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DRIVING INNOVATION IN ENGINEERING THROUGH INTERNATIONAL EXPERIENTIAL LEARNING PROJECTS

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Abstract: *This paper introduces the Cases for Experiential Learning (CEL) Project, a new framework that engages international, cross-disciplinary teams of engineering students in solving real-world research and industry challenges. The framework combines intensive work sessions, brainstorming activities, reflective discussions on results, virtual collaboration, and a final defense. The proposed activities aim to support both the consolidation of students' theoretical knowledge and the creation of innovative solutions. As a case example, the paper details the CEL project organized at the Technical University of Cluj-Napoca (TUCN) during the 2024 spring semester. The topic of the project challenged students to design a novel robotic gantry system. The students' proposed concepts are presented and analyzed. The results highlight the originality of the proposed solutions and the framework's potential to foster creativity and interdisciplinary innovation in engineering education.*

Key words: *innovative robotics, robotic gantry system design, experiential learning, international collaborative projects.*

1. INTRODUCTION

Project-based learning plays an important role in engineering education, enabling students to enhance their competencies by engaging them in relevant topics that apply previously learned theoretical concepts [1]. Often, these topics focus on real-world challenges and facilitate student integration within multidisciplinary teams [2]. The effectiveness of this approach can be further improved if students are also guided to reflect on the process and results in addition to the practical activity [3][4]. The concept is defined as experiential learning, and it was initially addressed by Dewey [5] and later expanded by Kolb [6]. They emphasized the strong connection between knowledge and direct experience, rather than relying on memorization. It is a cyclical process where students engage hands-on, critically reflect on their actions, interpret insights theoretically, and reapply them through experimentation in real-world contexts [6].

In the last decades, the concept of experiential learning has been increasingly integrated into engineering project-based activities, yielding good pedagogical results [4][7]. Cocota et al. [8] presented a project as part of a robotics course where undergraduate students in automation, control, and mechanical engineering worked in teams to design and build a low-cost six-degree-of-freedom manipulator. The project lasted for one semester and applied theoretical concepts in a hands-on setting. According to the authors, the activity enhanced students' understanding of robotics theory while improving motivation and reducing dropout rates.

Habib et al. in [9] presented the development of projects for final-year engineering students that engaged them in hands-on mechatronics activities. These activities included the design and control of robotic arms with integrated sensors and actuators. Their findings showed that the approach not only strengthened technical knowledge but also stimulated higher-order thinking, with students delivering original solutions and design improvements beyond the baseline project requirements.

Previous research highlighted that combining experiential learning with project-based tasks

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encourages teamwork and idea generation, sometimes leading to innovative design solutions. However, many of the studies examined local implementations, with relatively few studies investigating the potential advantages of implementing international and interdisciplinary approaches.

In this context, this paper introduces a new project framework entitled Cases for Experiential Learning (CEL) Project. The proposed framework brings together international students from multiple engineering programs to work in mixed teams to solve research or industry challenges. Conducted over the course of a semester, the activity combines intensive work sessions, reflective discussions on results, virtual collaboration, and a final project defense. By applying the proposed framework and receiving proper guidance from the supervisors, the project results can emphasize novelties in the respective fields.

As a case example, the paper details the CEL project organized by the TUCN during the 2024 spring semester. The project topic focused on the design of a novel robotic gantry system. The results analysis emphasizes the originality of the students' solutions and the framework's potential to support creativity and cross-disciplinary innovation.

The remainder of the paper comprises the following chapters: Chapter 2 introduces the project topic and design constraints; Chapter 3 presents the students' results; and Chapter 4 discusses the outcomes along with feedback from students and supervisors. Finally, the paper concludes with a summary of findings.

2. TUCN CEL Project

The CEL project framework is based on several models developed as part of different European funding projects [10-12]. The topics were initially proposed by companies. This approach exposes students to real-world engineering problems from companies, preparing them better for a career in engineering. This purpose was further extended within the CEL Project framework by adding research topics to support students who want to pursue a research or academic career.

As part of the NextGEng initiative, a total of 6 CEL projects were developed. Furthermore, the project developed by TUCN during the spring 2024 semester is presented.

2.1 TUCN CEL Project topic

The topic was proposed by the Applied Mechatronics Research Laboratory (AMRL) research group from TUCN and focused on the design of a 3-axis gantry robot (Figure 1) with all actuators mounted on the fixed frame. The aim was to create a lightweight structure that facilitates high dynamics.

The topic of the project follows the recent trends in industrial and service robotics, highlighting the growing demand for lightweight, high-speed, and energy-efficient manipulators [13][14]. Mounting all actuators on the fixed frame lowers the moving mass and improves the achievable accelerations, but at the same time, it challenges the designer (in this case, the participant students) to identify proper transmission solutions resulting in a system with more complex kinematics and system control.

To guide students in the design process of the robot, a set of requirements was imposed:

- the robotic system must comply with the kinematic specifications from Fig. 1;
- the carriages' displacement along axes (X, Y, Z) is performed using motors mounted on the fixed base of the robot, respectively, through transmission components (elements) from the motors to the sliders (moving platforms);
- the transmission elements can be of any type (mechanical or non-mechanical): tooth belt, ball/lead screws, pinion with rack, cables (wires), pneumatic, hydraulic, magnetic, electric, etc.;
- robot workspace (X, Y, Z): 200 x 300 x 120 mm^3;

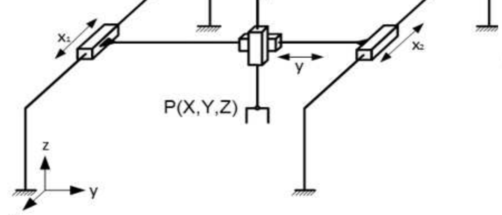


Fig. 1. Schematic of a gantry robot

- the gripper is mounted on the Z-axis and can manipulate cylindrical workpieces (Ø30 mm x 30 mm height, 50 g mass).

2.2 Project implementation

The CEL project implementation consists of four consecutive phases, as depicted in Figure 2. The preparation of the project started during the 2023 autumn semester and focused on identifying potential topics from research groups and partner companies. From this list, the most suitable one was selected. The selection process took into account the profiles and competencies of the potential students, the complexity of the topic, and the feasibility of being implemented in the project's proposed format.

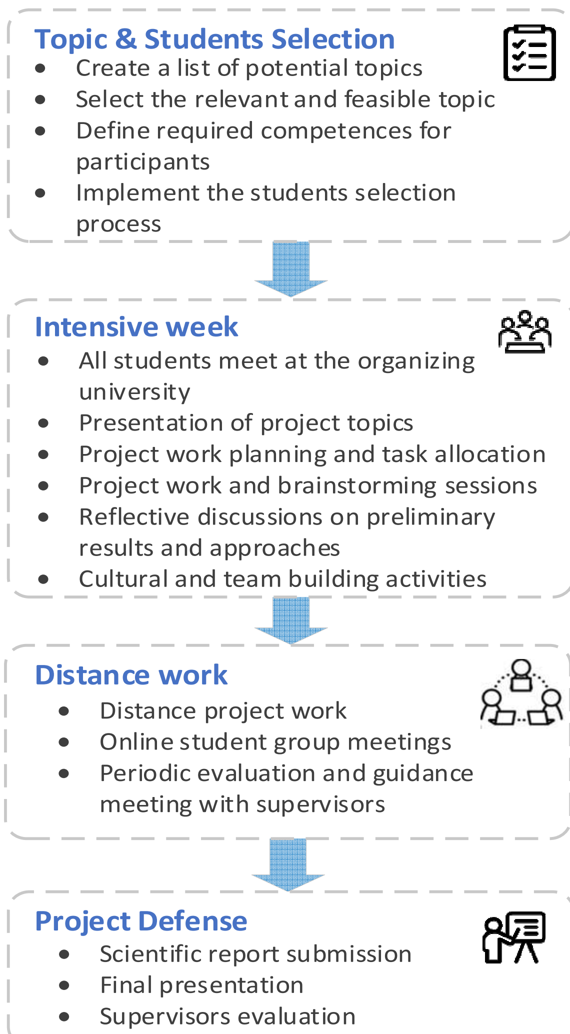


Fig.2. CEL Project implementation phases

Next, students were selected from each participating university: the Technical University of Cluj-Napoca (Romania), the JAMK University of Applied Sciences (Finland), and University of Jaén (Spain). The project was promoted to students from the specializations of mechatronics, mechanical engineering, electronics, and automation. The project involved 18 students, organized into three groups of six, each comprising students from every participating university. This setup supported strong multidisciplinary collaboration among the participants.

The intensive week started on 12 February with participant registration and a welcome session at TUCN. The agenda for the intensive week included:

- presentation of the project topic and the main goals that are expected to be achieved;
- a tailored course was given with the topic: Modeling mechatronic systems using Matlab/Simscape Toolbox;
- students attended six project work sessions where they defined roles, developed and assessed concepts, selected a final solution, planned tasks, built an initial virtual model, and prepared the oral presentation for the end of the intensive week;
- each day included a discussion session with the supervisors, where students' activities were analyzed, and they were encouraged to reflect on their outcomes as part of the experiential learning process.

The intensive week concluded with presentations from the three groups detailing to the supervisors and the TUCN research group representative the virtual work planning and a draft of a potential solution to the project.

During the distance work phase, student groups conducted regular meetings to coordinate their tasks. In this period, two virtual meetings were held with the supervisors and the research group representative to ensure guidance and feedback.

During the intensive week, a social event was organized that integrated cultural activities and aimed to strengthen the collaboration between the participating students and supervisors.

2.3 Evaluation Criteria

The evaluation criteria were communicated to the students at the beginning of the project, with a maximum total score of 100 points. The first criterion (C1, 20 points) assessed the number of motors used in the proposed concept, starting from the minimum of three required for the degrees of freedom, with any additional motors reducing the score. The second criterion (C2, 30 points) penalized the use of mobile motors not fixed to the frame, subtracting 10 points for each such motor due to their negative impact on the robot's dynamics. The third criterion (C3, 20 points) considered the number of main transmission elements—such as belts, screws, racks, or cables—where a minimum of one was required, and higher counts led to lower scores. Finally, the fourth criterion (C4, 30 points) involved a qualitative assessment carried out by supervisors from the three universities, who evaluated each team's solution in terms of its advantages, limitations, and overall novelty compared to conventional systems.

3. STUDENTS' RESULTS

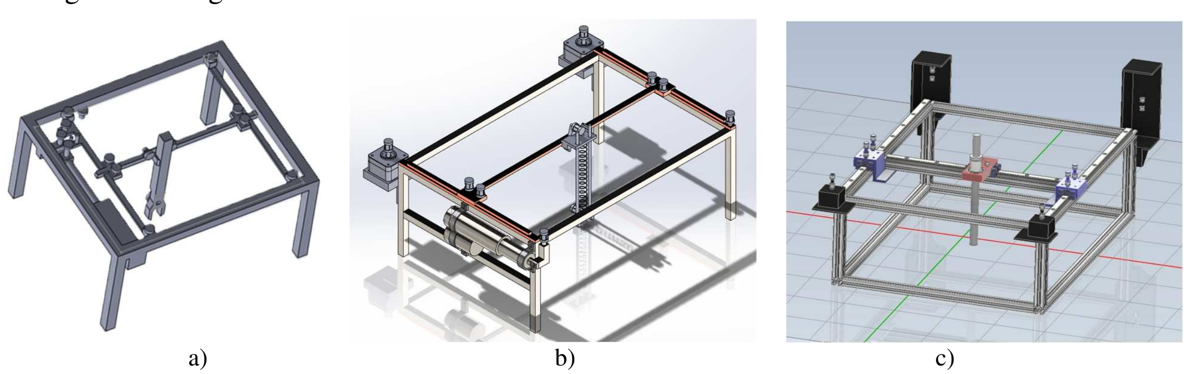
Each student group delivered a scientific report detailing their activity and the proposed concepts for the robot's structure. A summary of their results is presented below.

Group A proposed a three-axis gantry robot that combines an H-shaped belt-driven mechanism (H-bot) for motion along the X and Y axes with a piston-based system for vertical displacement (Fig. 3.a). The Z-axis is actuated by a piston that modifies the belt position, indirectly driving the gripper along a linear rail. A preloaded spring was integrated into the gripper structure to ensure constant belt tension. The design incorporates three actuators, all of which are fixed to the robot frame, thereby reducing the moving mass.

The team analyzed the robot's kinematics and created a virtual model in SolidWorks, which was exported to Simscape Multibody. A simplified version of the model operated correctly, however, the more detailed configuration with pulleys and belts encountered implementation issues and did not yeld complete simulation results. Further work is needed to refine the constraints and validate the full model through functional simulations.

Group B designed and developed a three-axis gantry robotic system that integrates a standard H-bot setup with an innovative spring-assisted transmission mechanism for the vertical axis (Fig. 3.b). The system incorporates three actuators, all of which are mounted on the fixed frame, ensuring a compact and lightweight moving structure. For the Z-axis, the team implemented a ball-chain transmission coupled with a central spring element. In this configuration, the piston compresses the spring during upward motion, storing potential energy that assists the return movement and ensures the gripper's vertical displacement. The kinematic behavior of the system was analyzed and modeled, and the feasibility of the proposed concept was validated through simulations performed in MATLAB/Simscape.

Group C proposed a robotic concept that uses three fixed motors and two belt transmissions arranged on two levels (Fig. 3.c). The first transmission is responsible for planar motion along the X and Y axes, adopting an H-bot configuration to optimize efficiency and minimize component count. The second transmission is dedicated to vertical movement along the Z axis. During operation, the movement of the two belts is synchronized.



a) b) c)

Fig.3. CAD model of the proposed robot a) Group A concept b) Group B concept c) Group C concept

The team presented the kinematics of the system and the model implemented in Matlab/Simscape for simulation.

4. DISCUSSIONS AND FEEDBACK

The evaluation of the students' results was done by the supervisors and research team representatives using the criteria presented in Section 2.3. All three international teams' proposals used a planar H-bot setup for the motion along the X and Y axes, but applied different transmission strategies to implement the Z-axis. Group A combined the H-bot setup with a piston-based vertical displacement system. However, their simulations were incomplete, leading to a final evaluation score of 85.7 points. Group B introduced a spring-assisted ball-chain transmission for the Z-axis, and achieved the highest score among the teams with 98.8 points. Group C implemented a dual-level belt-driven transmission to realize vertical motion, reaching a final score of 85.8 points.

Two feedback rounds were organized after the intensive week and after the end of the CEL project. The feedback was collected from all participants: teachers, researchers, and students. Students and supervisors found the intensive week valuable, well-organized, and a valuable opportunity for collaboration, learning, and networking. However, many felt that three days were too short and suggested extending the program with more face-to-face time.

The supervisors mentioned that students and teams were highly motivated to address the challenge beyond simply fulfilling project requirements, demonstrating strong engagement and good results.

4. CONCLUSION

The paper presented the implementation of the TUCN CEL Project within the NextGEng initiative. The project challenged three international student teams to design a gantry robotic system. The proposed solutions combined the H-Bot setup with frame-mounted actuation and a lightweight transmission system, demonstrating creative approaches that focused on improving the system dynamics.

The project validated the CEL framework as an effective method for integrating experiential learning into engineering education. Students applied their theoretical knowledge in a practical, multidisciplinary, and international setting. Feedback highlighted the value of the CEL framework, with participants particularly appreciating the opportunity for in-person teamwork, cultural exchange, and collaborative problem-solving.

Future developments will focus on extending the duration of face-to-face collaboration and refining evaluation methods to better capture both technical performance and collaborative outcomes.

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Promovarea inovației în inginerie prin proiecte internaționale de învățare experiențială

Această lucrare introduce proiectul Cases for Experiential Learning (CEL), un nou model de proiect care implică formarea echipe internaționale și interdisciplinare de studenți la inginerie pentru rezolvarea unor provocări reale din domeniul cercetării și industriei. Cadrul combină sesiuni de lucru intensive, activități de brainstorming, discuții de reflexie asupra rezultatelor, colaborare virtuală și o prezentare finală. Activitățile propuse urmăresc atât consolidarea cunoștințelor teoretice ale studenților, cât și crearea de soluții inovatoare. Ca exemplu de caz, lucrarea detaliază proiectul CEL organizat la Universitatea Tehnică din Cluj-Napoca (UTCN) în semestrul de primăvară 2024. Tema proiectului i-a provocat pe studenți să proiecteze un nou sistem robotizat tip portal. Conceptele propuse de studenți sunt prezentate și analizate. Rezultatele au evidențiat originalitatea soluțiilor propuse și potențialul cadrului de a sprijini creativitatea și inovația interdisciplinară în educația inginerească.

Cuvinte cheie: *robotică inovatoare, proiectarea unui system robotic de tip portal, invatara experientiala, proiecte internationale de colaborare*

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