A TWO-MODULE APPROACH TO ACHIEVING CDIO STANDARD 4 IN INTRODUCTORY ENGINEERING EDUCATION

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ABSTRACT

This study examines the implementation of a two-module structure for the introductory course Introduction to Engineering Education at D. Serikbayev East Kazakhstan Technical University, aligned with CDIO Standard 4. The first module, Business Creation, focuses on fostering students' creative and entrepreneurial thinking, while the second module, Fundamentals of Engineering, emphasizes project-based application of engineering principles. A comparative survey-based study was conducted to evaluate the effectiveness of the redesigned course structure, analyzing student engagement, motivation, understanding of engineering practice, teamwork, and acquisition of basic engineering and digital competencies. The descriptive survey results suggest that the two-module approach is associated with higher self-reported cognitive readiness, professional awareness, and practical skills compared to the traditional single-module format. Findings highlight the importance of early exposure to both creative and technical aspects of engineering education and demonstrate the potential of modular course design in promoting professional identity, problem-solving abilities, and project-based competencies within the CDIO framework.

KEYWORDS

introductory engineering education, two-module course structure, creative thinking, project-based learning, entrepreneurship education, CDIO Standard: 4.

INTRODUCTION

Modern engineering education must prepare specialists for complex professional tasks. Engineers should not only apply fundamental knowledge. They should also solve ill-structured problems, think creatively, work across disciplines, and collaborate in teams (Felder & Brent, 2016; Johri & Olds, 2011). These skills are especially important in the context of digitalization, Industry 4.0, and complex engineering systems. Therefore, cognitive and metacompetencies are becoming essential, including critical thinking, generation of non-standard ideas, and transformation of creative solutions into engineering projects (Cropley, 2015; Altshuller, 1999).

One widely recognized approach to modernizing engineering education is the CDIO initiative. CDIO means Conceive–Design–Implement–Operate. Unlike general active-learning approaches, CDIO uses the lifecycle of engineering products, processes, and systems as the educational context (Crawley et al., 2014). The framework is implemented through CDIO Standards. These standards guide curriculum design, integrated learning experiences, design–implement activities, active learning, assessment, and continuous improvement (Crawley et al., 2014; Malmqvist et al., 2020). Within this framework, introductory engineering courses play an important role. They introduce students to authentic engineering practice and prepare them for later project-based and team-oriented learning (Edström & Kolmos, 2014; Malmqvist, Hugo, & Kjellberg, 2015).

CDIO Standard 4 is especially important for introductory engineering education. It focuses on personal and professional skills and attributes. These include teamwork, communication, problem solving, reflection, and professional growth (Rugarcia, Felder, Woods, & Stice, 2000; Dym, Agogino, Eris, Frey, & Leifer, 2005). Integrating these skills into the curriculum helps prepare graduates who are technically competent, able to address ill-structured problems, and effective in multidisciplinary teams (Felder & Brent, 2016; Cropley, 2015).

This study proposes and analyzes an original two-module approach to the course "Introduction to Engineering Education" within the CDIO Standard 4 framework. The first module develops students' creative engineering thinking. It includes creative and TRIZ-based tasks, idea generation, and activities for overcoming cognitive barriers (Altshuller, 1999; Cropley, 2015). The second module focuses on an engineering project. In this module, students apply creative and analytical skills to move from conceptual ideas to technically substantiated solutions (Dym, Agogino, Eris, Frey, & Leifer, 2005).

The aim of this study is to compare one-module and two-module models for organizing an introductory engineering course. The comparison is based on student questionnaire data. The study evaluates how the preliminary creativity module affects students' cognitive readiness for project work, confidence in generating engineering solutions, engagement in learning, and self-assessed quality of completed projects.

The originality of this study lies in the curriculum architecture and competency staging of the course. The paper does not present creativity or project-based activities as isolated elements. Instead, it proposes a sequenced two-module model. In this model, creative and entrepreneurial preparation comes before introductory engineering implementation. The contribution is not a new assessment instrument. It is a structured curriculum model that operationalizes CDIO Standard 4 through staged development of problem framing, value awareness, teamwork, and concept-level engineering design. Unlike conventional introductory CDIO courses, which often combine orientation, teamwork, and projects in one block, this model separates creative problem identification from technical project work (Cropley, 2015; Dym, Agogino, Eris, Frey, & Leifer, 2005).

LITERATURE REVIEW

Engineering education has shifted toward closer alignment with modern industry needs. Traditional discipline-centered curricula have been criticized for weak engagement and limited exposure to engineering practice (Sheppard et al., 2009). Within the CDIO framework, introductory engineering courses are expected to motivate students, introduce authentic engineering activity, and prepare them for later design–implement experiences (Crawley et al., 2014).

A common approach is a single integrated module that combines engineering design, teamwork, communication, and basic technical content. Such courses are valued for compactness and administrative simplicity. They often include short design projects, hands-on activities, and problem-based learning, giving students early experience of engineering practice (Dym et al., 2005; Prince & Felder, 2006). Studies report positive outcomes, such as higher motivation, better understanding of engineering professions, and stronger first-year engagement. However, many objectives must be addressed in limited time. This creates trade-offs between breadth and depth and may constrain the development of engineering fundamentals and higher-level design competencies (Goldberg, 2020; Borrego & Newswander, 2008; Subramaniam et al., 2024).

In response, some institutions use multi-module or staged models. These models distribute learning objectives across modules and support gradual competency development. Pedagogically, this is consistent with constructivist learning and cognitive load management. It reduces the need to address technical, creative, and organizational skills at the same time (Prince & Felder, 2006). Multi-module models also make it easier to align learning outcomes with specific CDIO standards, especially when introductory orientation is separated from hands-on engineering implementation (Crawley et al., 2014).

Recent CDIO studies show that introductory courses often provide early exposure to engineering practice, teamwork, professional roles, and design–implement activities (Crawley et al., 2014; Malmqvist et al., 2020; Medina, 2023). However, many CDIO implementations combine orientation, creativity, teamwork, and projects within one course block. The preparatory stage of idea generation, entrepreneurial framing, and value-oriented problem formulation is often less explicit. This stage is important for engineering identity formation. First-year students begin to see themselves as future engineers when they define meaningful problems, understand user needs, and create value through engineering solutions (Jackson et al., 2022; Rodriguez et al., 2018). Therefore, the proposed two-module structure links entrepreneurial engineering education with early engineering identity formation by placing creativity and value-oriented problem framing before technical project work.

Entrepreneurial and value-creation competencies are also important in introductory engineering education. Modern engineers must solve technical problems and understand market needs, stakeholder expectations, and social context. Therefore, early engineering curricula increasingly include idea generation, business modeling, and innovation thinking (Barba Sánchez & Atienza Sahuquillo, 2018; Snihur, Lamine & Wright, 2021; Makai & Dőry, 2023). These concepts can strengthen systems thinking and help students view engineering as a value-driven activity, not only as a technical profession.

Despite growing research on introductory engineering courses, project-based learning, and entrepreneurial education, their modular architecture remains insufficiently studied. Existing studies usually focus on course outcomes, teaching methods, or specific pedagogical tools. Systematic comparisons between one-module and multi-module models are still limited (Sheppard et al., 2009; Jamieson & Lohmann, 2012). In particular, little is known about how a two-module structure, separating entrepreneurial orientation from foundational engineering implementation, can support staged competency development within the CDIO framework.

This gap motivates the present study. It compares one-module and two-module structures of the course "Introduction to Engineering Education." The proposed model separates a creativity- and entrepreneurship-oriented module from a fundamentals-oriented engineering project module. This separation aims to improve learning effectiveness and better align the course with CDIO principles and first-year students' learning needs.

EXPERIENCE OF EKTU IN IMPLEMENTING CDIO STANDARD 4

At D. Serikbayev East Kazakhstan Technical University, CDIO Standard 4 is implemented through the mandatory first-year course Introduction to Engineering Education. The course is taken by students from engineering, architecture, construction, energy, earth sciences, and ICT programs. It introduces them to engineering thinking, professional roles, teamwork, and the CDIO lifecycle.

Before the redesign, Introduction to Engineering Education was mainly theoretical and orientation-based. It introduced students to the university environment, the engineering profession, and general principles of engineering education. Teaching was based on lectures, discussions, and short assignments. This format helped students learn basic concepts and professional roles. However, it included limited hands-on project work. It also did not guide students from problem identification and idea generation to engineering concept development and presentation. Therefore, the redesign changed both the course structure and teaching approach. The course moved to a two-module structure and activity-based learning. Theoretical content was shortened, reorganized, and embedded into creative tasks, teamwork, problem formulation, concept development, and introductory project activities.

The redesigned course is organized into two sequential modules. The redesigned course consists of two sequential modules. The Business Creation module develops creative and entrepreneurial thinking before project work. The Fundamentals of Engineering module focuses on concept-level engineering implementation in the Fab Lab.

Table 1. Structure of the two-module introductory engineering course

Module	Weeks	Main focus	Key activities	Expected outcomes
Business Creation	1–5	Creativity and entrepreneurship	Design thinking, idea generation, contradiction solving, preliminary business model, product viability testing	Creative thinking, problem framing, value awareness
Fundamentals of Engineering	6–15	Project-based engineering implementation	Team project, problem analysis, concept development, sketching/design, prototyping or visualization, presentation	Engineering thinking, teamwork, basic design skills, communication

Although the course includes many activities, the expected project depth is introductory. The course has three contact hours per week. It is also supported by guided independent teamwork. Students are not expected to develop fully engineered or market-ready products. The intended outputs are a clear problem statement, analysis of existing solutions, a preliminary value proposition or business model, a concept sketch, basic engineering justification, a low-fidelity prototype or visual model, and a final presentation. Thus, the course focuses on early engineering formation, problem framing, teamwork, communication, and understanding of the CDIO lifecycle. It does not aim at comprehensive technical design or complete product development.

The transition between the two modules follows a structured idea-to-project process. At the end of the Business Creation module, teams prepare an idea portfolio. It includes the problem statement, target users, value proposition, preliminary solution, and feasibility considerations. Ideas are screened by relevance, user value, feasibility, available Fab Lab resources, and potential for concept-level engineering development. Selected ideas are then transformed into engineering project briefs. These briefs include functional requirements, constraints, expected outputs, and a prototyping or visualization plan. In the Fundamentals of Engineering module, students develop these briefs into engineering concepts through analysis, sketching, basic justification, prototyping or visualization, and final presentation.

Assessment is aligned with the staged course outcomes. In the Business Creation module, students are assessed on problem identification, idea originality, user needs, value proposition, feasibility, and teamwork. In the Fundamentals of Engineering module, assessment focuses on engineering concept development, analysis of existing solutions, design sketches, basic engineering justification, prototype or visual model quality, use of engineering and digital tools, teamwork, and final presentation. Peer evaluation supports individual accountability in team projects. Instructor assessment is based on rubrics aligned with each module and CDIO Standard 4.

The creativity-first sequence is based on scaffolding and constructivist progression. First-year students often have limited experience with ill-structured problems. They also struggle to connect technical solutions with user needs. Therefore, the Business Creation module acts as a preparatory scaffold. It develops problem awareness, idea generation, and value-oriented thinking before technical project work. This sequence may reduce cognitive load. Students do not have to learn engineering tools, teamwork, and project development at the same time. It also supports cognitive readiness for project-based learning (Wood et al., 1976; Sweller, 1988; Bransford et al., 2000).

EVALUATION OF THE TWO-MODULE COURSE STRUCTURE IMPLEMENTATION

Evaluation methodology

To evaluate the redesigned two-module structure of Introduction to Engineering Education, a comparative survey-based study was conducted. The course was aligned with CDIO Standard 4. The study assessed changes in student motivation, perception of the engineering profession, and self-assessed competencies. It focused on the transition from a traditional introductory format to a modular structure with active and project-based learning.

The study used a pre- and post-implementation comparative design. The pre-implementation survey involved students who completed the course before the redesign. At that time, the course was mainly theoretical and orientation-based. The post-implementation survey involved students who studied the redesigned course with the Business Creation and Fundamentals of Engineering modules.

Participants and cohort characteristics

The study involved two cohorts of first-year undergraduate students enrolled in the mandatory course Introduction to Engineering Education. The pre-implementation cohort included 85 students. The post-implementation cohort included 92 students. The first cohort completed the course before the redesign. The second cohort studied the redesigned course with the Business Creation and Fundamentals of Engineering modules. Both cohorts were comparable in academic level, year of study, institutional context, and field of study. Students represented engineering, architecture, construction, energy, earth sciences, and ICT programs. Since the course was mandatory, the samples consisted of regular course participants, not self-selected volunteers.

Survey instrument and construct mapping

The questionnaire measured students' self-reported perceptions related to CDIO Standard 4 and the two-module course objectives. It included Likert-scale items grouped into several constructs. These were engagement, understanding of the engineering profession, creative thinking, problem formulation, basic engineering and digital skills, teamwork, project-based learning experience, motivation, and perceived professional relevance. These constructs were mapped to CDIO Standard 4 outcomes. They covered early introduction to engineering practice, personal and interpersonal skills, teamwork, communication, and professional awareness. Closed-ended items used a five-point Likert scale. The percentages in Figure 5 show the proportion of students who selected “agree” or “strongly agree” for each survey dimension.

Data collection and analysis

The data were analyzed using descriptive and inferential statistics. Descriptive statistics summarized responses for each survey dimension before and after the redesign. Since the items used a five-point Likert scale, the Mann–Whitney U test was applied. This test is suitable for comparing two independent groups with ordinal data. Statistical significance was set at $p < 0.05$.

Effect sizes were calculated using the rank-biserial correlation coefficient, r. This helped estimate the practical magnitude of the observed differences. The interpretation followed conventional thresholds for small, medium, and large effects. The proportions of students selecting “agree” or “strongly agree” were also calculated for each survey dimension and used in Figure 5.

To support content validity, the questionnaire items were based on the course learning outcomes and CDIO Standard 4 competency areas. The items were reviewed by instructors involved in the two-module course implementation. This ensured alignment with course objectives and learning activities. Internal consistency was assessed using Cronbach's alpha. The result showed acceptable reliability, $\alpha = 0.82$.

Although the main dataset consists of student survey responses, the redesigned course also included performance indicators. These included project presentations, concept sketches, low-fidelity prototypes or visual models, and use of basic engineering and digital tools. These outputs were assessed using criteria such as problem formulation, feasibility, teamwork, engineering reasoning, prototype or visualization quality, and presentation clarity. However, these indicators were used mainly for course assessment. They were not fully included in the comparative statistical analysis. Therefore, the findings should be interpreted mainly as self-reported perceptions. Future research should combine survey data with rubric-based project assessment and objective competency indicators.

Results and discussion

A comparative analysis was conducted between two student cohorts. The first cohort completed Introduction to Engineering Education before the two-module redesign. The second cohort completed the redesigned course with the Business Creation and Fundamentals of Engineering modules. The comparison focused on professional self-determination, engineering thinking, motivation, and readiness for practical engineering activities.

The survey results show higher post-implementation values across all analyzed dimensions (Figure 1).

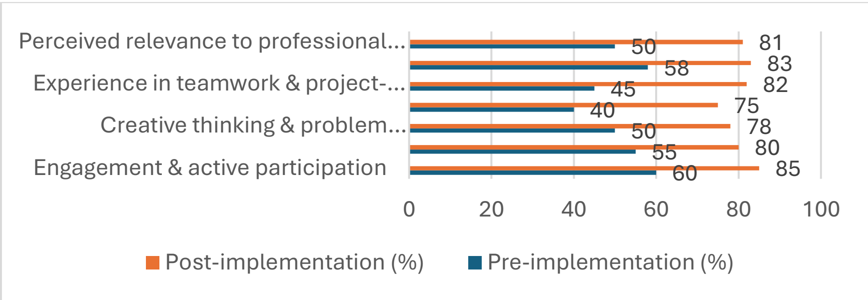

Figure 1. Percentage of students selecting “agree” or “strongly agree” (4 or 5 on a five-point Likert scale) for each survey dimension before and after implementation of the two-module course structure

The percentages in Figure 1 represent the proportion of students who selected “agree” or “strongly agree” on a five-point Likert scale. The largest differences were observed in engagement, understanding of the engineering profession, teamwork and project-based learning, acquisition of basic engineering skills, and perceived relevance to future professional practice.

Open-ended responses were used to contextualize these results. Post-implementation students more often referred to practical tasks, teamwork, project development, engineering tools, and professional roles. They also reported more reasoned career choices, stronger motivation, and clearer understanding of engineering practice. In contrast, pre-implementation students more often described engineering in general terms and reported limited experience with project work, teamwork, and engineering tools. These comments should be interpreted as self-reported perceptions, not as objective measures of learning outcomes.

The observed differences may be explained by the sequence of learning activities in the two-module model. The Business Creation module served as a preparatory stage. It developed problem awareness, idea generation, user orientation, and value-based reasoning before technical project work. This may have reduced the cognitive demands of the Fundamentals of Engineering module. Students entered the project phase with clearer intentions and more developed initial concepts. The second module then transformed these ideas into engineering outputs through teamwork, analysis, sketching, prototyping or visualization, and presentation.

Overall, the results suggest that the two-module structure improves the educational impact of Introduction to Engineering Education. The integration of Business Creation and Fundamentals of Engineering supports engineering identity, professional self-determination, practical engagement, and readiness for project-based learning. However, the findings should be interpreted mainly as evidence of students' perceived learning experience, since the study relies primarily on survey responses and open-ended comments.

The two-module structure also creates implementation challenges. The Fundamentals of Engineering module depends partly on Fab Lab infrastructure, digital fabrication tools, engineering software, and spaces for teamwork and prototyping. This may limit transferability to institutions with fewer resources. The model also requires close coordination between instructors responsible for creativity, entrepreneurship, and engineering projects. This increases faculty workload during idea screening, project supervision, and assessment. For larger cohorts, the model may require teaching assistants, standardized rubrics, peer evaluation, and structured project management procedures. Thus, the approach is scalable but resource-sensitive and should be adapted to each institution's infrastructure and teaching capacity.

CONCLUSIONS

This study examined the redesign of the first-year course Introduction to Engineering Education. The redesign used a two-module structure aligned with CDIO Standard 4. The model combines the Business Creation module and the Fundamentals of Engineering module. The first module focuses on creativity, entrepreneurial awareness, problem framing, and value-oriented thinking. The second module focuses on introductory project-based engineering implementation. The main contribution is the staged curriculum architecture. In this structure, creative and entrepreneurial preparation comes before concept-level engineering design and project work.

The results suggest that the two-module structure was associated with higher student engagement, clearer understanding of engineering practice, stronger motivation, and greater readiness for teamwork and project-based learning. These outcomes may be explained by the sequence of learning activities. Students first developed problem awareness and initial ideas. They then transformed these ideas into engineering concepts through teamwork, analysis, sketching, prototyping or visualization, and presentation. Thus, the model may support early engineering identity formation. It also provides a structured introduction to engineering practice within the CDIO framework.

At the same time, the findings should be interpreted with caution. The study was conducted in one institutional context. It also relied partly on students' self-reported perceptions. Survey results and course-based observations provide useful evidence of perceived effectiveness. However, further research is needed to strengthen the empirical basis of the model. Future studies should include larger and more diverse cohorts. They should also use longitudinal tracking, objective assessment of project performance and prototype quality, rubric-based competency evaluation, and comparison across programs or institutions. Further attention should be paid to scalability, Fab Lab infrastructure, and instructor workload.

Overall, the study shows that a staged two-module approach can help operationalize CDIO Standard 4 in introductory engineering education. Its effectiveness, however, depends on careful curriculum design, aligned assessment, available infrastructure, and institutional support.

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