SEFI Journal of Engineering Education Advancement
Vol. 2, No. 2, 2025, pp. 54-73, ISSN 3006-6301
DOI : 10.62492/sefijeea.v2i2.38

Empowering Future Engineers Through Extracurricular Challenge-Based Learning Projects

Eugenio Bravo[a,1], Dury Bayram[a], Jan van de Veen[a], Isabelle Reymen[a],

[a] Eindhoven School of Education, University of Technology,

Eindhoven, the Netherlands

ABSTRACT

This study aims to deepen our understanding of how participation in an engineering-oriented student team shapes students' learning experiences and supports learning gains during an extracurricular, challenge-based learning project in higher education. We conducted an artifact analysis workshop with seven team members and semi-structured interviews with four team members and two team advisors. The data were coded and analysed using deductive and inductive thematic analysis.
The findings reveal that the learning experience enabled students to achieve deeper knowledge and understanding of specific technologies, the design process, and hardware manufacturing techniques. Additionally, this experience improved their management and leadership skills. Participation in the project also strengthened their ability to leverage external networks and engage with diverse stakeholder and industry partner perspectives, while increasing their awareness of these stakeholders' expectations. Students came to appreciate the value of building alliances with companies and addressing the needs of stakeholders, which in turn enhanced their negotiation skills and improved their capacity to design technological products. Finally, engaging with real-life contexts clarified their future goals and professional aspirations.

KEYWORDS

Extracurricular, engineering, student teams, challenge-based learning, active learning

PUBLICATION

Submitted:
30th April 2025

Accepted after revision:
2nd September 2025

Introduction

Extracurricular activities enrich students' educational experiences, facilitating their learning in various areas such as initiative, teamwork (Larson et al., 2006), and management skills (Thompson et al., 2013). Research has indicated that students' awareness of their professional identity and career prospects increases through such activities (Seow & Pan, 2014).

Extracurricular, engineering-oriented teams offer students opportunities to develop innovation-related knowledge, skills, and competencies. Studies have shown that students gain hands-on prototyping experience (Dominguez-Ramos et al., 2019; Mariasiu & Raboca, 2017) and acquire technological

[1] Corresponding Author: Eugenio Bravo – Eindhoven University of Technology, e.bravo@tue.nl

expertise that enables them to transform ideas into technological solutions (Huerta et al., 2022; Sorici et al., 2023).

Despite these findings, to the best of our knowledge, qualitative research on the impact of extracurricular, engineering-oriented, challenge-based learning projects on student learning remains limited (Bravo et al., 2024; Doulougeri et al., 2024). This study aims to bridge this gap by exploring the learning experiences and the learning gains of student team members through their participation in designing and constructing a technology-based art installation for a light festival in the Netherlands.

Theoretical Background

Challenge-based learning (CBL) has emerged as an active learning pedagogy, primarily developed in engineering education (Doulougeri et al., 2024). CBL is a hands-on approach that empowers students to use technology to address global, real-world challenges emphasizing collaboration with peers, academia, and external stakeholders to ask questions, deepen knowledge, solve problems, and share experiences (Gallagher & Savage, 2020; Nichols & Cator, 2008). Three aspects have been outlined to define an educational intervention as CBL: (i) real-world, authentic challenges; (ii) the integration of deep content knowledge with a broad understanding of engineering; and (iii) learning activities that emphasize core engineering principles and skills (van den Beemt et al., 2022).

CBL focuses on relevant open-ended challenges, without a pre-made response (Membrillo-Hernández et al., 2019), as a way to trigger learning (van den Beemt et al., 2022). In these open-ended challenges, students discover the problem and create the solution (Lammi et al., 2018). The process involves identifying and analysing challenges, and designing solutions to socio-technical problems through a multi- or interdisciplinary approach (Doulougeri et al., 2024). The main outcome is a proposed actionable solution to the identified problem; however, the learning gains students achieve during the learning process are equally important (Doulougeri et al., 2024; Gallagher & Savage, 2020).

In CBL, students collaborate with academic and external experts who take on the role of facilitator, coach or even co-creator or co-researcher, and integrate their perspectives to design solutions (Membrillo-Hernández et al., 2019).

The learning process in CBL projects involves students identifying knowledge gaps, acquiring knowledge from different disciplines, and iterating through divergent and convergent phases to develop solutions (Jensen et al., 2018; Kohn Rådberg et al., 2018). These CBL projects have been implemented in both curricular and extracurricular settings. They can involve collaboration across departments, faculties, or institutes in intensive, short-term projects lasting a few weeks (Charosky & Bragós, 2021; Charosky et al., 2018), longer term bachelor's or master's degree projects (Kohn Rådberg et al., 2018; Valencia et al., 2020), or take the form of extracurricular initiatives such as competitions, hackathons (Arrambide-Leal et al., 2019; Gama et al., 2018), and engineering-oriented student teams (Bravo et al., 2024). To understand how students learn in extracurricular challenge-based learning (CBL), constructivist theories provide a valuable foundation. Constructivism emphasizes that learners actively build knowledge through meaningful interaction with their environment, rather than passively receiving information (Piaget, 1952; Vygotsky, 1978). Building on this perspective, Kolb's Experiential Learning Theory (1984) introduces a cyclical model of learning comprising four stages. The cycle begins with *Concrete Experience*, where learners engage directly in a new task or situation. This is followed by *Reflective Observation*, in which they step back to examine what occurred, considering the experience from various angles. In the third stage, *Abstract Conceptualization*, learners draw conclusions and develop generalizations or theories based on their reflections. Finally, during *Active Experimentation*, they apply these insights to new situations, testing and refining their understanding. The cycle then repeats, supporting continuous learning and skill development.

Vygotsky's (1978) concept of the Zone of Proximal Development (ZPD) enriches this framework by highlighting the crucial role of social mediation in learning. The ZPD defines the range of tasks a learner can perform with guidance but not yet independently, emphasizing the importance of scaffolding, peer collaboration, and mentorship — key elements in challenge-based engineering education. Building on this social dimension of learning, Illeris (2007) expanded previous theories by integrating both external environmental influences and internal individual processes into a comprehensive model. He identified two essential learning processes: *interaction,* which involves social engagement with the environment, and *acquisition*, which takes place within the individual. Moreover, Illeris outlined three key dimensions of learning—content (knowledge, skills, and personal qualities), incentive (emotions, motivation, and will), and social and societal factors—highlighting that motivation, particularly within the incentive dimension, significantly affects learning outcomes, comprehension, and knowledge acquisition, while also being susceptible to conflicts. Together, these perspectives offer a holistic understanding of learning that balances social context with individual psychological factors.

To investigate learning, scholars have introduced the concept of learning gains, which has been defined in various ways in the literature (van Uum & Pepin, 2022). For instance, Rogaten and Rienties (2021) conceptualized learning gains as improvements in knowledge, skills, and personal development throughout higher education. From a broader perspective, Vermunt et al. (2018) defined learning gains as changes in students' knowledge, skills, attitudes, and values throughout their academic journey. These can be subject-specific, focusing on content knowledge, or non-subject-specific, involving transferable skills, competencies, and personal development.

Studies on CBL in curricular settings have reported learning gains such as the acquisition and application of engineering knowledge, improved teamwork and communication skills, enhanced professional behaviour, and a deeper understanding of the business world (Kohn Rådberg et al., 2018; Membrillo-Hernández et al., 2019). Gathering evidence of students' learning in the context of extracurricular CBL is relevant, as it highlights the educational value of such experiences and informs the development of more effective strategies to support student growth (Bravo et al., 2024). However, qualitative research on extracurricular CBL projects remains limited. As a result, scholars have emphasized the need for further investigation to deepen our understanding of student experiences and learning outcomes within team-based settings in this context (Doulougeri et al., 2024; Gallagher & Savage, 2020; Leijon et al., 2021). This study specifically addresses that gap, aiming to contribute new insights to the existing body of knowledge.

Research Questions

This study explored the experiences and learning gains of an extracurricular CBL project team, examining what and how they learned after a one-year commitment. It addressed the following research questions:

RQ1: What learning gains do students achieve by participating in an extracurricular, engineering-oriented CBL project?

RQ2: How do students achieve these learning gains through participation in an extracurricular, engineering-oriented CBL project?

Context of the Study

At the University of Technology (pseudonym), approximately 30 interdisciplinary student teams participate annually in an extracurricular engineering program, engaging over 500 students. Each team typically consists of 10 to 30 members and works in distinct technical and innovative challenges that require self-directed learning. These challenges include, for instance, developing sustainable mobility solutions or accelerating the development of biosensors for health care. Students from various academic backgrounds voluntarily apply to join part-time or full-time, driven by personal interests and skills. Selection is carried out by existing team members through application reviews and interviews, ensuring a diverse mix of disciplines and alignment with the team's goals. Once formed, teams operate autonomously, with members taking on roles in technical, managerial, or communication-focused sub-teams to support effective collaboration. The program provides coaching, workspace, and guidance on financial and legal matters. Teams handle tasks ranging from system design to device development, fostering a shared understanding of objectives and promoting deep learning through hands-on experience.

This study examined the case of Team Airplane's (pseudonym) learning experiences while participating in Shine (pseudonym), an annual light art festival in the Netherlands. Team Airplane, specializing in innovative design, collaborated with artists, designers, and industry partners to create a system of 1,000 illuminated acrylic planes that served as road signs for the festival venue. They secured project approval by presenting design options, justifying their decisions, and outlining construction plans to Shine's organizers. Team Airplane also received support from two external advisors and industry partners.

Methods

Research Design

This study employed a qualitative case study design to explore students' experiences and learning gains. A case study was chosen for its ability to examine complex, real-world phenomena in specific contexts (Savenye & Robinson, 2005; Yin, 1994). This method effectively captures the interaction between an event and its environment, making it ideal for this research. The operational definition of learning gains followed Vermunt et al. (2018), as detailed in the Theoretical Background.

Participants

This study involved nine of the eleven Team Airplane members who worked on Shine. Mostly engineering students, they shared similar knowledge paradigms, while one nursing student contributed a distinct perspective. Participants were bachelor's and master's students from two higher education institutions in the Netherlands. See Table 1.

Two Team Airplane advisors also participated in this study, each contributing distinct expertise to support the students' development. Advisor X provided guidance across managerial, technical, and artistic dimensions of the project, helping students navigate complex design and coordination challenges. Advisor Y, drawing on extensive industry and academic experience, facilitated networking opportunities and supported team management practices. Both advisors met with the team on a flexible basis, responding to the evolving needs and demands of the project. Their involvement was shaped by the students' initiative, allowing for targeted feedback and mentorship at critical stages of the project.

Data Collection

This study used self-reported data, a valuable method when direct measures are unavailable (Ro & Knight, 2016). Based on students' self-assessments (Picard et al., 2022), such reports are widely used in higher education to evaluate learning gains from co-curricular activities (Davis et al., 2023). They promote self-reflection (Hmelo et al., 2000), support self-regulation through self-monitoring (Schmitz & Perels, 2011), and provide detailed insights into individual learning (McGrath et al., 2015).

Table 1: Information on study participants

Participant	Role	Academic background	Participation
Student A	Business manager	MSc. Industrial design	Interview
Student B	Human resources	BSc. Nursing	Interview
Student C	Team manager	MSc. Industrial design	Workshop & interview
Student D	Technical manager and board member	BSc. Industrial design	Workshop & interview
Student E	Technical	MSc. Industrial design	Workshop
Student F	Technical	BSc. Industrial design	Workshop
Student G	Technical	MSc. Electronic engineering	Workshop
Student H	Technical	BSc. Industrial design	Workshop
Student I	Technical	BSc. Mechanical engineering	Workshop
Advisor X	Advice on management and design	PhD. Industrial design	Interview
Advisor Y	Advice on management and networking	PhD. Industrial Engineering	Interview

Data collection spanned a two-month period. The process followed a sequential approach, beginning with an artifact analysis workshop involving seven team members. This was followed by four semi-structured interviews with students—two who had participated in the workshop and two who had not—

allowing for a deeper perspective on the learning experience. Finally, two semi-structured interviews were conducted with team advisors to gain insights into their observations of student learning. Semi-structured interviews were chosen for their ability to reveal nuanced learning trajectories (Eichelman et al., 2015; Immekus et al., 2005). This approach enabled triangulation of data and provided a comprehensive understanding of both the tangible outcomes produced by the students and the learning processes they underwent.

Students were recruited via a board-led campaign, while advisors were invited directly. Participation was voluntary, and all students had completed their year-long commitment prior to the study. All sessions were conducted in English and facilitated by the first author.

Artifact Analysis Workshop

During the 90-minute, audio-recorded artifact analysis workshop (with participants' consent), team members reflected on their design and construction processes using their prototypes and one of the final acrylic planes as discussion points. A custom-designed flip chart, divided into three sections, guided the reflection. In the triggering factors section, students noted questions and prior knowledge about the project's challenges. The critical steps section outlined the processes followed, shared learning experiences, and identified helpful resources. In the learning gains section, participants documented acquired knowledge, supported by sticky notes and written summaries.

Interviews

Four semi-structured individual interviews were conducted with team members who volunteered to participate; see Table 1. These hour-long interviews, recorded with consent, focused on members' perspectives regarding their perceived learning and the processes that facilitated it.

Finally, two team advisors participated in individual one-hour interviews, which were audio-recorded with their consent, to explore their perceptions of students' learning throughout the project phases.

Data Analysis

To address the first research question, workshop and interview data were transcribed using Otter software. The first and second author reviewed the dataset to gain an overall understanding, then identified and categorized quotes related to skill mastery or knowledge acquisition as learning gains. This process involved deductive coding and manual classification using the CDIO Syllabus 3.0 (Malmqvist et al., 2022), which outlines learning goals for undergraduate engineering programs, including fundamental knowledge, personal and professional skills and attributes, interpersonal skills, the innovation process, and leadership in engineering and entrepreneurship.

The CDIO framework is particularly well-suited to capturing learning gains in engineering education. Unlike other models that focus on cognitive, metacognitive, or affective dimensions of learning (Vermunt et al., 2018), CDIO integrates technical knowledge with personal, professional, and interpersonal development across the entire engineering lifecycle. This integration reflects the multifaceted nature of the engineering profession, encompassing, among other things, problem-solving, teamwork, innovation, leadership, and entrepreneurship.

By providing learning outcomes aligned with industry expectations, CDIO Syllabus 3.0 offers a robust framework for assessing diverse forms of student development beyond the classroom. It enables a nuanced analysis of complex learning processes in engineering education, particularly in real-world, project-based contexts.

For the second research question, inductive coding was used to identify factors influencing student learning. The first author generated initial codes from recurring themes, which were refined through collaborative review with the second author. After several iterations, the final code list was applied to the dataset. Inter-rater reliability, assessed with 60% of the coded quotes, showed an 80% agreement rate, considered very good (Huberman & Miles, 1994).

Results

What Do Students Learn?

Students' learning gains were analysed using the CDIO 3.0 syllabus (Malmqvist et al., 2022), with quotes highlighting their experiences. The analysis starts at the team level and then shifts to individual perspectives.

Team Level

Personal and Professional Skills and Attributes: Students reported learning gains in time and resource management. They expressed that, throughout their participation in the project, team members became aware of the importance of defining roles based on individual motivation and expertise to effectively tackle the project's challenges. They also recognized the value of leveraging their network of industry partners to obtain the technical resources required for implementing their design. In addition, they deepened their understanding of the trade-off between finishing on time and increasing the sophistication of their designs. For instance, they had to adjust their planning and exclude certain features from the final design to meet the deadlines and the Shine festival's requirements (installing fully functional LED-illuminated acrylic planes before the start of Shine).

Interpersonal Skills: Students expressed that they increased their awareness of the importance of stakeholder engagement. They realized that ineffective communication with stakeholders can be challenging and may lead to misunderstandings, resulting in reduced stakeholder engagement.

In addition, students reported learning gains in communication strategy, becoming aware of how the information they provided influenced suppliers' responses. For instance, they noted that suppliers responded more quickly to technical questions once they understood that the students intended to purchase more than 1,000 devices.

The Innovation Process: While adapting products from a supplier, team members faced the challenge of creating waterproof connectors for the planes' LEDs, due to the extremely wet conditions. This experience led to learning gains related to hardware manufacturing, arising from the real-world implementation of the solution.

In addition, the team had to test different settings for integrating the hardware and software associated with the LED system. They aimed to establish the technical specifications required for the components before placing a purchase order, thereby minimizing technical and financial risks. Through this process, they gained a deeper understanding of how the testing process works and why it is important.

Finally, students indicated that they applied knowledge from previous courses throughout various project activities, depending on their roles and backgrounds. The integrated knowledge included modelling and basic electronics, and they utilized a software package for 3D visualization and animation.

Leading Engineering Endeavours and Entrepreneurship: During the design phase, students faced challenges with data communication between the LED system and its controller. Under time pressure, they contacted multiple cable suppliers to inquire about the suitability of their products for wet, outdoor environments. This experience helped students realize the value of supplier advice, which they incorporated into their final design, thereby enhancing their understanding of conceiving products around technology.

Individual Level

Fundamental Knowledge and Reasoning: Student A (business manager, interview) enhanced his general technological knowledge through interactions with partner companies, attending technical meetings, and participating in demonstrations where companies showcased the technological capabilities of their products. However, he noted that his knowledge remained broad rather than deep.

On the other hand, Student D (technical manager and board member, interview) said he deepened his knowledge of a specific aspect of LED connectors—their waterproof design. Drawing from his own and his teammates' experiences, he learned in detail how to design and build a waterproof power and data cable connector for the LED-lit acrylic planes.

In addition, Student B (human resources, interview) indicated that she gained engineering-related knowledge through conversations with members of the technical group. Her learning gains included a better understanding of the technology used in the project and basic electronics concepts. In her case, the knowledge gained was broad rather than deep.

Personal and Professional Skills and Attributes: Student A (business manager, interview) indicated that he experienced learning gains related to his life intentions. Due to his role and interactions with professionals, he realized he did not wish to pursue a career as a business manager.

In a second testimony, Student B (human resources, interview) indicated that she learned the importance of balancing personal and professional life. Her role exposed her to various situations where students had to choose between team work, personal life, and their studies, prompting her to reflect on her own life goals and explore more effective time management strategies.

Student C (team manager, interview) mentioned gaining insights into her vision for professional development. For example, she expressed greater clarity about the type of work environment she wants to be in, the kind of people she wishes to collaborate with, and the nature of the relationships she wants to build with them.

Student D (technical manager and board member, interview) highlighted his heightened awareness regarding the importance of professional behaviour. He emphasized the necessity for the team to focus on both their behaviour and the quality of their deliverables for stakeholders.

Interpersonal Skills: Student A (business manager, interview) indicated that he achieved learning gains in coordination and management of team processes and handling diverse perspectives. He mentioned that he now felt more confident in setting up meetings with companies, having learned how to prepare agendas, set goals, and outline follow-up actions. He also recognized the importance of incorporating diverse viewpoints from the team and stakeholders to maintain strong internal and external relationships. Finally, he expressed that he learned about stakeholder engagement, particularly how to approach unfamiliar companies and build relationships.

Student B (human resources, interview) indicated that she enhanced her awareness of the existence of diverse perspectives on a topic, shaped by people's varied backgrounds such as their studies, previous experiences, or jobs.

Student C (team manager, interview) indicated that she gained insights into team leadership, specifically the importance of delegating tasks. As part of the project, students organized meetings with companies and stakeholders, which generated numerous follow-up actions that she had to delegate to other team members.

Student C also increased her awareness of the relevance of creating a network that can be beneficial for the team.

Finally, Student D (technical manager and board member, interview) indicated that he learned about the importance of understanding different points of view. Based on this understanding, he felt better equipped to prepare strategies for forming a team and achieving his business goals.

The Innovation Process: Student A (business manager, interview) reported his learning about enterprise strategy and forming alliances with companies. He also recognized the value of seeking not only financial support but also technical assistance and strategic advice. According to him, this diversified approach significantly increased their chances of securing meaningful contributions from industry partners.

Student B (human resources, interview) shared that she gained valuable insights into the importance of understanding the diverse needs of stakeholders. This experience highlighted the contrast between artistic and engineering viewpoints, reinforcing the need to accommodate a variety of perspectives to effectively meet stakeholder expectations.

Student C (team manager, interview) gained valuable insight into the importance of understanding stakeholders' needs to achieve their goals. She noted that this experience taught her how to treat every external party in their own way. She also emphasized the importance of properly conveying messages to align expectations and gain stakeholders' confidence. Through this process, Student C came to understand that effective stakeholder management significantly impacts the project's progress, and that the experience and competence of those managing stakeholders' expectations are crucial in the innovation process.

Student D (technical manager and board member, interview) also referred to learning gains associated with enterprise strategy. He indicated that he learned that there are limitations within an organization when it comes to designing or producing certain technological components, and that there comes a point when outsourcing can be a strategy for delivering the product on time.

Finally, Student D also recognized the relevance of not overengineering designs (trade-offs among goals, concept, and structure), due to its impact on manufacturing and cost.

Leading Engineering Endeavours and Entrepreneurship: Student A (business manager, interview) indicated that he achieved learning gains associated with the way the business world works, particularly in terms of business culture and the strategies available to address project challenges.

Student C (team manager, interview) indicated she learned about finances and their relevance when making decisions and negotiating.

Finally, Student D (business manager and board member, interview) indicated that he increased his awareness of how pricing works, its effects on the decision-making process, and what can be expected from certain markets regarding pricing. In his view, this understanding helped him make better decisions with a greater sense of reality.

Advisors' Perspective

In individual interviews, Advisors X (management and design) and Y (management and networking) discussed the learning they observed in students during the project, focusing on the guidance process and the production of artifacts for the light festival.

Personal and Professional Skills and Attributes: Advisor X (management and design) reported that students experienced learning gains connected to urgency and will to deliver. He observed these learning gains when students explored solutions for the technical challenges posed by the light festival's site conditions and deadlines.

Advisor Y (management and networking) indicated that students experienced learning associated with enabling learning from others. She observed that they became more aware of the importance of gaining knowledge from previous team members to work more effectively under the pressure generated by stakeholders' expectations and the festival's milestones.

Advisor Y also noted improvements in students' time and resource management. She observed that they became more effective at organizing their schedules and adapting to changing project demands.

Interpersonal Skills: In the interpersonal skills category, Advisor X indicated that students showed improvements in incorporating diverse stakeholders' inputs.

Advisor Y reported that students learned about forming teams and assigning roles. She noted that they implemented an organizational change in response to the festival's technical requirements and deadlines.

Advisor Y also noted that students improved their professional communication skills through their interactions with the organization running Shine, as they needed to explain their project management and design decisions to secure their participation in the light festival.

The Innovation Process: In the innovation process category, Advisor X indicated that students increased their understanding of the design process because of their exposure to a real-life project that required conception, design, construction and implementation of their artistic artifact in a light festival. In addition, Advisor X noted that students improved their understanding of design process phasing by incorporating the experience shared by former team members, who advised the board on this matter, to allocate more time to the creative part of the innovation process.

Advisor Y observed that students improved their skills in establishing key alliances by attending social and business activities, such as workshops and conferences. These events offer opportunities to expand their network and create beneficial alliances for their team.

Table 2: Illustrative quotes

CDIO category	Level	Learning gain	Participant	Quotes
Personal and professional skills and attributes	Team	Time and resource management	Student E (technical role, workshop)	We were excited about making a user interface for the LED strings guiding festival visitors—it would've been a major achievement, but realistically, we wouldn't have finished it in time.
The innovation process	Team	Hardware manufacturing	Student G (technical role, workshop)	We learned a lot—how to design the cable, automate its removal, optimize the setup, and think ahead, since ordering cables also meant planning for LED extensions and cable covers.
Leading engineering endeavors and entrepreneur ship	Team	Conceiving products around new technology	Student C (team manager, workshop)	What we asked the cable manufacturer to do was highly customized. He explained that power had to go through first, then data, and both had to return in the opposite direction—so that's why we designed it this way.
Personal and Professional Skills and Attributes	Individual	Life intentions	Student A (business manager, interview)	I realized I don't want to run a business myself. I enjoy product design, so I want to focus more on that.
Interpersonal skills	Individual	Existence of diverse perspectives	Student B (human resources, interview)	It was a pleasure learning about technical topics. It opened up a new world of knowledge. Meeting people from that background and hearing their perspectives showed me how differently people can think.
Leading Engineering Endeavors and Entrepreneur ship	Individual	Business world	Student A (business manager, interview)	I got a much better understanding of business rules, like what kind of companies exist. For example, there are different ways to talk to big companies and small companies.
Personal and professional skills and attributes	Advisors	Enabling learning from others	Advisor Y (management and networking)	You can see they're really thinking about how to organize themselves to learn from previous teams. They even connect with team alumni to gain insights from their experiences and lessons learned.
Interpersonal skills	Advisors	Incorporating diverse stakeholders' inputs	Advisor X (management and design)	There are different voices that they need to evaluate before making their own decision. They learned this process.
The innovation process	Advisors	Desing process	Advisor X (management and design)	One important learning experience for the students was developing an overview of their design process and starting to work hard right from the beginning.

Leading Engineering Endeavours and Entrepreneurship: Advisor Y reported that she observed learning gains in students related to conceiving products around new technologies. She mentioned that they proactively contacted companies to seek advice and obtain technological components for their project.

This initiative stemmed from their growing awareness of the importance of integrating existing market technologies to meet technical requirements and project deadlines.

Advisor Y also observed that students developed valuable team-building skills. As they encountered challenges during project execution, they became more aware of their own limitations and took steps to address them.

Table 2 provides illustrative quotations that exemplify the learning gains reported by the students and advisors in this section.

Learning Gains Overview

Table 3 presents reported learning gains across various categories of the CDIO Syllabus 3.0 (Malmqvist et al., 2022), revealing some trends. In the personal and professional skills and attributes category, students (individual level) reported enhanced understanding of life intentions and professional behaviour. Within interpersonal skills, students, teams, and advisors identified gains in stakeholder management and dealing with diverse perspectives during design and decision-making processes. Regarding the innovation process, all participants reported learning gains related to design and manufacturing, including understanding stakeholder needs, testing, and avoiding overengineering. Additionally, learning gains in enterprise strategy and alliance formation were mentioned. Finally, in the leading engineering endeavours and entrepreneurship category, participants reported increased understanding of the business world and the development of technology-based products.

How Do Students Learn?

Beyond identifying reported learning gains, we examined how students' interactions with their environment supported their learning. Insights from interviews and workshops revealed that engagement with various stakeholders—namely industry partners, festival organizers, advisors, current and former team members— as well as opportunities provided by the university, played a significant role in this process.

Industry Partners, Festival Organizers, and Advisors

Students reported that their technical learning, focused on designing and manufacturing the solution, was driven by experimentation. They explored various designs, materials, and processes, guided by feedback from industry partners, festival organizers, and advisors. Each stakeholder played a distinct role: industry partners provided technical expertise and practical insights into their companies' technologies; festival organizers offered contextual feedback on the event's needs and constraints; and advisors supported the learning process as multifaceted mentors—combining managerial, technical, and creative guidance with industry and academic insights to facilitate networking, resource access, and effective team coordination. This diverse forms of support encouraged reflection and continuous refinement. Throughout the process, students actively engaged external networks to access additional resources and expertise. For example, Student C remarked that confronting challenges often motivated the team to seek knowledge beyond their immediate group, highlighting the value of fresh perspectives.

Building on this, Student D emphasized the value of industry partners in transferring knowledge and providing both material and technical support. He viewed this relationship positively, stating: "They advised us on what was possible, what was not, what the most viable option was, and what it would cost."

Additionally, Advisors X and Y noted that stakeholders played a crucial role in students' learning by offering feedback and creating pressure through technical, economic, and deadline constraints. This sense of urgency drove students to develop creative and practical solutions to meet external expectations.

Team Members and Alumni

Current and former team members played a relevant role in promoting team learning. The team organized activities where alumni shared experiences, transferred knowledge, and provided feedback. Student B, for instance, participated in meetings with the current team to reflect on technical and organizational challenges. These sessions deepened her understanding of project tasks and engineering concepts, with observation and reflection accelerating her learning.

Student C highlighted the value of board reflection sessions and the buddy system, through which she learned directly from her predecessor. This helped her grasp tacit knowledge not captured in documentation.

Student D noted the benefits of sessions with alumni, during which the team received feedback on decisions and external collaborations. They implemented suggestions, evaluated outcomes, and reflected as a team. He described this as valuable: “We managed to have the previous team manager and the one before that. So in January, we went back three generations. Quite a good pool of knowledge.”

Advisors also emphasized the impact of alumni involvement. Advisor X noted that former members offered feedback on decisions such as organizing the light festival and securing technical support. Advisor Y highlighted the team board’s role as a facilitator, coordinating resources that supported learning.

Opportunities Provided by the University

Students noted that university-organized activities, such as workshops and trainings, contributed to their learning, particularly by providing explicit knowledge and best practices in areas like teamwork, personal and professional development, and prototype manufacturing.

The findings related to the research question *'How do students learn?'* are summarized in Table 4.

Vol. 2, No. 2, 2025, pp. 54-73, ISSN 3006-6301
DOI : 10.62492/sefijeea.v2i2.38

Table 3: Learning Gains Reported by Students and Advisors

CDIO category	Team	Student A Business manager	Student B Human resources	Student C Team manager	Student D Tec. manager and board member	Advisor X	Advisor Y
Fundamental knowledge and reasoning	-	Eng. knowledge	Eng. knowledge	-	Eng. knowledge	-	-
Personal and professional skills and attributes	Time and resource management	Life intentions	Balancing personal and professional life	Vision of professional development	Professional behavior	Urgency and will to deliver	Enabling learning from others Time and resource management
Interpersonal skills	Communication strategy Stakeholder engagement	Coordination and management of team processes Handling diverse perspectives Stakeholder engagement	Existence of diverse perspectives	Team leadership Creating a network	Understanding different points of views	Incorporating diverse stakeholders' inputs	Forming teams, assigning roles, and responsibilities Professional communication
The innovation process	Hardware manufacturing Testing process Use of knowledge in design	Enterprise strategy Forming alliances with companies	Understanding the specific needs of various stakeholders	Understanding the specific needs of various stakeholders	Enterprise strategy Not overengineering designs	Design process Design process phasing	Establishing key alliances
Leading engineering endeavours and entrepreneurship	Conceiving products around new technology	Business world	-	Finances	Pricing	-	Building the team Conceiving products around new technology

Table 4: Learning Environment Elements Supporting Student Development

Learning Environment Elements	Kind of Support
Industry Partners	Provided technical expertise and practical insights into real-world technologies
Festival organizers	Provided contextual feedback related to the event's needs and constraints
Advisors	Provided managerial, technical, and creative guidance; facilitated networking opportunities, resource access, and team coordination.
Team Members and Alumni	Shared experiences and transferred knowledge; provided feedback on technical and organizational challenges; facilitated reflection and learning; supported decision-making and implementation.
Opportunities Provided by the University	Provided knowledge and best practices in diverse topics such as personal, professional and, interpersonal skills, as well as the innovation process.

Discussion and implications

This study aimed to deepen our understanding of the experiences and learning gains that student team members achieved as a result of their participation in an extracurricular CBL project associated with the Shine Light Art Festival. The findings provide meaningful insights into both what students learn and how they learn through this experience. Evidence indicates that students achieved learning gains across all main CDIO categories, including fundamental knowledge; personal and professional skills and attributes; interpersonal skills; innovation process; and leading engineering endeavours.

The learning gains observed were linked to the specific roles students held within their teams. For example, those involved in manufacturing and testing reported learning gains related to the innovation process, while students in managerial roles developed competencies in enterprise strategy and team leadership. These patterns are in line with earlier research highlighting the differentiated impact of roles—and their associated activities—on student learning (Bravo et al., 2024; Clark et al., 2015).

In terms of *fundamental knowledge*, students reported acquiring engineering knowledge, particularly through a heightened awareness of the technologies required for their projects—confirming the findings from earlier studies on extracurricular automotive competition teams (Dominguez-Ramos et al., 2019; Mariasiu & Raboca, 2017).

The results of this study also provide evidence of students' learning gains in the category of *personal and professional skills and attributes*. Specifically, learning gains were reported in areas such as time and resource management, life intentions, balancing personal and professional life, vision of professional development, and enabling learning from others. These support the findings of previous research, highlighting the value of extracurricular activities in preparing engineering students for professional practice (Clark et al., 2015; Gerber et al., 2012).

Vol. 2, No. 2, 2025, pp. 34-72, ISSN 3006-6301
DOI : 10.62492/sefijeea.v2i2.38

With respect to *interpersonal skills*, the findings show that both students and advisors reported learning gains related to stakeholder engagement, such as managing diverse perspectives, integrating stakeholder input into the design process, and developing effective communication strategies. These results echo previous studies that emphasise the educational value of stakeholder engagement in engineering education (Payne & Jesiek, 2018; Tembrevilla et al., 2023).

Regarding learning gains within the *innovation process*, students reported a deeper understanding of design phases, hardware manufacturing, testing procedures, and the practical application of engineering concepts. They also developed the ability to transform innovative ideas into tangible technological artifacts. These findings are supported by previous studies that provide evidence of the educational value of hands-on, project-based contexts particularly in developing prototyping competencies (Dominguez-Ramos et al., 2019; Gerber et al., 2012; Huerta et al., 2022; Sorici et al., 2023). Moreover, students also developed an appreciation for the importance of building strategic alliances and understanding stakeholders needs as key factors in designing high-quality, user-centred products. These results are consistent with prior findings that have shown the educational value of industry collaboration in the design process and its role in enhancing students' design-related knowledge and competencies for innovation (Kilic-Bebek et al., 2023; McGregor, 2017).

Finally, in relation to *leading engineering endeavours and entrepreneurship*, students reported learning gains in areas such as technological product conception, business practices, and financial awareness. This evidence aligns with prior investigations demonstrating that the interaction with real-life stakeholders can foster a strong understanding of modern management techniques and entrepreneurial thinking among engineering students (Tasdemir & Gazo, 2020).

The evidence also shed light on how students learned—through interactions with festival organization, industry partners, advisors, peers, and team alumni, as well as engagement in a real-life project. These experiences involved challenges like resource sourcing, navigating legal considerations, and team formation, issues typically hard to address in traditional courses due to constraints like semester length, fixed learning outcomes, and limited stakeholder involvement.

Additionally, students shaped their own learning paths, driven by intrinsic motivation and choices about how to engage with third parties for feedback and advice. The real-life context empowered them to take ownership of their learning, enhancing their awareness and strategies for ongoing professional development.

The inclusion of a nursing student in a team primarily composed of engineering students added a valuable interdisciplinary dimension. While we lack direct feedback from the technical team regarding their perception of the value of having a member from a different discipline, the nursing student's reflections suggest that her background in human-centred care brought a distinct perspective to team discussions—whether in addressing project challenges or contributing to conversations related to her role in human resources. Her experience revealed a growing appreciation for diverse viewpoints, increased sensitivity to stakeholder needs, and a deeper understanding of the importance of balancing personal and professional priorities. These insights indicate that her participation not only complemented the team's technical focus but also enriched the collaborative process.

However, while students engaged in meaningful learning through their participation in the extracurricular challenge-based learning (CBL) team, some obstacles emerged that hindered the full realization of experiential learning as described by Kolb's Experiential Learning Theory (Kolb, 1984), thereby limiting their overall learning outcomes. One significant barrier was ineffective communication with the festival organization. The inconsistent information flow and unclear communication channels led to confusion about the expected quality of deliverables, making it difficult for students to receive timely and constructive feedback, which is essential for the *reflective observation* and *abstract conceptualization* phases of Kolb's model. Without a clear understanding of their performance and outcomes, students struggled to engage in meaningful reflection or adjust their approaches based on real-world insights.

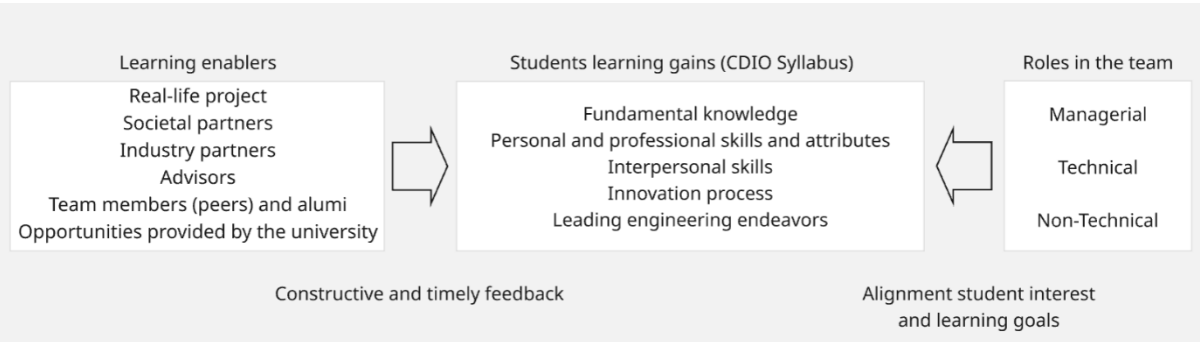
Limited constructive and timely feedback from the festival organizers made it more challenging for the students to identify knowledge gaps, refine their outputs, and benefit from guided development. Feedback is widely recognized as a critical component of effective learning, as it enables learners to interpret their experiences, adjust their strategies, and improve performance. Drawing on Vygotsky's concept of the Zone of Proximal Development (ZPD), timely and targeted feedback is essential for supporting learners in progressing beyond what they can achieve independently (Vygotsky, 1978). In the absence of such support, students were left to navigate complex and unfamiliar tasks on their own, which constrained their development within the ZPD. This lack of scaffolding also risked undermining motivation, which is a key factor influencing learning outcomes (Illeris, 2007).

However, this situation did not persist throughout the entire project. As the collaboration matured, communication with the festival organizers gradually improved. Feedback became more consistent and actionable, allowing students to better understand expectations and align their work accordingly. This shift not only enhanced students' ability to reflect on and improve their performance but also re-established the project as a valuable learning environment. The evolution of the feedback process highlights the importance of communication structures in collaborative, real-world learning settings, particularly when external stakeholders are involved.

In sum, this study underscores the significant educational value of extracurricular, team-based experiences in engineering education. These environments offer rich opportunities for experiential learning, particularly when supported by timely and constructive feedback in a motivating environment. To fully harness this potential, institutions should design supporting activities that intentionally align with all stages of Kolb's Experiential Learning Cycle (Kolb, 1984) and formally recognize the learning outcomes that emerge beyond the traditional curriculum. Central to this process is the active involvement of stakeholders—faculty, industry partners, and advisors, who serve as essential scaffolds in supporting student learning. Providing targeted training for these stakeholders can further enhance their ability to guide student development effectively.

The findings also highlight the importance of peer collaboration and real-world problem-solving in shaping students' professional competencies and engineering identities. To maximize the benefits of participating in student teams, it is crucial that students' learning interests align with their assigned roles, as these roles often serve as key sites for learning. While student-led and self-regulated learning is a strength of these environments, some degree of coordination within the team is necessary to ensure an educationally meaningful experience. By acknowledging and investing in these informal yet powerful learning ecosystems, engineering education can evolve to better prepare students for the complexities and demands of professional practice. The interactions and actors within the extracurricular student teams learning environment are shown in Figure 1.

Figure 1. Interactions and actors of the extracurricular student team learning environment



Contribution

This study presents a qualitative report on students' experiences and learning gains after completing a year-long, extracurricular, engineering-focused CBL project. The project offered students the opportunity to engage in the full cycle of conceiving, designing, and implementing solutions in real-life contexts, underscoring the educational value of such activities.

Furthermore, this research contributes to the existing body of CBL literature on learning gains, which has primarily focused on curricular activities, such as CBL courses, master's or bachelor's CBL projects linked with a thesis, as well as short-term, interdepartmental or inter-institute CBL projects. Given the limited number of empirical studies on extracurricular CBL projects in the existing literature, this study holds particular significance.

This study provides new insights into the impact of exposing students to real-world projects. These projects offer students opportunities to clarify their future career paths, expand their professional networks, and increase their awareness of work life. They also help students understand how to incorporate the perspectives of stakeholders, advisors, and industry partners within the product development process—an aspect that is often challenging to implement in traditional educational environments.

Additionally, this study contributes to our understanding of how different learning environments shape student development by providing insights into the learning gains in extracurricular Challenge-Based Learning (CBL), enabling a meaningful comparison with curricular CBL. While both contexts support learning, their structural differences influence the nature and depth of these outcomes. Extracurricular CBL offers an open-ended environment that nurtures autonomy, motivation, and fosters engagement with real-world stakeholders.

However, the absence of formal scaffolding and timely and consistent feedback may hinder reflective learning and long-term growth. In contrast, curricular CBL provides structured guidance, formal assessment, and alignment with academic objectives, which support the achievement of predefined learning outcomes. Yet, its rigid timelines and preset learning outcomes can limit opportunities for self-directed exploration and may reduce student motivation. By examining these contextual dynamics, the study encourages a rethinking of how learning environments are designed, suggesting that hybrid models—integrating structured scaffolding and timely feedback with the authenticity, autonomy, and motivation found in extracurricular experiences—can more effectively promote comprehensive student learning.

Moreover, this study provides an effective method for gathering students' self-reported learning gains through workshops, individual semi-structured interviews, and feedback from team advisors. By triangulating this information, the study increased its reliability and reduced the effects of overestimated knowledge and subjective biases.

Finally, this study highlights the usefulness of the CDIO syllabus for classifying learning gains in an organized, descriptive, and meaningful manner for educators, program directors, and engineering education researchers.

Limitations and Future Research

This study's focus on a single extracurricular student team provides a rich description but limits the generalizability of its findings. Learning gains in challenge-based learning (CBL) projects can vary significantly across teams. Factors such as assigned roles, specific tasks, and duration of engagement have been shown to influence learning outcomes (Clark et al., 2015). However, this study offers more *in-depth* understanding of students' learning in a CBL team. In our case, participation was entirely voluntary, with students from engineering-related bachelor's and master's programs committing either part-time or full-time effort without receiving academic credit. This likely attracted highly motivated individuals and may not reflect the dynamics of credit-bearing or mandatory programs.

While most members of the team had engineering backgrounds, other teams may feature more interdisciplinary or less technically experienced profiles, which could influence learning outcomes. Additionally, team structure—from an organizational perspective—may also shape individual learning experiences. Some teams are organized into distinct sub-teams with specialized responsibilities, while others follow more integrated or flexible structures. These organizational differences affect the nature and frequency of interactions, distribution of tasks, and opportunities for collaboration. We hypothesize that such structural variations can impact both the type and depth of learning, particularly when comparing students across different teams or sub-teams within the same project. Understanding these variations is essential for interpreting differences in learning outcomes across contexts.

By relying primarily on final evaluations rather than incorporating observations and interviews throughout the project, we may have missed opportunities to capture individual learning progress as it developed. Although workshops and interviews captured critical incidents and key milestones, the absence of learning journals or progress logs limited our insight into students' ongoing development. As a result, advisors' evaluations were based on general impressions rather than systematic tracking of individual growth.

Future research should expand participation to include more diverse student teams, participant profiles, projects, and stakeholder groups. Additionally, incorporating role rotation within team could offer insights into how different responsibilities influence learning gains. These strategies would enable both richer qualitative insights and more robust quantitative analyses of learning patterns. Longitudinal data collection methods—such as portfolios, learning diaries, and guided reflections—should also be implemented to more accurately trace individual learning trajectories throughout CBL experiences. These approaches would contribute to a more nuanced understanding of the transferability of findings.

We propose introducing artificial intelligence tools to collect and analyze data from the large and diverse participant population in the extracurricular student team program, enabling scalable mixed-method research with deeper insights and more generalizable conclusions.

Finally, further investigation is needed to assess the effectiveness, scalability, and student engagement associated with continuous assessment tools. These methods may offer more comprehensive and reliable evidence of learning gains than endpoint evaluations alone.

Acknowledgements

The authors would like to thank the students who participated in this study for their enthusiasm and commitment, which were essential to the success of both the project and the research. Their dedication and collaborative spirit made a significant contribution to the field of engineering education.

Declaration of interest

No potential conflict of interest was reported by the author(s).

Ethical approval

This study was conducted in accordance with the Netherlands Code of Conduct for Research Integrity and the Code of Scientific Conduct of Eindhoven University of Technology. It received approval from the university's Ethical Review Board (number ERB2022ESOE7, 22-11-2022) and complies with the General Data Protection Regulation (GDPR) of the European Union.

All study participants were provided with the purpose of the research and consented to participate.

Notes on Contributors

All authors contributed to the study's conception, design, research, writing, and editing.

Eugenio Bravo is an engineer and doctoral researcher at Eindhoven University of Technology (TU/e), working on the project Extracurricular Learning & Competence Development within TU/e Innovation Space. He has played a key role in implementing Challenge-Based Learning courses in engineering higher education. His research focuses on innovating engineering education, with particular emphasis on enhancing support for self-directed learning in open and flexible learning environments.

Dury Bayram is an Assistant Professor at the Eindhoven School of Education (ESoE), Eindhoven University of Technology (TU/e). Her research interests are Socio-scientific Issues (SSI), science education for citizenship, pedagogy of physics, Pedagogical Content Knowledge (PCK) of physics/science teachers, formative evaluation of SSI lessons, and innovation in education.

Jan T. van der Veen is a full Professor at the Eindhoven School of Education (ESoE), Eindhoven University of Technology (TU/e). His research focuses on innovating STEM education in secondary and higher education including the professional development of STEM educators. He contributes to the international community working on rewarding teaching excellence.

Isabelle Reymen is the Scientific Director of TU/e Innovation Space and a Professor of Design of Innovation Ecosystems in the Innovation, Technology Entrepreneurship, and Marketing (ITEM) group at Eindhoven University of Technology. She founded TU/e Innovation Space with the ambition to fundamentally change education, and after seven years, she leads an award-winning team dedicated to advancing educational innovation with a commitment to the highest standards of quality.

Funding information

This work was supported by TU/e innovation Space, Eindhoven University of Technology.

References

Arrambide-Leal, E. J., Lara-Prieto, V., García-García, R. M., & Membrillo-Hernández, J. (2019). *Impact of active and challenge-based learning with first-year engineering students: Mini drag race challenge*. Paper presented at the IEEE 11th International Conference on Engineering Education, Kanazawa, Japan. https://doi.org/10.1109/ICEED47294.2019.8994939

Bravo, E., Bayram, D., van der Veen, J. T., & Reymen, I. (2024). Students' learning gains in extracurricular challenge-based learning teams. *European Journal of Engineering Education, 50*(2), 342-359. https://doi.org/10.1080/03043797.2024.2386108

Charosky, G., & Bragós, R. (2021). Investigating students' self-perception of innovation competences in challenge-based and product development courses. *International Journal of Engineering Education, 37*(2), 461–470.

Charosky, G., Leveratto, L., Hassi, L., Papageorgiou, K., Ramos-Castro, J., & Bragós, R. (2018). *Challenge-based education: An approach to innovation through multidisciplinary teams of students using design thinking*. Paper presented at the XIII Technologies Applied to Electronics Teaching Conference, Tenerife, Spain. https://doi.org/10.1109/TAEE.2018.8476051

Clark, G., Marsden, R., Whyatt, J. D., Thompson, L., & Walker, M. (2015). 'It's everything else you do…': Alumni views on extracurricular activities and employability. *Active Learning in Higher Education, 16*(2), 133–147. https://doi.org/10.1177/1469787415574050

Davis, K. A., Grote, D., Mahmoudi, H., Perry, L., Ghaffarzadegan, N., Grohs, J., Hosseinichimeh, N., Knight, D. B., & Triantis, K. (2023). Comparing self-report assessments and scenario-based assessments of systems thinking competence. *Journal of Science Education and Technology, 32*(5), 793–813. https://doi.org/10.1007/s10956-023-10027-2

Dominguez-Ramos, A., Alvarez-Guerra, M., Diaz-Sainz, G., Ibañez, R., & Irabien, A. (2019). Learning-by-doing: The Chem-E-Car Competition® in the University of Cantabria as case study. *Education for Chemical Engineers, 26*, 14–23.

Doulougeri, K., Vermunt, J. D., Bombaerts, G., & Bots, M. (2024). Challenge-based learning implementation in engineering education: A systematic literature review. *Journal of Engineering Education, 113*(4), 1076–1106. https://doi.org/10.1002/jee.20588

Eichelman, K. M., Clark, R. M., & Bodnar, C. A. (2015, June). *Assessing the impact of game based pedagogy on the development of communication skills for engineers*. Paper presented at the ASEE Annual Conference and Exposition, Seattle, Washington.

Gallagher, S. E., & Savage, T. (2020). Challenge-based learning in higher education: An exploratory literature review. *Teaching in Higher Education, 28*(6), 1135–1157. https://doi.org/10.1080/13562517.2020.1863354

Gama, K., Alencar, B., Calegario, F., Neves, A., & Alessio, P. (2018). *A hackathon methodology for undergraduate course projects*. Paper presented at the 48th Frontiers in Education Conference, San Jose, CA. https://doi.org/10.1109/FIE.2018.8659264

Gerber, E. M., Olson, J. M., & Komarek, R. L. D. (2012). Extracurricular design-based learning: Preparing students for careers in innovation. *International Journal of Engineering Education, 28*(2), 317–324.

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *Journal of the Learning Sciences, 9*(3), 247–298. https://doi.org/10.1207/S15327809JLS0903_2

Huberman, A. M., & Miles, M. B. (1994). Data management and analysis methods. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 428–444). Sage Publications.

Huerta, H., Díaz, C., Avelar, M., & Rosas-Elguera, J. G. (2022). Research, development and innovation: An extracurricular club case study. *IEEE Access, 10*, 66625-66633, doi: 10.1109/ACCESS.2022.3169790

Illeris, K. (2007). *How we learn: Learning and non-learning in school and beyond* (1st ed.). Routledge. https://doi.org/10.4324/9780203939895

Immekus, J., Maller, S., Tracy, S., & Oakes, W. (2005, June). Evaluating the outcomes of a service learning based course in an engineering education program: Preliminary results of the assessment of the engineering projects in community service - EPICS. *In Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition* (pp. 5923-5938). ASEE.

Jensen, M. B., Utriainen, T. M., & Steinert, M. (2018). Mapping remote and multidisciplinary learning barriers: Lessons from challenge-based innovation at CERN. *European Journal of Engineering Education, 43*(1), 40–54. https://doi.org/10.1080/03043797.2017.1278745

Kilic-Bebek, E., Nizamis, K., Vlutters, M., Bebek, O., Karapars, Z. G., Unal, R., Yilmaz, D., & Ugurlu, B. (2023). Transdisciplinarity as a learning challenge: Student experiences and outcomes in an innovative course on wearable and collaborative robotics. *IEEE Transactions on Education, 66*(3), 263–273. doi: 10.1109/TE.2022.3229201

Kohn Rådberg, K., Lundqvist, U., Malmqvist, J., & Hagvall Svensson, O. (2018). From CDIO to challenge-based learning experiences – Expanding student learning as well as societal impact? *European Journal of Engineering Education, 45*(1), 22–37. https://doi.org/10.1080/03043797.2018.1441265

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development* (2nd ed.). Prentice-Hall.

Lammi, M., Denson, C., & Asunda, P. (2018). Search and review of the literature on engineering design challenges in secondary school settings. *Journal of Pre-College Engineering Education Research, 8*(2), 5.

Larson, R. W., Hansen, D. M., & Moneta, G. (2006). Differing profiles of developmental experiences across types of organized youth activities. *Developmental Psychology, 42*(5), 849–863.

Leijon, M., Gudmundsson, P., Staaf, P., & Christersson, C. (2021). Challenge based learning in higher education– A systematic literature review. *Innovations in Education and Teaching International, 59*(5), 609–618. https://doi.org/10.1080/14703297.2021.1892503

Malmqvist, J., Lundqvist, U., Rosén, A., Edström, K., Gupta, R., Leong, H., Cheah, S. M., Bennedsen, J., Hugo, R., Kamp, A., Leifler, O., Gunnarsson, S., Roslof, J., & Spooner, D. (2022). The CDIO Syllabus 3.0 - An Updated Statement of Goals. In M. S. Gudjonsdottir, H. Audunsson, A. M. Donoso, G. Kristjansson, I. Saemundsdottir, J. T. Foley, M. Kyas, A. Sripakagorn, J. Roslof, J. Bennedsen, K. Edstrom, N. Kuptasthien, & R. Lyng (Eds.), *Proceedings of the 18th International CDIO Conference* (pp. 18–36). Chalmers University of Technology.

Mariasiu, F., & Raboca, H. M. (2017). Assessment of extracurricular activities' effects on automotive engineering education: A cross-national study. *International Journal of Mechanical Engineering Education, 45*(2), 120–141.

McGrath, C. H., Guerin, B., Harte, E., Frearson, M., & Manville, C. (2015). *Learning gain in higher education*. RAND Europe. https://www.rand.org/pubs/research_reports/RR996.html

McGregor, S. L. (2017). Transdisciplinary pedagogy in higher education: Transdisciplinary learning, learning cycles and habits of minds. In P. Gibbs (Ed.), *Transdisciplinary higher education* (pp. 3–16). https://doi.org/10.1007/978-3-319-56185-1_1

Membrillo-Hernández, J., Ramírez-Cadena, J. M., Martínez-Acosta, M., & others. (2019). Challenge-based learning: The importance of world-leading companies as training partners. *International Journal on Interactive Design and Manufacturing, 13*(4), 1103–1113. https://doi.org/10.1007/s12008-019-00569-4

Nichols, M., & Cator, K. (2008). *Challenge based learning*. [White paper]. Apple, Inc.

Payne, L., & Jesiek, B. (2018). Enhancing transdisciplinary learning through community-based design projects: Results from a mixed methods study. *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship, 13*(1), 1–52.

Piaget, J. (1952). *The origins of intelligence in children* (2nd ed.). International Universities Press.

Picard, C., Hardebolle, C., Tormey, R., & Schiffmann, J. (2022). Which professional skills do students learn in engineering team-based projects? *European Journal of Engineering Education, 47*(2), 314–332.

Ro, H. K., & Knight, D.B. (2016). Gender differences in learning outcomes from the college experiences of engineering students. *Journal of Engineering Education, 105*(3), 478–507. https://doi.org/10.1002/jee.20125

Rogaten, J., & Rienties, B. (2021). A critical review of learning gains methods and approaches. *Learning Gain in Higher Education, 14*, 17–31. https://doi.org/10.1108/S1479-362820210000014003

Savenye, W. C., & Robinson, R. S. (2005). Using qualitative research methods in higher education. *Journal of Computing in Higher Education, 16*, 65–95.

Schmitz, B., & Perels, F. (2011). Self-monitoring of self-regulation during math homework behavior using standardized diaries. *Metacognition and Learning, 6*(3), 255–273. https://doi.org/10.1007/s11409-011-9076-6

Seow, P., & Pan, G. (2014). A literature review of the impact of extracurricular activities participation on students' academic performance. *Journal of Education for Business, 89*(7), 361–366.

Sorici, C. O., Sălceanu, C., Matei, R. S., Sburlan, D. F., Țiței, A., & Gîrțu, M. A. (2023). An extracurricular project-based training course in innovation and entrepreneurship delivered to a transdisciplinary group of students in engineering, social sciences, arts and medicine. *Education Sciences, 13*(10), 967. https://doi.org/10.3390/educsci13100967

Tasdemir, C., & Gazo, R. (2020). Integrating sustainability into higher education curriculum through a transdisciplinary perspective. *Journal of Cleaner Production, 265*, 121759.

Tembrevilla, G., Nesbit, S., Ellis, N., & Ostafichuk, P. (2023). Developing transdisciplinarity in first-year engineering. *Journal of Engineering Education, 112*(1), 43–63.

Thompson, L. J., Clark, G., Walker, M., & Wyatt, J. D. (2013). 'It's just like an extra string to your bow:' Exploring higher education students' perceptions and experiences of extracurricular activity and employability. *Active Learning in Higher Education, 14*(2), 135–147.

Valencia, A., Bruns, M., Reymen, I. M. M. J., & Pepin, B. E. U. (2020). *Issues influencing assessment practices of inter-program challenge-based learning (CBL) in engineering education: The case of ISBEP at TU/e Innovation Space*. Paper presented at the SEFI 48th Annual Conference, Twente, the Netherlands. https://www.sefi.be/wp-content/uploads/2020/11/Proceedings-DEF-nov-2020-kleiner.pdf

van den Beemt, A., van de Watering, G., & Bots, M. (2022). Conceptualizing variety in challenge-based learning in higher education: The CBL-compass. *European Journal of Engineering Education, 48*(1), 24–41. https://doi.org/10.1080/03043797.2022.2078181

van Uum, M., & Pepin, B. (2022). Students' self-reported learning gains in higher engineering education. *European Journal of Engineering Education, 48*(1), 42–58. https://doi.org/10.1080/03043797.2022.2046708

Vermunt, J. D., Sonia, I., & Vignoles, A. (2018). Building the foundations for measuring learning gain in higher education: A conceptual framework and measurement instrument. *Higher Education Pedagogies, 3*(1), 266–301. https://doi.org/10.1080/23752696.2018.1484672

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Yin, R. K. (1994). Discovering the future of the case study. Method in evaluation research. *Evaluation Practice, 15*(3), 283–290.