CDIO METHODOLOGIES IN FIRST-YEAR PROJECTS OF MECHANICAL, CHEMICAL, AND FOOD BIOPROCESSES ENGINEERING

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ABSTRACT

This work delves into the integration of CDIO principles within first-year integrated group projects, highlighting collaborative efforts within discipline-specific groups, diverse project deliverables, and the unique emphasis on the Project Showcase for assessment. The integration of CDIO has been applied to methodologies within first-year integrated group projects in Mechanical, Chemical, and Food Bioprocesses Engineering. Students collaboratively conceive solutions to engineering challenges within their respective disciplines. The group dynamic fosters creative thinking, problem-solving, and discipline-specific collaboration. The projects involve diverse deliverables, with the final assessment placing a higher weight on the collective group performance during the Project Showcase. This live demonstration is a pivotal evaluation moment, integrating CDIO principles into a real-world context. The showcase not only provides a platform for students to communicate their design rationale, operational strategies, and project outcomes to a broader audience but also places a heightened emphasis on the collective group performance during this interactive and operational presentation. Graduates emerge with not only technical proficiency but also with the invaluable skills of teamwork, communication, and adaptability, which are essential attributes for success within their chosen engineering field.

KEYWORDS

Integrated group projects, First-year students, CBL, Engineering, Public showcase, CDIO, Standards: 1, 3, 4, 6, 8, 11

INTRODUCTION

The first year of engineering studies lays the groundwork for students' future professional paths (Lakin et al., 2020), which is why the decision is made to incorporate CDIO principles into integrated group projects for first-year engineering students (Karhunen, 2008).

In the first year of their academic journey, students often express concerns about the predominantly theoretical nature of their studies, perceiving an imbalance with practical application (BOE-A-2021-15781, 2021). The implementation of integrated projects based on the CDIO philosophy has emerged as a solution to this challenge. Pereira et al. (2017) demonstrate how integrating projects can bridge the gap between fundamental or theoretical course subjects, leading to a more practical approach and ultimately enhancing student satisfaction. These projects provide students with the opportunity to witness, from their first year, how the theoretical concepts they are learning directly apply to real-world situations (Saeidlou et al., 2023). By addressing real problems and working on the conception, design, implementation, and operation of solutions, students find meaning and practical applicability in what they are learning. Siew Ping et al. (2010) also shows that the project facilitates the conceive-design process and helps integrate knowledge from different modules together without needing any extra resources. Consequently, the implementation of these projects catalyzes a more enriching and motivating educational experience (Alpay et al., 2008) right from the beginning of their academic journey.

The benefits of these projects extend to first-year students by providing them with a practical and collaborative educational experience. Alaya et al. (2017) demonstrate how this activity improve their personal and technical skills. It allows them to apply the knowledge acquired through solving real-world problems, fostering creative thinking and teamwork skills (Vijayaratnam, 2012). Moreover, as Jonassen et al. (2006) says, practicing engineers are hired, retained, and rewarded for solving problems, so engineering students should learn how to solve real-world problems. Real-world engineering problems are substantively different from the kinds of problems that engineering students most often solve in the classroom; therefore, learning to solve classroom problems does not necessarily prepare engineering students to solve workplace problems. This project, within the CDIO framework, helps students develop a comprehensive understanding of the engineering creation process and acquire essential skills to address real-world challenges (Wordley et al., 2023).

The culmination of the project with a public presentation not only serves as a final assessment but also enhances students' motivation. The dynamics of the public presentation foster competition among groups to achieve outstanding solutions and bring out the best in each team. Group competition acts as a positive stimulus; students strive to excel and overcome challenges, contributing to a dynamic and engaged learning environment. Therefore, a culture of collaboration is promoted, where the individual success of a group translates into collective success, emphasizing the fundamental principles of CDIO that advocate collaboration and teamwork in the field of engineering (Goh et al., 2023; Siegkas, 2021). Teo et al. (2013) demonstrates how students are motivated and engaged in participating through an integrated project that leads to an exhibition and competition. Furthermore, beyond its immediate impact on students during presentations, this dynamic also equips them with tools for the future. The public presentation at the end of the project underscores the importance of communication and results presentation, preparing students for success in their future endeavors.

This work outlines the integrated projects in three academic disciplines, mechanical engineering, chemical engineering, and food bioprocess engineering programs. In mechanical engineering, this project is implemented in the subject Integrated Project I (Projecte Integrador I - 20224125) which is part of the second term of the first year of the undergraduate program of Mechanical Engineering Bachelor from Universitat Rovira i Virgili (URV). The Integrated Project (IP) subject intend to force the students, to put into practice the knowledge acquired in some of the core topics of the Mechanical Engineering program. In the first year, the IP deals with basic Physics, Mathematics, Engineering Design with emphasis in Computer Aided

Design, and computer programming. The IP has 6 ECTS credits, with a total workload for the student of 150 h. A 30% of these (45 h), are developed in-person with the professor in the classroom. In the case of chemical engineering and food bioprocess engineering, the subject pertaining to integrated projects is "Fundamentals of Process Engineering," encompassing a total of 9 ECTS. Of these, 6 ECTS are directly allocated to project implementation, while the remaining 3 ECTS focus on in-class theory, providing the necessary knowledge for effective project execution.

The proceeding begins with a presentation of the methodology used, detailing the approach applied at each degree and including an example of its implementation. Following this, the results section reflects student opinions regarding the initiative, particularly within the framework of the CDIO syllabus. Finally, the limitations and conclusions are exposed.

METHODOLOGY

This project has been ongoing for several years, and each year the statement is modified to be aligned with the engineering context and updated (Standard 1). Despite changes in the statement, the desired objectives remain consistent, and the purpose of the project stays unchanged. The objectives of the projects are:

- Execute the project to facilitate the effective integration of competencies developed in various subjects.
- Develop a practical study on obtaining a product from raw materials, thereby fostering the student's capacity for analysis and synthesis in the design of a manufacturing process.
- Present a functional machine that successfully passes a public test, considering this achievement as crucial for the approval of the subject.
- Promote teamwork, interdependence, and the development of technical and social skills in the student.

After establishing the objectives, the implementation strategy varies between the Mechanical Engineering program (BSME) and the Chemical (BSQE) and Food Bioprocess Engineering (BSFB) program.

Methodological Framework for Mechanical Engineering Integrated Projects

The course is distributed over a term of 15 weeks (3 h/week), 1 h for theoretical lectures (all students) and 2 h for laboratory activities, where students are divided into smaller groups with a maximum of 20 students per group. The theoretical presentations (T1 to T10) deal with product design concepts such as: Product planning, customer needs identification, product specifications, concept generation, proof of concept, industrial design, need for prototypes, product management, etc (Standard 8). During the course, there are also programed two seminars (S1 and S2) that deal with gender equality. These seminars are taught by experts in the matter from the humanities department at URV. A tentative weekly planning is included in table 1 for reference.

Table 7. Weekly planning of BSME project.

Week	T (1h)	h	LAB (2h)	h
1	Presentation / Outline	1		
2	Problem statement E1	1	Tutorial E1	2
3	T1	1	Tutorial E1	2
4	T2	1	Tutorial E1	2
5	Deliverable E1/ Problem statement E2	1	Tutorial E2	2
6	T3	1	Tutorial E2	2
7	T4	1	Tutorial E2	2
8	T5/Deliverable E2/ Problem statement E3	1		
9	T6	1	Open fab. lab	2
10	S1	1	Open fab. lab	2
11	S2	1	Open fab. lab	2
12	T7/Deliverable E3	1	FINAL presentation	2
13	T8	1	FINAL presentation	2
14	T9	1	Prototype testing	2
15	T10	1	Prototype testing	2
16		1	FINAL CONTEST (E4)	4

The subject is organized around the main project, that implies the conception, design, implementation and operation (CDIO) of a device to solve a challenge posed by the professors. Students form groups of around 5 individuals, that work together to solve the challenge. The problem is introduced and described in a progressive manner by means of several problem statement lectures (E1 to E4). Figure 1 shows that the different execution phases of the course project (E1 to E4) can be linked to the CDIO principles.

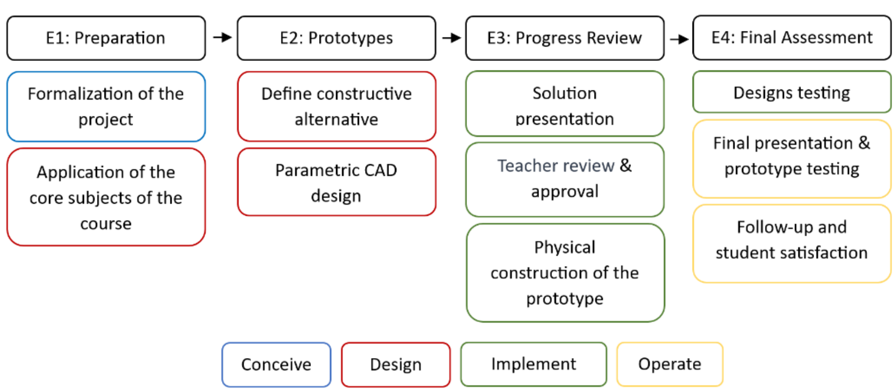


Figure 4. CDIO principles in the execution phases.

The first problem statement (E1) is the formalization of the project which involves establishing, in a clear and detailed manner, the essential aspects. This formalization includes defining objectives, identifying requirements, developing the work plan and assigning roles and responsibilities. Student can formalize this part thanks to the statement of the project. The statement also establishes certain size limitations restrictions and the way it has to be manufactured. During the formalization of the project, students are also working on conceptualizing the project from the perspective of physics and mathematics (Standard 4). The task focuses on forcing the students to work the physics, describing the parameters to consider and to derive the equations that govern the problem, thus providing a practical application of the concepts learned in theoretical classes. They end up delivering a report with all the theoretical considerations, as well as numerical solutions of the expressions found, and their graphical representations.

In the second problem statement (E2), students define constructive alternatives to implement the parameters they calculate in the preceding stage and formulate different solutions. They define a design and use parametric CAD tools such as Autodesk Inventor, to implement it. Finally, they generate a final design report that includes the analysis of alternatives and the engineering and manufacturing drawings of the device. The next stage is the presentation of the solution in front of all other students and professors. Students are required to prepare an oral presentation, summarizing the reports presented for E1 and E2. Once this stage has been finished and approved by the professors, students can start the manufacturing of the device. During the physical creation phase of the project, students have access to the laboratories (Standard 6). Finally, students have the opportunity to test their designs prior to the final competition. The idea of the testing stage is to put into practice the theoretical findings to see if it works as expected or there are experimental deviations that can be corrected with calibration, or if they need to redesign small parts of it. The testing implies quantitative measurements. In the final presentation, all groups are assessed in a public exhibition open to anyone interested. Each group brings its prototype and undergoes various tests in an area of the university adapted to the statement. Before conducting tests on the prototype, a representative from each group gives a brief presentation of the team and the work to share the entire project process.

The final grade of the subject (Standards 11) is obtained from the partial grades obtained from reports E1 and E2, the oral presentation E3 (all three accounting for a 35% of the final grade) and the performance achieved in the final competition (accounting for a 35% of the final grade). The other 30% of the grade comes from 2 different tests that deal with the theoretical contents of the subject. In the academic year 2022/23 the challenge posed to the students was to design a machine to shoot a tennis ball to a basketball board, configured at a certain height and at different distances. The machine had certain size limitations restrictions, and needs to be manufactured using basic operations, therefore welding, advanced manufacturing, or CNC are not allowed as they will learn all this processes in third year. The energy to throw the ball needs to come from potential energy, that is also limited by the problem statement.

Table 8. Specific example of the BSME methodology.

E1	The problem statement is provided, and students carry out the formalization of the project to understand all aspects required by the task. Additionally, in the report, students are also required to integrate theoretical concepts. They had to provide the expressions of the horizontal and vertical position of the ball as a function of time, along with the trajectory and the initial speed of the ball in relation to the throw angle. Moreover, in this case, they had to calculate the optimal angle for each distance and height to the basketball board. Students are required to code using MATLAB to produce this initial report. Some of the results to this initial stage of the problem appear as an example, in figure 2, as implemented by the professor.

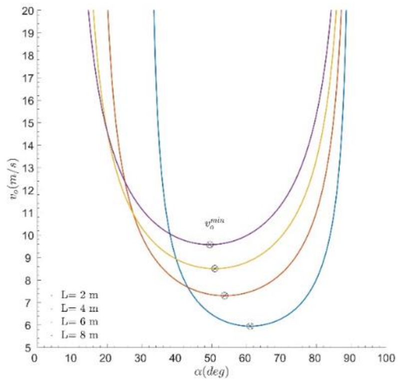
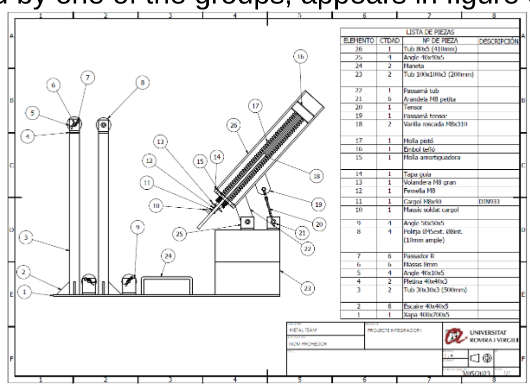
	 $v_0^2 = \frac{gL\cos\beta}{\sin(2\alpha-\beta)-\sin\beta}$ Figure 5. Initial stage of the problem.
E2	In the second problem statement (E2), students define constructive alternatives to implement the solutions found in the previous stage. An example of one of the drawings generated by one of the groups, appears in figure 3 (Standard 3).  Figure 6. Example of one of the drawings generated.
E3	They present the solution to the professors and other groups. Once approved by the professors, students start the manufacturing of the device.
E4	Teams start testing their prototype, measurements were obtained using image analysis of the tennis ball thrown to compute velocity and trajectory. After the testing period, there is the final competition, where students show up the performance of their devices. In the final contest, each team had to perform 5 ball throws, 3 at fixed distances of 8, 6 and 4 m, plus two more of their election, between the three previous distances. The maximum score was only achieved when the ball entered the basket, but lower scores were obtained depending on where the ball touched the basket board, that was divided in a 3x3 array of areas. No score was given in the case of missing the board or the basket. The 5 throws led to an average score that ranked all the teams. An image of one of the teams throwing the ball with their invention appears in figure 4.

	 Figure 7. Final competition.

Methodological Framework for Chemical Engineering (BSQE) and Food Bioprocess Engineering (BSFB) Integrated Projects

The integrated preliminary project of the first year (API1) in Chemical Engineering (BSQE) and Food Bioprocess Engineering (BSFB) is based on the execution and coordination of several organized activities. Figure 5 shows the relationship between these activities and the CDIO fundamentals.

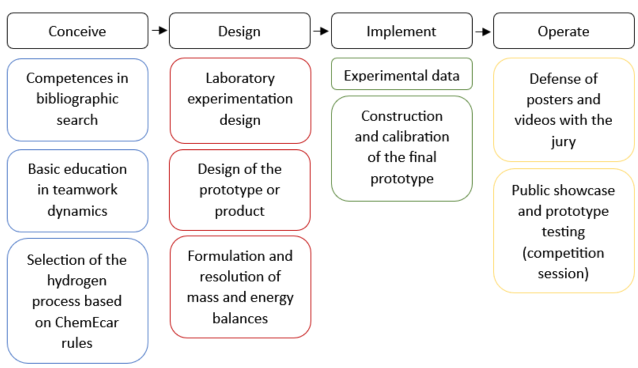


Figure 8. CDIO principles in the activities.

The objective of API1 in every degree is:

- Conceive, design, implement, and operate a vehicle powered by a chemical process (Chem-E-Car, BSQE).
- Conceive, design, implement, and operate an innovative, eco-friendly, and marketable food product (Food Challenge Design, BSFB).

The initial stage involves providing students with all the necessary tools to carry out the project (conceive). An initial training session by the university library staff is scheduled to introduce the use of the digital library of the university, the search engine, and the catalog, as well as a description of the concepts and uses of Manuals, Encyclopedias, Scientific Journals, etc. Moreover, a set of techniques and methodologies is introduced that allow building human teams that are more cohesive and motivated to fulfill their tasks. Under the principles of complementarity and solidarity, the members of a team feel more confident to tackle any project, they feel more satisfied when they work, they achieve their goals more efficiently and with higher quality. Likewise, they must draw up a Team Charter for the team, under the direction and advice of the corresponding leader. Once they have settled the group, teams have to choose the product or groups of products on which the overall API1 will be developed, which must be directly involved in the propulsion of the vehicle or the execution of the food product.

Once the project foundations are set, teams start the design phase. The team plans a simple laboratory experiment that allows characterizing some aspect related to the propulsion of the vehicle or the creation of the food product (Standard 8). This experiment must be chosen and prepared according to the availability of resources in the laboratory and must be planned meticulously under the supervision of the laboratory supervisors. Teams have laboratory sessions (Standard 6) to carry out the scheduled experimentation and at the end, they prepare a report summarizing the results of the laboratory experiments. In order to grasp all theoretical concepts, teams conduct an extensive bibliographic search on the chosen product, covering: a) Its properties, uses, industrial production, and other relevant aspects such as handling or storage conditions (product datasheets) b) Existing or possible production processes, their locations, capacities, and pertinent characteristics. The design of the vehicle or the food product is started as soon as they feel capable of doing so, simultaneously engaging in the tasks described in this phase.

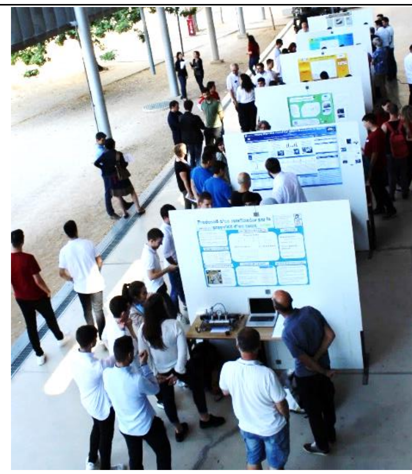
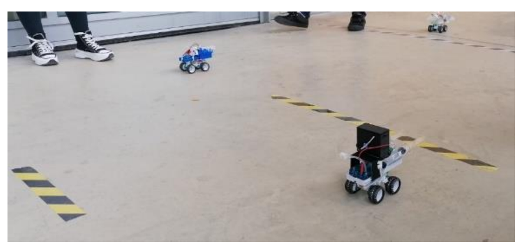
During the implementation phase, the teams develop a graphical description in the form of a block diagram and a report of the selected process. They also formulate and solve the relevant material balances for individual operations and the overall process. The results are presented in the form of a numerical table attached to the block diagram, specifying flow rates and operating conditions for a given calculation basis. Finally, each team plans and executes the construction of a vehicle (BSQE) or the development of a food product (BSFB) according to the specified characteristics and requirements. During this phase, the teams have access to the laboratories. Finally, the team presents a final report, a descriptive video of the construction and configuration of the vehicle or the food product, as well as a poster for the public presentation.

The day of the showcase, the groups give a presentation and publicly defend the results of the report through the display of the poster and video. During the public presentation session, open to all interested parties, all team members are interviewed by the professors, who will provide individual assessments. Additionally, two professional juries examine the presented works and evaluate them, awarding prizes to the best projects in each specialty, BSQE and BSFB. The final grade of the project (Standards 11) is obtained from the partial grades obtained from the different activities (45%) and the final grade from the show case (20%). The remaining 35% corresponds to exams assessing theoretical concepts conducted throughout the course. A specific example is presented, addressing the design and construction of a vehicle powered by hydrogen.

Table 9. Application of the BSQE methodology.

Conceive	Students are organized into teams. Each one is assigned a tutor from among of the degree professors and a leader from the 4th-year students. The car must be based on ChemEcar rules (Chem-E-Car AIChE, 2023), adapted to the conditions of their knowledge level. And a kit with the base of the car is given to the students. The objective is that teams have to produce their own hydrogen to operate the vehicle. The process on which

	the overall API1 is developed is the production of the hydrogen thanks to an electrolysis of an electrochemical path.
Design	The team conduct a laboratory experiment, which is based on the research done of the relationship between the potential of an electrochemical cell and the working temperature. Apart, they have other laboratory sessions where they must achieve specific objectives. The first one is to practice with the proposed chemical method to produce hydrogen and its optimization. Once the chemical part is solved, the teams must be able to obtain hydrogen with the technical requirements to be able to operate the fuel cells, this means that must, at least, be hydrogen 95% in volume. So, they must be able to measure this concentration and design and build a method to achieve it. They have valves, tubes and other standard materials to do it, and the assistance of lab personnel.  Figure 9. Laboratory practices example.
Implement	Each team constructs a vehicle in accordance with the characteristics and requirements defined. They applicate their hydrogen product in the small fuel cells cars that they have to build and operate from the delivered kit (Figure 7). Once the car moves, the teams calibrate it in order to perform the competition with the specified rules. They also approach and resolve a material balance. The evaluation of the activity considers the difficulty of the calculations involved, the solution chosen and phase balances that require the solution of systems of n equations with n unknowns. All activities are in accordance with the skills acquired in the subject of computing in process engineering (Standard 3).  Figure 10. Final prototype of the ChemEcar.
Operate	Finally, they elaborate a poster (size A0) and a video (maximum 2 minutes) describing the API1, with emphasis on the design of the vehicle.

	 Figure 11. Exhibition of the poster and video. Figure 8 shows the final showcase where the groups present their poster and videos. At the end of the presentation, a competition takes place among the cars of each group. The competition is based on a playoff scheme similar to the final ChemEcar event (Chem-E-Car AIChE, 2023). Throughout the various phases, each car must reach different distances. Figure 9 illustrates the final competition.  Figure 12. Competitive car race showcase.

RESULTS

The evaluation of these projects aims to assess the positive impact they have on students' learning experience and the quality of their execution. In this case, the assessment was conducted through a survey, designed to guide questions towards the principles of the CDIO syllabus (Malmqvist et al., 2022). Table 4 shows the 15 questionnaire items administered to students and their relationship with the competencies outlined in the CDIO syllabus. The statements allow students to express their level of agreement, using a scale from 1 to 10, where 1 indicates total disagreement and 10 indicates total agreement.

Table 10. Relationship between the statements and the CDIO syllabus.

CDIO Syllabus 3.0	Statements
1. Fundamental knowledge and reasoning	S1- This project allowed me to put into practice the concepts learned in classes of this or other subjects.
	S2- I had to search and analyze information from different sources to understand the problem and propose a solution.

2. Personal and professional skills and attributes	S3- Working on this project helped me identify the strengths and weaknesses in my technical knowledge.
	S4- I had to manage time and resources effectively to achieve the objectives of the activity.
3. Interpersonal skills: collaboration, teamwork and communication	S5- Defining the roles and responsibilities of team members was essential for the development of the project.
	S6- In this project, I have realized the importance of knowing how to work in a team.
	S7- Through this project, I was able to enhance my oral and written communication skills.
4. Conceiving, designing, implementing and operating systems in the enterprise, societal and environmental context – the innovation process	S8- The fact that the project had a real-life statement helped me realize the impact of my discipline on society and the environment.
	S9- The activities prior to the project helped me acquire the knowledge necessary for carrying out the work.
	S10- The project's design process allowed me to enhance the prototypes from a functional perspective.
	S11- I find it satisfying to see how my idea transforms into a design and, ultimately, into a functional prototype.
Student satisfaction statements	
S12- I tried to participate in this project to the best of my abilities.	
S13- I am confident in applying the skills I have acquired in the future.	
S14- I believe the preparation time for each delivery is sufficient.	
S15- I think the assessment methods (presentation, report writing, prototype creation, etc.) are appropriate.	

The 201 students enrolled on course 2022-23 had an average age of 18 years, with 26% of women. The results shown on Figure 10 are made with the students answers and since the survey was optional, 52 students answered the questionnaire. The results from the sample of 52 answers from a population size of 201 is a low number of responses, but they are statistically significant at a 90% confidence level, with a margin of error of 10%. The proportion of answers of women was similar as the proportion of women enrolled. These responses measure student satisfaction and contribute to the continuous improvement of project quality, enhancing the overall educational experience for everyone involved.

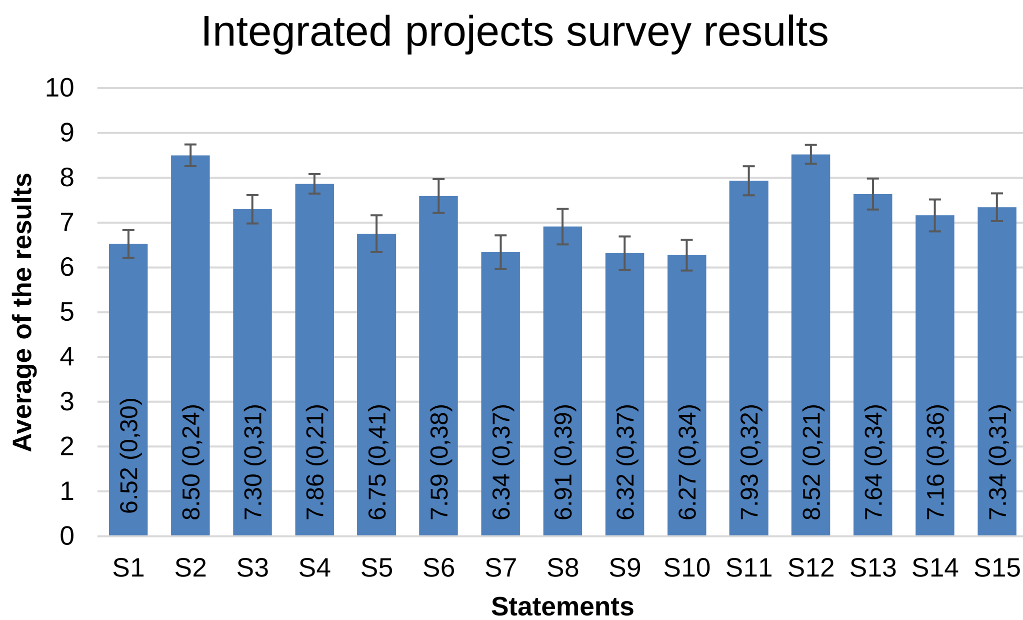


Figure 13. Integrated projects survey results with average of every statement and its standard error (see values between parentheses).

At the end of the assessment, there was an open question where students shared their impressions and experiences, as well as provided recommendations and suggestions for potential improvements. We show an excerpt of the students' opinions regarding the experience: STUDENT A: "I find it very interesting to see how a group of first-year students can undertake such a demanding project." STUDENT B: "It's a very good project for the future employment, but many times, the assignments pile up during the final exams period" STUDENT C: "This project is well implemented and helps understand how engineering projects impact the real world." STUDENT D: "A possible improvement would be to carry out the conceive activities before starting the task that requires this knowledge. Personally, I felt overwhelmed by receiving a lot of information at once. Nevertheless, I consider the sessions necessary and well-planned in terms of content."

Other results and a proof of the motivation that these projects make excel the students is that, in 2017, one of the cars powered by a chemical process won an award in a global competition (URV team, 2017). Additionally, the university is renowned for these public competitions among first-year students. An example is this video (Universitat Rovira i Virgili, 2022) summarizing the achievements during the year 2022, specifically the mechanical engineering project.

CONCLUSIONS

The integrated project results reflect a generally positive evaluation of the CDIO educational program's impact on the students' learning experience, which demonstrates the benefits of the integration of the CDIO syllabus into their educational experience. The survey results suggest that the program has been particularly effective in areas related to teamwork and communication (Statements S5 to S7), as well as the practical application of learned concepts (Statements S1, S8, S10, S11). This aligns with the principles of the CDIO initiative, which seeks to combine theory with practical application, thereby enhancing the development of both technical and interpersonal skills. However, opportunities for improvement have been identified through student feedback. For instance, one student suggested spacing out pre-work activities to prevent information overload, which could improve knowledge retention and practical application. Another student pointed out the challenge of balancing project workload with final exam preparation, suggesting the need for better scheduling or additional support during exam periods. So, improving these aspects could contribute to a more effective and satisfying educational journey for all program participants.

The limitations of this work are related to the specific disciplines studied, and our findings may not be directly applicable to other engineering disciplines or educational contexts. Another limitation is that while this methodology has been applied for more than 10 years, the assessment through student surveys has only been implemented in the 2022-23 academic year and the survey was completed by 26% of the enrolled students. Results from surveys conducted over multiple years would help to confirm the findings.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

The authors would like to thank the funding from the School of Chemical Engineering (ETSEQ) from Universitat Rovira i Virgili.

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BIOGRAPHICAL INFORMATION

Albert Fabregat Sanjuan is Assistant Professor in the Mechanical Engineering Department at the Universitat Rovira i Virgili (URV). He holds a MSc degree in Industrial Engineering (2005) and Phd in Mechanical Engineering (2015). He mainly researches about materials characterization and about medical technologies for clinical neurophysiology. As a leader and active member of several education innovation projects, his particular interest focuses on implementing innovative methods of teaching. He has been awarded for the quality of his teaching methods in the collective (2015) and individual (2018) category from the URV Social Council.

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Ricard Garcia Valls is Professor at Universitat Rovira i Virgili (URV) since 1998. PhD in Chemistry from the Autonomous University of Barcelona (1995), he was a researcher at the Chemical Engineering department of the Massachusetts Institute of Technology (1996-1998). At the moment, its main lines of research and innovation focus on fuel cells, decarbonization, nanoencapsulation for applications in cancer, and green hydrogen. From the teaching activities he has been the responsible for the open projects' activities during many years and the person who started the open laboratory in first year of the Chemical engineering degrees.

Montse Ferrando is Associate Professor in Food Technology at the Chemical Engineering Department, Universitat Rovira i Virgili. Her doctoral training was obtained at the Federal Research Centre for Nutrition in Karlsruhe (Germany) and she was a postdoctoral fellow at the Helmholz Institute for Biomedical Engineering at RWTH Aachen University in Germany (2002). Her research focuses on designing innovative encapsulation systems for food applications and valorization of agri-food byproducts with green technologies.

Xavier Farriol is Full Professor in the Chemical Engineering Department at URV. He has more than 40 years' experience of education development. His research and development interests are in vegetal biopolymers, innovation in lignocellulosic derivatives, and thermal valorisation of residual lignocellulosics.

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Ioanis Katakis is Associate (since 1997) and Distinguished (since 2017) professor of Chemical Engineering at the Universitat Rovira i Virgili. M.Eng and PhD from University of Texas at Austin, 1992 and 1994. In 2000 he worked in Bayer Diagnostics (Elkhart, IN) developing minimally invasive glucose sensors. In URV he was director of DINAMIC technology innovation centre (2001-10) and served as director of the Chemical Engineering graduate programme (2001-04) and of the Department of Chemical Engineering (2004-12). His research interests center in the fields of Bioelectrochemistry and Bioengineering. He has led the creation of two technological companies and has received awards for his innovation activities.

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