CDIO-INFUSED SERVICE LEARNING: MANUFACTURING PROJECTS FOR SOCIETAL IMPACT THROUGH COLLABORATIVE PROJECTS

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ABSTRACT

This work explores the integration of the CDIO framework within a third-year Mechanical Engineering course focused on manufacturing, with a focus on service learning. University students collaborate with peers from vocational schools to optimize manufacturing processes and materials selection, delivering impactful projects to social entities. The service learning component enhances the practical application of CDIO principles, emphasizing the societal impact of engineering solutions. The third-year Mechanical Engineering curriculum at Universitat Rovira Virgili introduces a distinctive approach by integrating CDIO principles with service learning. The projects, designed with a focus on service learning, culminate in the delivery of tangible solutions to social entities. In this combination of CDIO principles and service learning, the third-year Mechanical Engineering course becomes a crucible for transformative education. Graduates emerge not only with technical proficiency but with a heightened sense of social responsibility, teamwork, and adaptability, which are essential attributes for success in engineering with a societal impact. The vocational school students have the first contact with the university and motivate them to excel in the manufacture of the projects that are delivered to social entities. The projects stand as tangible proof of the CDIO-infused service learning journey, illustrating the potential of engineering to create positive change in communities.

KEYWORDS

Service Learning, Vocational School, Mechanical Engineering, Manufacturing; Standards: 1, 3, 6, 8, 11.

INTRODUCTION

The integration of service learning in the project aligns with the CDIO initiative by providing students with a holistic engineering education. Service-learning is a pedagogical approach that has gained prominence in various academic disciplines and institutions (Salam et al., 2019). It entails the integration of academic coursework with community service, emphasizing key elements such as reciprocity, reflection, and addressing community-expressed needs. Compared to other interactive and experiential-based learning approaches, such as project-based learning or problem-based learning, service learning stands out for its direct engagement with community issues and its integration of service as a core component of the educational experience. While project-based learning often revolves around completing a project to demonstrate mastery of academic content, and problem-based learning centers on solving complex problems, service learning goes a step further by emphasizing the importance of social responsibility and civic engagement. This concept provides students with the opportunity to apply their knowledge to real-world social issues (Tsang et al., 2001). In doing so, students acquire crucial skills, such as the ability to work in multidisciplinary teams, understand ethical and professional responsibilities, communicate effectively, and have a comprehensive education that enables them to grasp the impact of engineering solutions on a global and societal level (J. Duffy et al., 2000). CDIO principles emphasize the importance of conceiving, designing, implementing, and operating real-world systems, and the service-learning aspect of this project allows students to apply these principles to address community needs (Cea et al., 2014; Díaz Lantada et al., 2019). Furthermore, the students, in this case, can choose the project topic, so this presents an opportunity to analyze and identify ways they can create solutions that benefit the community.

This project not only stands out for the implementation of service learning but is also made possible through collaboration with several vocational training schools. The university handles the project's conceptualization, while the construction phase takes place in the vocational training school. Nevertheless, throughout each phase, both entities remain in contact. During the construction phase, the vocational training school assists the university students in ensuring the prototype is feasible for construction. Similarly, during the construction phase, vocational training schools maintain communication with the university to address any queries regarding the construction procedures. Every project is assigned to a specific training vocational school, this involves adapting the project to the machinery available in that place. This approach not only enhances pedagogy but also facilitates the coordinated construction of a technical environment, fostering the exchange of facilities and knowledge. Students are challenged to adapt and closely collaborate with the vocational school, providing a multidisciplinary approach to the project and significantly contributes to higher quality in the execution of future projects (Zeman & Hrad, 2014). Upon completing the project, students have gone through the various phases involved in a project. Furthermore, as it involves a final physical construction, students can appreciate how their prototype benefits society.

The emphasis on multidisciplinary teamwork, ethical responsibility, and effective communication, as highlighted by CDIO, is evident in the collaborative nature of the project involving both university and vocational school students (Thomson, 2019). The students' active involvement in selecting and analysing real-world problems mirrors CDIO's focus on preparing graduates to engage with contemporary issues and work on solutions that have a positive impact on society (Basso et al., 2020). The paper's aim is to explore the integration of SL and CDIO frameworks in engineering education to enhance the societal impact of engineering solutions and how the students perceive the benefits of this integration in their academic training and the collaboration with external organizations. The pedagogical approach based on CDIO allows to improve the connection between the university and vocational training schools so that university students can perform tasks very similar to real ones they will encounter when working, since the designs created are validated for manufacturing, unlike other subjects where tasks are not validated in a real environment.

This project is part of the subject "Manufacturing" of 3 ECTS, but it is also related with the subject “Manufacturing Laboratory” of 3 ECTS, which help students to better understand the limitations of the manufacturing processes for the projects. These subjects are carried out during the third academic year of mechanical engineering degree at Universitat Rovira i Virgili, Catalonia, Spain. It's worth noting that these subjects integrate both theoretical content and the practical execution of the project in a coordinated manner. The project has a 30% weight in the subject assessment and specific sessions (minimum of 3) to review and support the projects are carried out. This project has been developed since the academic year 2017-2018, and this proceeding examines the impact and evaluation that students have had since that year.

METHODOLOGY

The two subjects that contribute to this project are distributed over a term of 15 weeks (7 h/week), with 4 hours allocated for theoretical lectures and 3 hours for laboratory activities. In the theoretical developments, all students are in the same group in the lecture room with the professor, whilst in the laboratory activities, students are divided into smaller groups. The theoretical presentations explain the key concepts for manufacturing pieces such as: manufacturing processes for parts, geometric verification of parts, treatment of tolerances and fits, identifying machines, tools, fixtures, and elements; calculation issues related to different forming processes, programming in numerical control and welding processes. At the same time, in the laboratory, practical exercises related to each concept explained in the theoretical part are carried out. This allows students to apply theory in practical laboratory scenarios, thereby promoting active learning (Standard 8).

The project grade accounts for 30% of the total grade in the Manufacturing subject. This score is determined using a rubric that assesses various aspects of the written work (Standard 11). The rubric primarily focuses on the quality of the project's content, as well as aspects such as research, organization, references, among others.

So, the subjects provide all the necessary concepts to implement the main project, which involves the conception, design, implementation, and operation (CDIO) of a device to address a societal need. The project evolution can be broken down by following the principles of the CDIO philosophy (Goh et al., 2023). The following diagram illustrates how each of these principles can be linked to different project phases.

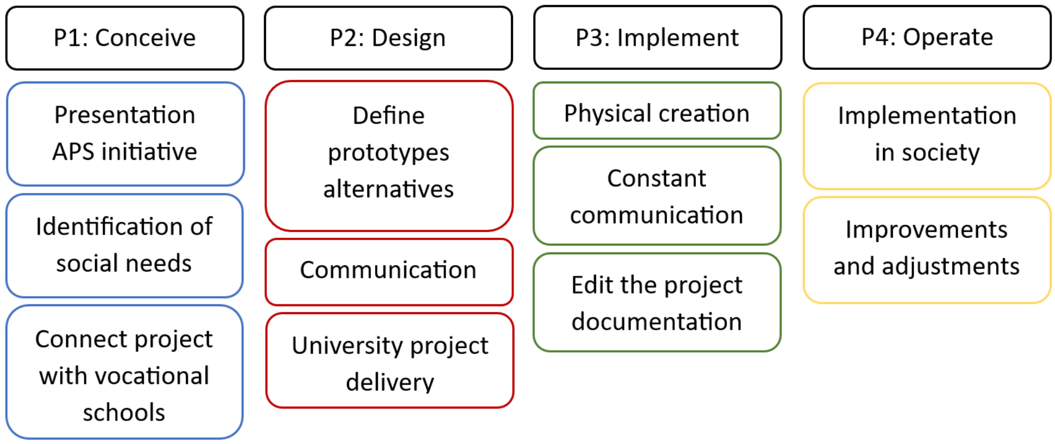

Figure 14. CDIO principles in the execution phases.

During the first phase of the project (conceive), the concept of Service-Learning (SL) is introduced. The premise is to develop a project with the goal of building something that contributes significantly to society and can be manufactured by a vocational training school. Students are assigned the task of analyzing societal needs to identify an issue that can be resolved collaboratively (Standard 1). Given the scale of the project, groups of 7-8 students are formed. During the initial weeks, groups are tasked with determining the theme of their project and appointing a representative, crucial for efficient organization due to the project's magnitude. Once the theme is chosen, the representative presents it in a class forum, providing a brief summary of the project. At this stage, the teacher reviews the proposal and gives approval once the project is correctly defined and could be manufactured with the skills and equipment from vocational schools. Subsequently, the teacher associates each project with a specific vocational training school, considering the various machinery and resources available at each school. The evaluation is based on the alignment of vocational school resources with the specific needs of each project. With the teacher's approval, students can start the project execution.

The second phase, led by university students, focuses on the design. Each group develops various prototypes that are subsequently sent to the corresponding vocational school. Therefore, an evaluation is conducted to facilitate the selection of the optimal prototype for manufacturing. Following this choice, the group proceeds to address all aspects of the project. The project involves the creation of a three-dimensional design for the graphic representation of the equipment. This model serves as the foundation for the development of manufacturing drawings. Each group adapts the manufacturing methods of the components to the capabilities of the machines available at their vocational training school. To guide the manufacturing process, specific details are provided, such as the initial material, manufacturing drawing, and the manufacturing procedure guide. Additionally, manufacturing time calculations are carried out to apply the concepts taught during the course (Standard 3). Once this part is completed, university group present the memory of the project and a video presentation.

Vocational school starts the implementation phase of the project. Initially, they conduct a comprehensive evaluation of the project, normalizing many of the components to optimize them for workshop manufacturing processes. During this stage, they make necessary adjustments, including redrawing certain aspects to align with the capabilities of their machinery (Standard 6), ensuring better applicability to the workshop fabrication process. Throughout this implementation process, there is constant communication established between vocational school students and university students. This ongoing collaboration allows for the exchange of recommendations and the prompt resolution of any challenges that may arise. As vocational school students progressively construct the physical prototype, university students remain actively, they continuously edit the project documentation, marking and documenting the changes made during the implementation phase. This iterative feedback loop ensures that the evolving needs and adaptations on the vocational training school side are accurately reflected in the project documentation, promoting a seamless integration of efforts between the two educational institutions.

During the final phase of the project, the Operate stage, the constructed prototype becomes a tangible reality. The prototype is tested in the specific societal context it aims to assist. Both the university and vocational school components actively participate in this phase to ensure the functionality of the machine and address any technical issues that may arise. This operational testing phase serves as a crucial step to validate the practical application of the project and its potential impact on society. It provides an opportunity to identify and resolve any unforeseen challenges or errors that may have emerged during the construction and implementation stages. In cases where improvements or refinements are identified during the operational phase, these insights are documented. The findings, along with suggested enhancements, are then presented as a project for the following academic year. This creates a dynamic and multidisciplinary initiative, fostering collaboration among students within the same degree or training cycle. The continuous cycle of improvement ensures that each iteration of the project builds upon the experiences and lessons learned from the previous one, contributing to an ongoing and evolving educational endeavor.

A specific example is presented, addressing the design and construction of an innovative machine designed for the collection of microplastics—an environmentally pressing issue. Throughout the detailed phases in the methodology, from the formalization of the project to the final operation, this example serves as a practical illustration of how theory translates into a concrete solution with a direct impact on society.

Table 11. Specific example of the methodology.

P1: Conceive	The group decides to develop a machine for filtering microplastics of the sand. The decision to undertake this project is because of an issue on the beaches of Tarragona related to the abundance of microplastics, specifically plastic pellets. Although the beaches are cleaned with large machines that collect waste, this type of plastic is too small to be filtered by this equipment. Therefore, the removal of these plastics is done manually with strainer. The goal of the machine is to streamline and automate the process of filtering plastic pellets, providing a more effective and efficient solution. After the topic was chosen, the summary was posted on the class forum, and the proposal was accepted by the teacher. To carry out the project, a collaboration was established with the "El Palau" vocational training school, considering that it had all the necessary tools to implement this machine.
P2: Design	The design phase begins, and various prototypes are proposed to the vocational school to assess their functionality and construction. Figure 2 shows different prototypes.

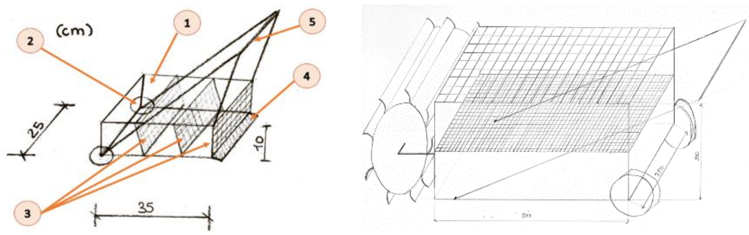

Figure 15. Prototypes of the machine for filtering microplastics

Once they have the final prototype, students begin the part design and 3D construction phase.
For each component, it was developed the manufacturing drawing, identified the required machining equipment, and created the process sheets.

Operation Nº	Equipment	Sketch	Machined length (mm)	Feed (mm)	Feed rate (mm/min)	RPM	Vc (m/min)	Time (min)	Observations
11	Lathe		30	2	0,2	1400	80	0,22	Rough-turn (for attaching the foot support with bearing)
12	Lathe		30	1	0,1	1900	96	0,16	Finished-turn (for attaching the foot support with bearing)
~~13~~	~~Lathe~~		~~64~~	~~1~~	~~0,2~~	~~1300~~	~~80~~	~~0,25~~	~~Rough-turn (for setting the grindstone)~~

Figure 16. Example and corrections on a process sheet.

Figure 3 illustrates an example of the process sheets for one of the pieces, with the vocational school's correction indicating that step number 13 is not necessary.

P3: Implement

Once the prototype is available, the vocational training school initiates the construction phase using the lathe, milling machine, and band saw. Students possess the necessary skills to carry out these operations and adjusted the drawings (Figure 4) for a more efficient construction. Throughout the process, unforeseen challenges emerged, leading to modifications in various parts. University and vocational training students work together to solve the problems.

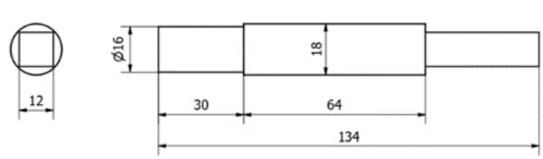

Figure 17. Drawing adjustment.

P4: Operate

Once the machine is constructed (Figure 5), it was taken to the beach "Platja Llarga", in Tarragona to verify its functionality. Different

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<td>students with a representative from the university group and another from the social entity that promoted the prototype went to the location to implement the machine. Local television covered the trial, and this video (CCMA, 2023) showcases the events that took place on that day. Multiple news articles (Riu, N., 2023) (Diari de Tarragona, 2022) have been published regarding the implementation of this machine.

During the beach trial, some deficiencies in the machine were identified. For instance, it only filtered dry sand, not wet sand; the wheels did not rotate or move correctly in the sand, and only a small amount of sand was filtered at a time, among other observations. All aspects requiring improvement were compiled and presented this year as a Service-Learning project to students currently enrolled in the course.

Figure 18. Final prototype built</td>
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Below, additional examples of projects are presented:

Figure 6. Knee rehabilitation equipment

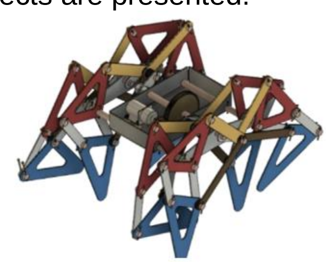

Figure 7. Walking robot.

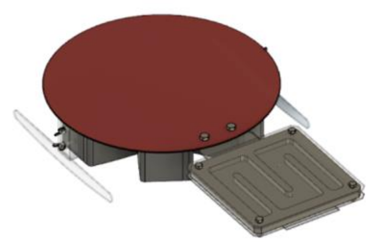

Figure 8. Bosu for people with disabilities

RESULTS

To carry out an assessment of the project, a survey was implemented with the aim of gathering students' perceptions. The three main objectives of the survey were as follows:

- Understand students' perception of the tasks carried out.
- Understand students' perception of their relationship with the faculty and the vocational school.
- Understand students' overall assessment of the Service-Learning experience (SL).

The survey comprised six questions, where participants were required to assign scores ranging from 1 to 10, with 1 indicating completely disagree and 10 indicating completely agree. Additionally, a general assessment question was included, rated on a scale from 1 to 10. Below, detailed results derived from this assessment since 2017 are presented in Figure 9, Table 2 and 3.

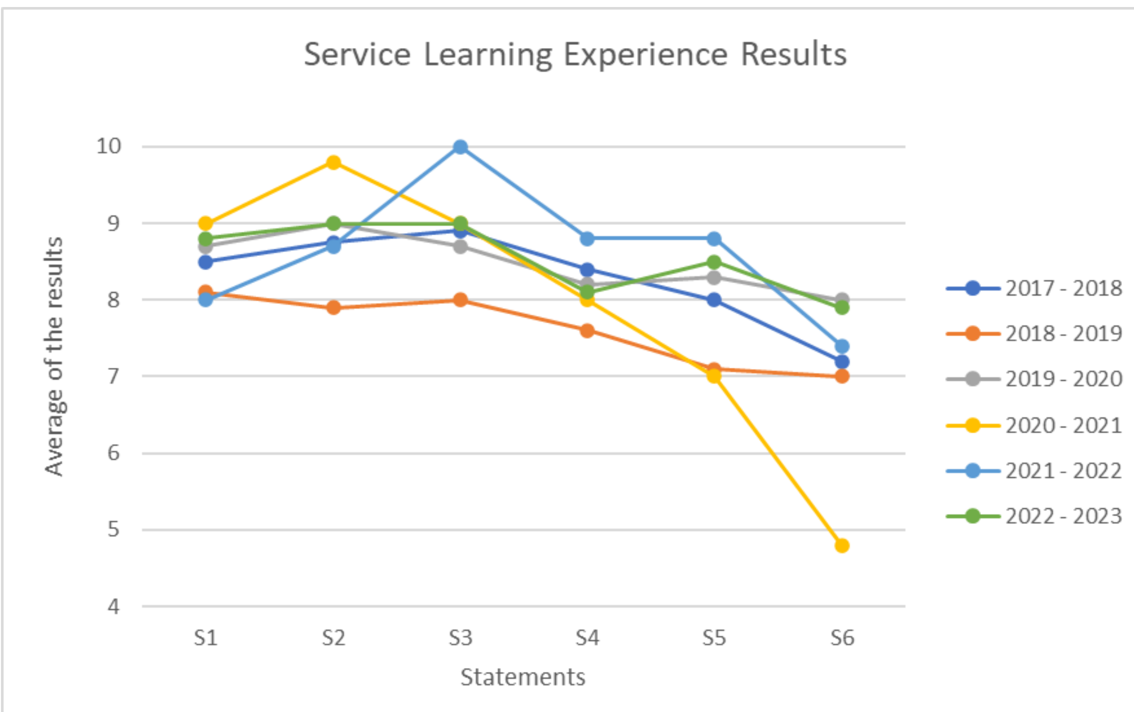

Figure 19. Results of the survey since 2017.

Where:

Table 12. Survey statements.

S1	I have carried out the proposed tasks.
S2	The performed tasks have had a direct relationship with my academic training.
S3	I have put into practice the knowledge acquired previously at the University.
S4	The SL experience has been a formative complement.
S5	I have received information, guidance, and support from the university faculty.
S6	I have received supervision and support from the external organization in the development of tasks.

Finally, table 3 shows the average of the general assessment question with its standard deviation values:

Table 13. Results of the general qualification.

Year	Average general qualification	Standard deviation
2017 - 2018	7,51	1,58
2018 - 2019	7	2,58
2019 - 2020	7,86	2,57
2020 - 2021	7,67	2,07
2021 - 2022	7,5	0,71
2022 - 2023	7,85	0,99

Given that the implementation of Service Learning in the project is a new concept, students conducted a reflection on SL in which they shared their impressions and experiences, as well as provided recommendations and suggestions for potential improvements. Below is shown an excerpt of the students' opinion regarding the experience:

GROUP A: "To conclude, we will say that we feel very proud to have carried out this great work. We have worked hard to achieve a good final grade on the project, but beyond that, we feel satisfied with the service we have provided to the community. We hope that one day the construction of this saw at El Palau vocational school becomes a reality, and above all, that it proves to be truly useful for those who will have to use it."

GROUP B: "This experience has led the members of the group to grow both professionally and personally. It has opened many doors by demonstrating that achieving a successful project not only allows for manufacturing, but the simple act of social commitment is a significant step towards achieving socially responsible professional development."

GRUP C: “The time required to complete the projects I consider fair, but I believe that to produce a high-quality project, perhaps a longer timeframe should be included. It could be done over two semesters. I find it to be an interesting project as it simulates the actual work of an engineer.”

GRUP D: “Up until now, many of the assignments we have undertaken for university or other studies had little utility for society; they were more about earning a grade than making a meaningful impact. That's why we believe Service-Learning (APS) is a good way to promote education, as it ensures that the work being done will have a lasting impact and contribute to helping someone."

GROUP E: "… we have gained insight into all the machines and equipment in the vocational school's facilities. This allows us to carry out and plan machining processes that are suitable for the available resources, ensuring the proper manufacturing of the projects. Having a dedicated section on Moodle (the URV's e-Learning platform) with subsections for each working group has been an innovative and effective idea. It has enhanced communication among ourselves and the students at the vocational school. However, we acknowledge that we could have utilized this efficient APS system more effectively. Looking ahead to future projects in our program, we will undoubtedly take this into account and leverage it more extensively."

CONCLUSIONS

The analysis of the service learning experience (survey data and student feedback) indicates that students have positively rated their experiences with SL projects. The survey results show a general trend of students agreeing that they have carried out the proposed tasks (S1), found a direct relationship between these tasks and their academic training (S2), applied knowledge acquired from the university (S3), and viewed the SL experience as a formative complement (S4). However, it is important to highlight that the scores for faculty support (S5) and external organization support (S6) have consistently been the lowest throughout the years. Highlighting the year 2020-2021, this result could be due to the COVID-19 pandemic, which affected communication between teams and the external organization.
This less favorable trend regarding communication between students and entities has been a constant focus of improvement each year. To enhance this communication some strategies have been implemented, such as facilitating open and structured feedback channels, and encouraging active participation from both parties in project planning and execution. These measures would not only strengthen collaboration but also contribute to a more efficient and enriching process for all parties involved.

The average general qualification has fluctuated over the years, with a peak in 2019 – 2020. The overall trend indicates a generally positive performance, with the majority of years reflecting averages above 7. This suggests a consistent level of academic achievement. However, it's noteworthy that the participation of students in the satisfaction survey is low. To improve participation, we try to implement strategies such as incentivizing responses emphasizing the significance of feedback in enhancing educational experiences. Enhancing the survey administration process can contribute to a more accurate understanding of student satisfaction and facilitate targeted improvements in the academic environment.

The qualitative feedback from the groups (A, B, C, and D) reveals that students have found value in the SL projects beyond academic achievement, expressing pride in their community service, personal and professional growth, the utility of their work for society, and a desire to see their projects implemented and used in the real world. In conclusion, students' reflections reveal a deeper appreciation for the practical application of their studies, the social impact of their work, and the collaborative process of learning. It will be beneficial for the university to continue fostering these opportunities and perhaps focus on enhancing the aspects of communication and project management to further improve the student experience.

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