving answers forced our group to clarify our assumptions and argue for our choices, which made our reasoning much stronger.

Written feedback from multiple cohorts indicated that such interactions helped students structure their reasoning and articulate early ideas more clearly. The module was also valued for its broader relevance. Students recognised that early idea development occurs in many organisational settings and that understanding how ideas evolve before detailed planning is essential in both technical and organisational contexts. Many described an improved understanding of entrepreneurship, including drivers of entrepreneurial action and early

development processes. Some highlighted learning about how relationships with users, customers or external partners can influence early progress, even in non-commercial projects.

Early course evaluations show that some concerns were present during initial years, particularly regarding the inclusion of entrepreneurship within a technically focused curriculum. These concerns decreased over time as expectations became clearer and the module became an established part of project-based learning. In several cases, students reported that the component led to internal group discussions about purpose, direction and the reasoning behind technical decisions. This occasionally resulted in revised plans or reframed project goals. Over time, several students described gaining interest in entrepreneurship they had not anticipated, becoming more aware of how early idea development intersects with their engineering practice.

Across many years of implementation, student reflections indicate that the entrepreneurship component has become an integral element of project-based learning. Students encounter it alongside technical work, which supports clearer reasoning, more explicit articulation of early ideas and a deeper understanding of how technical development interacts with considerations of value, users and context.

5. Discussion

Long-term integration of the entrepreneurship component was supported by clear expectations and a stable assignment requiring students to explain their idea, identify users and value, describe uncertainties, and justify a direction. This structure anchored the component in project work and enabled consistent delivery across cohorts (Gartner and Vesper, 1994; Gabrielsson *et al.*, 2025). The transition from an early business plan format to the more concise IdeaPM strengthened alignment with the exploratory character of the CDIO project courses. By focusing on need, user value, assumptions, and uncertainty, the instrument matched the conditions students encountered in their technical projects, where early information is often fragmented and decisions iterative. This approach aligns with CDIO recommendations emphasising simple and adaptable tools suited to project stages where information is limited and solutions still forming (Malmqvist *et al.*, 2020; Sánchez, 2013).

Interactions during workshops reinforced continuity. Facilitators encouraged students to articulate underlying assumptions, clarify value arguments, and weigh different possible directions. Students reported that these activities improved the clarity of their reasoning and strengthened confidence in early decisions. This interactive style reflects reflective and action-oriented traditions in entrepreneurship education in which structured dialogue supports learning and decision-making capability (Schön, 2017; Rasmussen and Sørheim, 2006).

Organisational placement played a central role. Because the component was embedded in compulsory project courses, participation did not depend on individual motivation or prior interest in entrepreneurship. Activities were integrated into existing timetables, staffing plans, and resource structures, creating continuity across variations in teaching and project themes. Research on educational ecosystems highlights that such embedded arrangements maintain pedagogical practices and support capability development (Wright *et al.*, 2017; Gabrielsson *et al.*, 2025).

Programme-level coherence developed through repeated exposure to the same reasoning task across different technical contexts. Students from various specialisations increasingly used a shared vocabulary when describing purpose, value, direction, and user needs. This pattern supported progression and reinforced understanding of how early idea development relates to engineering practice. Such outcomes align with CDIO work on integrated competence development, which emphasises longitudinal exposure to shared tools and processes (Malmqvist *et al.*, 2020; Cheah *et al.*, 2025). These conditions demonstrate that a compulsory component can be combined with student engagement when tasks remain relevant, concise, and well connected to authentic project decisions. Prior research similarly notes that opportunity recognition may increase even among students who do not initially

identify with entrepreneurship, and that competence development is a suitable outcome in project-intensive engineering programmes (Karimi *et al*., 2016; Sánchez, 2013; Gibb, 2002).

5.1 Factors supporting long-term integration and programme coherence

Long-term integration was shaped by three primary conditions: a consistent task, a facilitation style aligned with project uncertainty, and an organisational structure that placed entrepreneurship within compulsory courses. The consistent assignment, later refined into the IdeaPM, enabled students to work with a stable early-stage reasoning task across cohorts and project themes. By asking students to explain user needs, articulate value, identify assumptions, and justify a direction, the instrument became a natural part of project work (Gartner and Vesper, 1994; Gabrielsson *et al*., 2025). Its concise format aligned with the open-ended and iterative character of CDIO project courses, where students work with incomplete information. CDIO literature emphasises using adaptable tools suited to early project stages when uncertainty is high and decisions must be revised (Malmqvist *et al*., 2020; Sánchez, 2013).

Facilitation strengthened these patterns by encouraging students to articulate assumptions, explore alternatives, and clarify value. Students described how this approach improved their understanding of users and strengthened confidence in early decisions. This style aligns with reflective and action-oriented pedagogical traditions emphasising dialogue, questioning, and iterative sense-making (Schön, 2017; Rasmussen and Sørheim, 2006).

Embedding the component in compulsory project courses ensured broad participation regardless of individual interest in entrepreneurship. Established timetables, staffing routines, and access to exemplars supported delivery and reduced vulnerability to shifts in teaching resources or student motivation. Research on educational ecosystems highlights that organisational anchoring supports continuity and capability development (Wright *et al*., 2017; Gabrielsson *et al*., 2025). Programme coherence was further strengthened by students' repeated exposure to the same reasoning task across courses. A shared vocabulary around users, value, and direction developed across specialisations, supporting collective progression and reinforcing the relevance of early idea development within engineering practice. This pattern is consistent with CDIO work on integrated competence development across programme curricula (Malmqvist *et al*., 2020; Cheah *et al*., 2025). Prior studies show that integrating entrepreneurship into compulsory project courses can combine broad reach with meaningful engagement, even among those without prior interest, while supporting opportunity recognition and capability development (Karimi *et al*., 2016; Sánchez, 2013; Gibb, 2002).

5.2 An institutionalisation process for embedding entrepreneurship

The findings highlight an institutionalisation process through which entrepreneurship education became durably embedded within CDIO-based project courses over time (Malmqvist *et al*., 2020; Wright *et al*., 2017). Rather than emerging from the introduction of a predefined structure, sustained integration developed through repeated alignment between project-based learning environments, pedagogical intentions, and organisational routines. CDIO contexts consistently confront students with uncertainty, evolving problem definitions, and iterative technical decision-making, reflecting conditions central to engineering practice (Norrman *et al*., 2014; Malmqvist *et al*., 2020). When entrepreneurial reasoning was positioned within these conditions, it became part of everyday project activity rather than a parallel or supplementary element.

A key feature of this process was the gradual consolidation of a stable early-stage reasoning task centred on articulating user needs, value, assumptions, and uncertainty. This task evolved through repeated course deliveries and adjustments, shifting away from predictive or comprehensive artefacts towards a concise format aligned with early project stages (Sánchez, 2013). Such alignment mattered because students engaged with entrepreneurial reasoning at

moments when technical solutions were still tentative and information incomplete. Across cohorts and technical domains, the recurring task functioned as a common reference point, providing continuity while allowing adaptation to different project characteristics (Norrman *et al*., 2014; Cheah *et al*., 2025).

Facilitation practices played an important role in reinforcing this institutionalisation process. Workshops that prioritised questioning, comparison of alternatives, and articulation of assumptions supported students' reflective engagement with early decisions. This approach is consistent with action-oriented and reflective traditions in entrepreneurship education that emphasise learning through dialogue and engagement with uncertainty (Gibb, 2002; Rasmussen and Sørheim, 2006; Schön, 2017). Importantly, facilitation practices proved repeatable across courses with different sizes, technologies, and group dynamics, contributing to continuity even as project conditions varied. Assessment routines that focused on clarity of reasoning rather than outcome quality further stabilised these practices, particularly among students whose primary orientation was technical performance (Malmqvist *et al*., 2020; Sánchez, 2013). Through repeated exposure to a similar form of early idea reasoning across multiple project contexts, programme-level coherence gradually developed. Students increasingly drew on a shared vocabulary when discussing purpose, value, users, and direction, indicating that entrepreneurship became integrated into how engineering work was conceptualised rather than treated as a distinct domain. This cumulative effect did not result from a single intervention, but from sustained participation in institutional arrangements that connected pedagogical tasks, facilitation, and organisational anchoring across academic cycles. Such patterns align with ecosystem-oriented perspectives emphasising how durable practices emerge through repeated interaction rather than through isolated initiatives (Wright *et al*., 2017; Gabrielsson *et al*., 2025). The outcomes observed in this case should be understood in relation to the specific institutional context in which the component was developed and maintained. The long-term integration described here relied on a relatively stable organisational environment, sustained faculty engagement, and continuity in teaching responsibility across academic cycles. In less stable settings characterised by frequent staff turnover, reduced institutional support, or organisational reconfiguration, mandatory entrepreneurship components embedded in project courses may be more vulnerable, and their long-term effectiveness may depend on the presence of comparable structural and human support.

Beyond coherence within the programme, the process illustrates how entrepreneurship education can become institutionalised as part of professional formation in engineering. Sustained engagement with early idea reasoning contributed to normalising attention to users, value, and uncertainty as integral aspects of engineering practice rather than peripheral concerns (Gibb, 2002; Norrman *et al*., 2014). Over time, students were exposed to entrepreneurship as a form of judgement under uncertainty, relevant not only for venture creation but also for innovation-oriented roles in established organisations, public agencies, and collaborative ecosystems (Sánchez, 2013; Wright *et al*., 2017). While the specific arrangements examined here are context-dependent, the process may inform other engineering education settings seeking to embed entrepreneurial learning within compulsory project environments, if transfer is approached with sensitivity to local institutional stability and organisational conditions rather than treated as a universally applicable solution.

6. Conclusions, implications and future research

The study has examined how entrepreneurship education can remain an integral element in engineering programmes shaped through project-based learning and CDIO traditions. A key conclusion is that long-term presence in this case depended on how entrepreneurship aligned with existing pedagogical structures rather than on isolated initiatives. When entrepreneurial reasoning is embedded in authentic project environments, students meet early idea challenges

in situations already characterised by uncertainty, iteration and responsibility, closely matching CDIO insights on integrated competence development (Gunnarsson *et al*., 2010).

The material shows that entrepreneurship is more likely to be sustained when it centres on early idea development. Activities that focus on assumptions, users and possible directions resonate with the complex and uncertain contexts typical of engineering education. This broader purpose aligns with competence-based perspectives where entrepreneurial capability is framed as judgement under uncertainty rather than as preparation for starting ventures (Sánchez, 2013). It also reflects the reality that questions of purpose and value arise in many organisational settings beyond start-ups, supporting relevance for a wide range of future career paths (Parker *et al*., 2025).

Continuity is further supported when teachers and student expectations remain stable across cohorts. Clear learning outcomes allow teachers to adapt activities without changing the underlying intent, and students understand how early reflections connect to their ongoing project work. This echoes observations that predictable assessment structures and shared pedagogical intentions are central to sustained educational integration (Fayolle and Gailly, 2008; Adamowicz, 2019). Flexible teaching practices also contributed to durability. Question-led workshops, structured reflection and digital communication enabled consistent support even as project topics, conditions and group sizes varied, consistent with experiential and reflective traditions that emphasise learning through participation and inquiry (Lave and Wenger, 1991; Rae and Wang, 2015).

The findings also indicate programme-level effects. When entrepreneurship recurs in several technical contexts, it contributes to curricular coherence by offering shared ways of reasoning about users, assumptions and value. Such cumulative exposure strengthens capability development and aligns with arguments that repeated engagement with authentic tasks deepens judgement over time (Blenker *et al*., 2014; He, 2025). Taken together, the study suggests that durable integration depends less on how much entrepreneurship content is included and more on how it is positioned, how clearly it is communicated and how well it aligns with project-based rhythms. Entrepreneurship remains embedded when it forms part of real project activity, maintains a stable aim and uses teaching approaches that support reflection under uncertainty. These insights indicate how entrepreneurial reasoning can become a natural extension of technical learning rather than a separate curricular element.

6.1 Implications for theory

The case has theoretical implications for how entrepreneurship education in engineering is conceptualised, reframing it as a programme-level design issue where durability emerges from alignment with CDIO-based project ecologies and repeated exposure over time. Integration is understood as an institutional arrangement rather than a discrete pedagogical intervention, linking early idea reasoning to technical uncertainty and collective practice. This supports positioning competence development as the key outcome category, where learning is expressed as judgement under uncertainty rather than near-term venture results (Sánchez, 2013; Gibb, 2002). More broadly, the findings contribute to theory by shifting attention from isolated interventions to programme-level capability formation, conceptualising entrepreneurship as a mode of reasoning embedded across technical work rather than a separate domain, and thereby informing integrated educational designs that combine professional, technical, and innovation-related learning. The case further extends theory on the role of universities in innovation systems by highlighting how embedding entrepreneurial reasoning in compulsory project courses scales beyond start-up formation to broader competence development among graduates in organisations, public agencies, and ecosystems, positioning universities as sites for developing judgement under uncertainty across domains and expanding innovation capacity beyond venture-centric outcomes.

CDIO scholarship offers a useful complementary perspective. Optional standards, progression maps and project sequences make professional competences visible and

assessable, thereby stabilising expectations and enabling cumulative learning (Malmqvist *et al*., 2020). Empirically, the case shows that lightweight tools aligned with project cadence retain relevance across engineering domains while supporting a shared language for value, assumptions and users (Norrman *et al*., 2014). These observations invite theoretical work that connect structural embedding, the economy of tasks and facilitative pedagogy to capability formation and programme coherence in engineering curricula (Cheah *et al*., 2025). They also highlight cohort-related dynamics. When all students repeatedly encounter the same reasoning task in different technical contexts, they develop shared concepts and forms of explanation that contribute to identity formation as engineers able to articulate purpose under uncertainty. This recurrence across courses suggests a meso-level explanation for programme coherence in which durable practices, rather than individual course designs, account for lasting effects.

6.2 Implications for practice

For programme leaders, the findings indicate that entrepreneurship is most effectively sustained when placed within compulsory CDIO project courses where authentic uncertainty is already a central organising condition and where structured planning supports delivery across academic cycles (Malmqvist *et al*., 2020). A concise early-idea assignment that focuses on users, need, value and assumptions can be applied across projects of different size and technical focus, enabling scale without reducing relevance (Norrman *et al*., 2014). Assessment should emphasise clarity of reasoning and reflective justification rather than prediction-oriented artefacts, consistent with competence-based learning goals (Sánchez, 2013). Facilitation is most effective when question-driven and designed to invite comparison of alternatives, highlight uncertainty and retain ownership within student teams, following established principles for supportive and inquiry-oriented entrepreneurship pedagogy (Gibb, 2002).

Framing entrepreneurship as early idea reasoning that applies broadly across organisational contexts strengthens legitimacy among students who expect careers in established organisations as well as start-ups. It also provides a cross-cutting vocabulary that supports programme identity and shared academic purpose (Cheah *et al*., 2025). Implementation can be reinforced by mapping visible progression across CDIO phases, scheduling interaction points to coincide with key project decisions, using short templates and shared rubrics to limit administrative burden and curating exemplars that illustrate strong reasoning within diverse technical domains.

6.3 Future research

Future research could build on the present study by further examining how different organisational formats for entrepreneurship education operate within engineering programmes. While this study demonstrates the viability and efficiency of a compulsory, curricular approach embedded in CDIO-based project courses, it does not examine or compare this format with extracurricular or elective arrangements. From a competence-based perspective, comparative studies could therefore analyse how curricular and extracurricular learning environments support judgement under uncertainty, progression, and professional formation in different ways (Sánchez, 2013; Malmqvist *et al*., 2020; Norrman *et al*., 2014). Such research would help clarify how mandatory and elective approaches may function as complementary educational options rather than as competing alternatives within engineering education (Cheah *et al*., 2025; Klofsten *et al*., 2024).

Finally, studies following graduates into innovation-oriented roles could examine how programme coherence translates into professional capability in practice, distinguishing intrapreneurial development from venture creation pathways (Klofsten, 2002, 2024; Cheah *et al*., 2025). Multi-institution collaborations could also pilot shared repositories of anonymised student artefacts and facilitation prompts, enabling replication studies and meta-analyses capable of tracking developments in reasoning quality across time and

institutional contexts, thereby separating cohort effects from local pedagogical variation through transparent protocols and reporting guidelines.

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Corresponding author
Magnus Klofsten can be contacted at: magnus.klofsten@liu.se