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EDUCATION 4.0 SUPPORTING REMOTE, HYBRID, AND FACE-TO-FACE TEACHING-LEARNING SYSTEMS FOR ACADEMIC CONTINUITY DURING THE COVID-19 GLOBAL PANDEMIC: THE MECHATRONIC PRODUCT DESIGN COURSE IN HIGHER EDUCATION AS CASE STUDY

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OUTLINE

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1. Introduction

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During 2020 and 2021, face-to-face academic activities were suspended worldwide due to prevention and mitigation measures to contain the spread of the the coronavirus (SARS-CoV-2) .

New pedagogical models, learning methods, delivery modalities, and teaching-learning programs powered by 4.0 technologies were emerged.

However, the courses had to be flexible enough to adapt to the possibility of returning to a remote education format at any time. These activities were accompanied by implementing safety measures such as mask-wearing, social distancing, best practices, and knowledge gained during the crisis.

1. Introduction

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During academic continuity efforts amidst the pandemic, various challenges arose, including infrastructure issues such as access to platforms and devices, stable electricity and connectivity, training stakeholders in Information and Communication Technologies (ICTs), and designing new pedagogical procedures to maintain student engagement and assess their knowledge effectively.

Higher education faced unique difficulties, particularly with face-to-face access to specialized labs needed for practical learning and developing disciplinary competencies.

To address these challenges, the educational sector embraced Education 4.0, a combination of technological advancements and pedagogical procedures [1].

2 Education 4.0 in Higher Education

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This work uses the concept of Education 4.0 to design new teaching-learning systems and pedagogical procedures, with a case study on the "Mechatronic Product Design" course demonstrating the application of ICTs and learning methods for remote, hybrid, and face-to-face dynamics.

II. EDUCATION 4.0 IN HIGHER EDUCATION

2 Education 4.0 in Higher Education

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Concept of Education 4.0:

"Education 4.0 is the period in which the education sector takes advantage of emerging ICTs to improve pedagogical processes that are complemented by new learning methods and innovative didactic and management tools, as well as the smart and sustainable infrastructure used during current teaching-learning processes for the training and development of key competencies in today's students" [13].

13. Miranda, J., Navarrete, C., Noguez, J., Molina-Espinosa, J. M., Ramírez-Montoya, M.S., Navarro-Tuch, S.A., Bustamante-Bello, M.R., Rosas-Fernández, J. B., Molina, A.: The Core Components of Education 4.0 in Higher Education: Three Case Studies in Engineering Education. In: Computers and Electrical Engineering, in press (2021)

2 Education 4.0 in Higher Education

1) **Training key competencies**, covering both soft and hard competencies for students.

2) **Applying active teaching-learning methods** with various modalities, such as problem-based learning, project-based learning, experiential learning, and gamified learning.

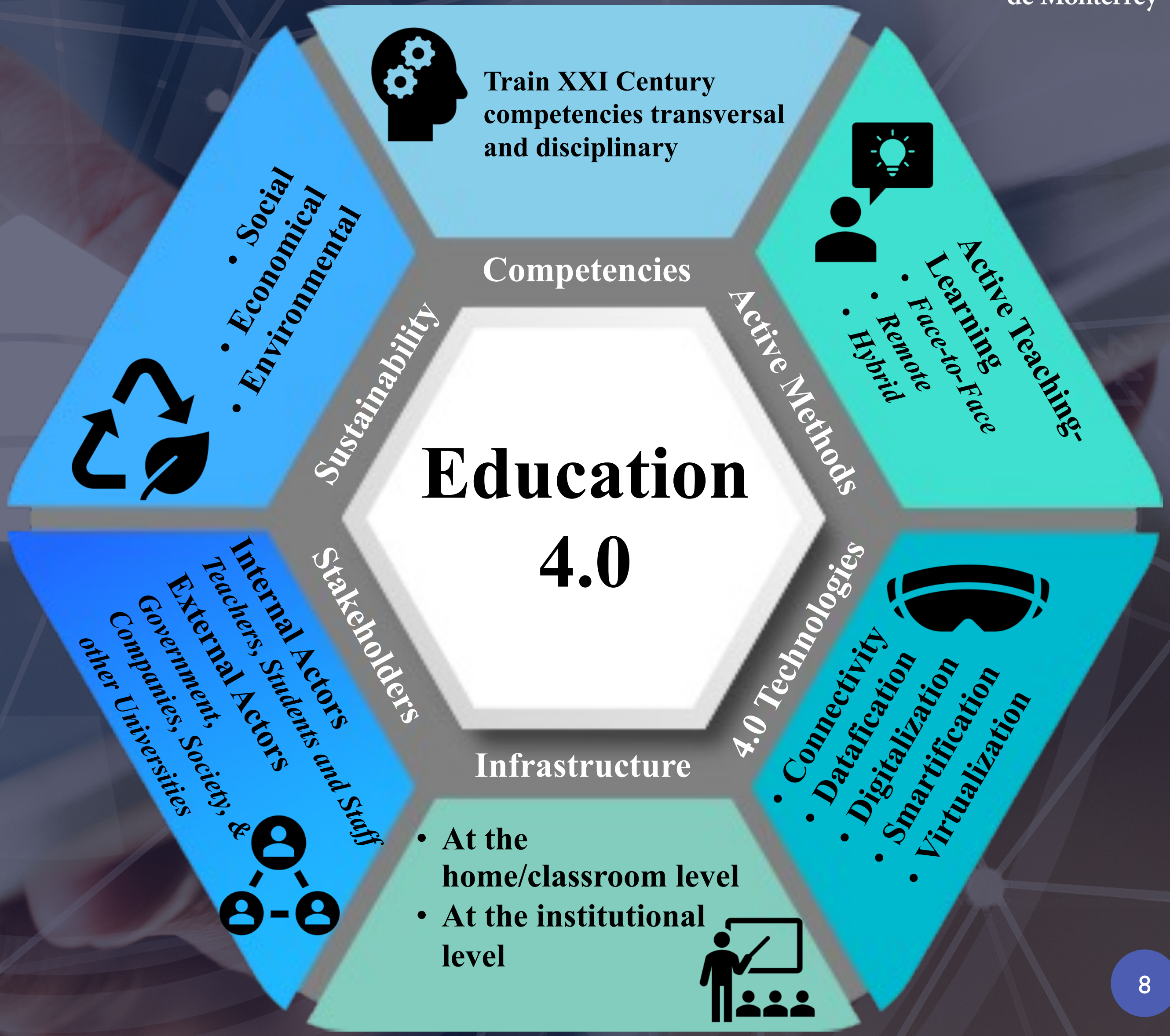
3) **Utilizing 4.0 Technologies**, which involve connectivity, datafication, digitalization, smartification, and virtualization.

4) **Implementing innovative infrastructure**, including services, facilities, devices, and physical-virtual environments to enhance teaching-learning processes.

5) **Involving relevant stakeholders**, such as internal actors (teachers, students, staff) and external actors (government, industry, society, other universities) in the teaching process.

6) **Considering sustainable impacts** by aligning with the UN Sustainable Development Goals (SDG) to create positive social, economic, and environmental effects.

Fig. 1. Six key enablers of Education 4.0, adapted from [15].



III. THE EDUCATION 4.0 REFERENCE FRAMEWORK FOR DESIGNING TEACHING-LEARNING SYSTEMS

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The reference framework incorporates the six key enablers of Education 4.0, enabling resources to support training in transversal and disciplinary competencies through active teaching-learning processes in various delivery modes (face-to-face, hybrid, remote). This innovative infrastructure, with the participation of key stakeholders and the support of 4.0 Technologies, facilitates positive social, economic, and environmental benefits. It is, therefore, necessary to have an integrative vision that can offer a new education product, a new teaching-learning process, and the necessary infrastructure to achieve more efficient and effective processes and a better user experience. Although this framework allows an integrated design (product-process-infrastructure), it can also facilitate the design process for individual entities, as presented in the case study section for the design of a "teaching-learning process."

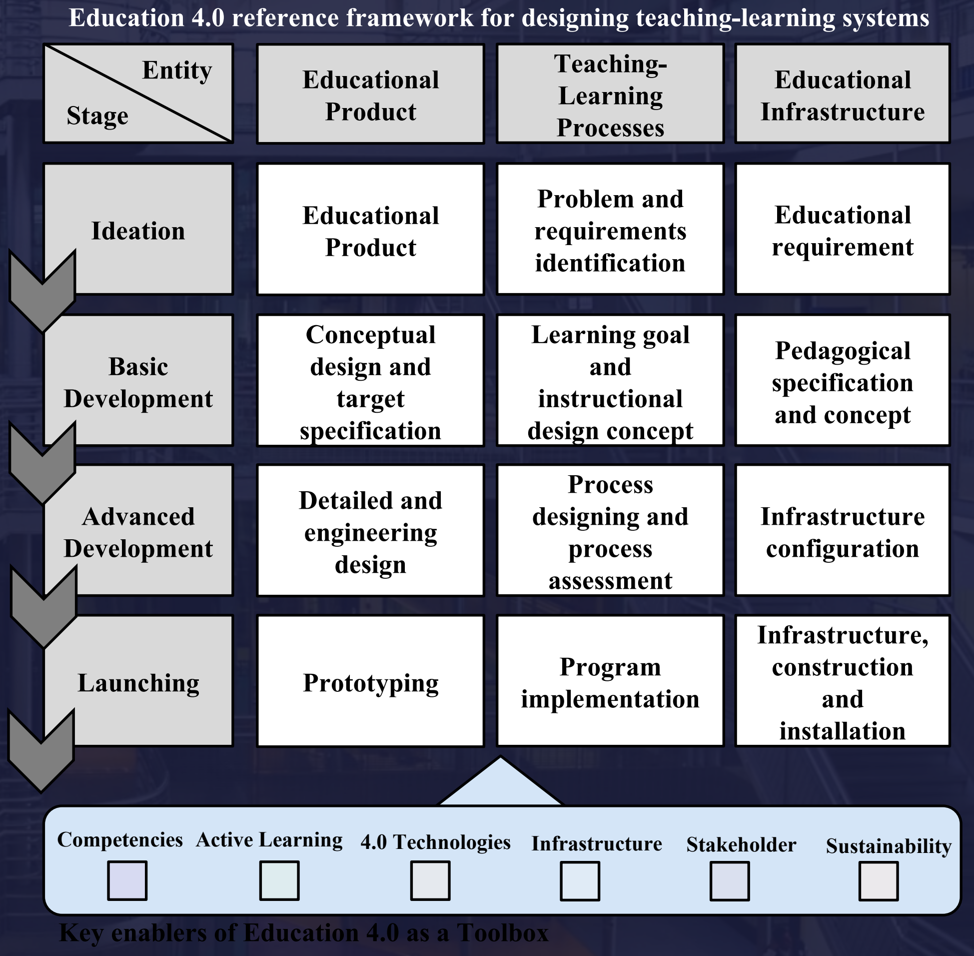

Fig. 2. The Education 4.0 reference framework for designing teaching-learning systems.

IV. CASE STUDY: THE MECHATRONIC PRODUCT DESIGN COURSE IN HIGHER EDUCATION

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The course "Mechatronic Product Design" is presented as a case study to illustrate the design, development, and implementation of new teaching-learning systems in Education 4.0 to design teaching-learning processes. This course is among the academic offerings in the mechatronics engineering and mechanical engineering careers at Tecnologico de Monterrey in Mexico

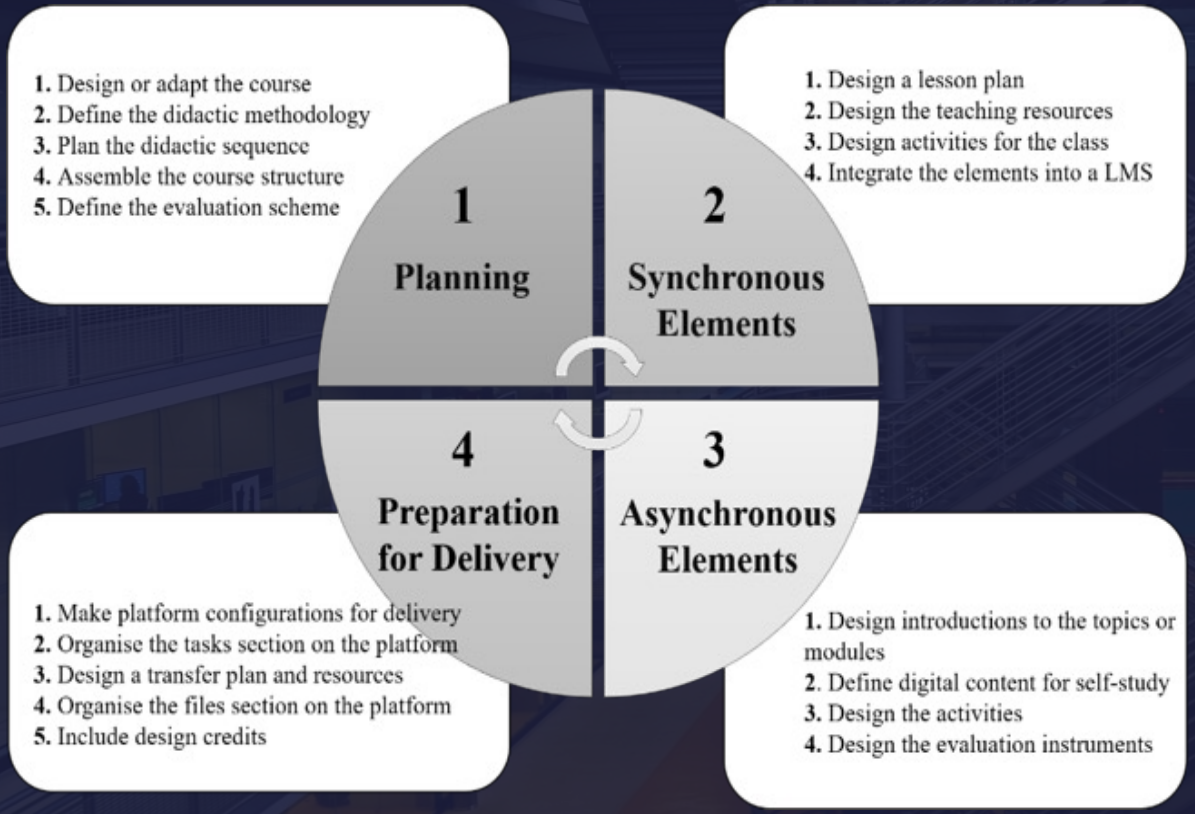

Fig. 3. Six key enablers of Education 4.0, adapted from [15].

TABLE I. SUMMARY OF THE DESIGN PROCESS, TEACHING-LEARNING PROCESS ENTITY

#	Activities	Particular Model
1	Problem and Requirement identification specification	**Problem:** Redesign the "Mechatronic Product Design" course from face-to-face to remote and hybrid delivery modalities and provide adequate training and development of key transversal and disciplinary competencies considering experiential and practical learning as core issues. **Student profile:** Undergraduate Mechatronics Engineering and Mechanical Engineering students at Tecnologico de Monterrey, Mexico. Semester: 8 or 9. **Previous knowledge:** Embedded systems, computerized control, and machine analysis and synthesis. **Duration:** 22 sessions (2 hours per session), 44 hours for summer sessions. And 16 sessions (3 hours per session), 48 hours for a semester session. Delivery Modality Goal: Remote (synchronous and asynchronous) and Hybrid. Academic periods to be implemented: Summer courses and Semestral courses.
2	Learning goals definition and instructional design concept	**Learning Outcomes:** At the end of this program, participants learn best practices and apply the appropriate tools of technology-based and mechatronic product, process, and manufacturing systems designs, create working prototypes, identify market segments, and define business models and manufacturing systems.
3	Process designing and process assessment. Program assessment	**Process designing:** Application of the transformation model from traditional courses to remote and hybrid courses: (i) Planning, (ii) Synchronous elements, (iii) Asynchronous elements, and (iv) Preparation for delivery. **Assessment Instrument:** The "i-Scale" was implemented [17]. This tool covers qualitative evaluations for learning outcomes, the nature of innovation, growth potential, institutional alignment, and financial viability. This evaluation indicated that this course has few or no drawbacks to be implemented.
6	Program implementation	**The number of students and delivery modality:** 28 students from 7 campuses across Mexico (Summer 2020, Remote). 56 students from 2 campuses in the Central Mexico region (February-June 2021, Hybrid and Flexible). 50 students from 2 campuses in the Central Mexico region (February-June 2022, Face-To-Face and Flexible). **Students' assessment method:** Mixed method analysis applying surveys about the perception of the transversal competencies trained and a qualitative evaluation of the working prototypes. Research question for quantitative analysis: What is the student's perception of the training of transversal competencies in these courses? **Research question for qualitative analysis:** What are the results of developing mechatronic working prototypes in these courses?

IV. CASE STUDY: THE MECHATRONIC PRODUCT DESIGN COURSE IN HIGHER EDUCATION

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Table II presents the teaching-learning process, highlighting how the Education 4.0 enablers shaped the "Mechatronic Product Design."

TABLE II. THE MECHATRONIC PRODUCT DESIGN COURSE CONSIDERING THE EDUCATION 4.0 ENABLERS

Modules	Education 4.0 Enablers	Goal
1. Introduction to innovation and new product and process design Key concepts related to innovation and methodologies for new product and process design and development.	**Main Competencies:** Soft: Critical Thinking; Hard: Methodologies Design **Main Active Methods:** Active Learning and Flipped classroom **Main 4.0 Technologies:** LMS, Web-conference platform, and instant message systems. **Main Infrastructure:** At institutional, access to remote labs and virtual classrooms At home, connected and connectivity services **Main Stakeholders:** At least two teachers were involved **Sustainability:** SDGs were promoted	• Identify types and sources of innovation. • Identify the methodology and techniques to be used.
2. Mechatronic Product Design Design and development of a mechatronic product through four stages: (i) Conceptual design, (ii) System design, (iii) Engineering and detailed design, and (iv) Prototyping and validation.	**Main Competencies:** Soft: Collaboration, Cooperation, Creativity & Innovation. Hard: Mechatronic principles and integrated product design **Main Active Method:** Blended-based Learning and Learning by Doing **Main 4.0 Technologies:** LMS, Virtual labs for simulation, and 3D modeling systems **Main Infrastructure:** At the institution, access to physical and remote labs and virtual classrooms, At home, connected and connectivity services **Main Stakeholders:** At least two teachers and one specialist from the industry were involved **Sustainability:** Design for Sustainability (DfS) and Life Cycle Assessment (LCA)	• Identifying opportunity areas • Understanding painful situations and customer/user requirements. • A prototype of the proposed mechatronic product. • Evaluation of the mechatronic working prototype.
3. Manufacturing Process Design Design and development of a manufacturing process through three stages: (i) Conceptual design, (ii) Technology selection, (iii) Production Plan.	**Main Competencies:** Soft: Collaboration, Critical Thinking.Hard: Process Design, Production Scheduling, and Virtual Commissioning. **Main Active Method:** Blended-based Learning and Learning by Doing **Main 4.0 Technology:** Spreadsheets, Software for Plant Design, Project Management, and Plant Simulation **Main Infrastructure:** At institutional, access to remote labs and virtual classrooms. At home, connected and connectivity services. **Main Stakeholders:** At least two teachers and one specialist from the industry are involved. **Sustainability:** Design for Sustainability (DfS) and Life Cycle Assessment (LCA)	• Definition of materials and processes to be used. • Organization of the plant and schedule of activities. • Analysis of main costs and projected sales.
4. Business Model and Launching Define and validate the value proposition of the product/process/business and product pitch.	**Main Competencies:** Soft: Communication. Hard: Enterprise creation and marketing principles **Main Active Method:** Blended-based Learning and Learning by Doing. **Main 4.0 Technology:** LMS, Virtual Classroom, and Collaborative Virtual Platforms. **Main Infrastructure:** At institutional, access to remote labs and virtual classrooms. At home, connected and connectivity services. **Main Stakeholders:** At least two teachers and one specialist from the industry are involved. **Sustainability:** Business sustainability assessment (short-medium-long term).	• Product market-fit • Product pitch • Product business model

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Figure 4 presents the results of an applied survey about the perception of the trained transversal (soft) competencies during the impartation of this course. The graphics compare both surveys, a pre-survey based on the perception of how often these competencies are trained during their classes and a post-survey based on the perception of how often the competencies were trained during the boot camp. These surveys were applied during three periods (2020, 2021, and 2022) to analyze how the three different delivery modalities impacted the designed course. The presented results show that most of the students perceived that the promoted key competencies were trained during the activities of this course. Figure 4 shows a significant increase in the feeling of accomplishment of the students regarding the soft competencies that were designed and implemented in the course. Additionally, general satisfaction with the course experience was positive in 75% of the cases.

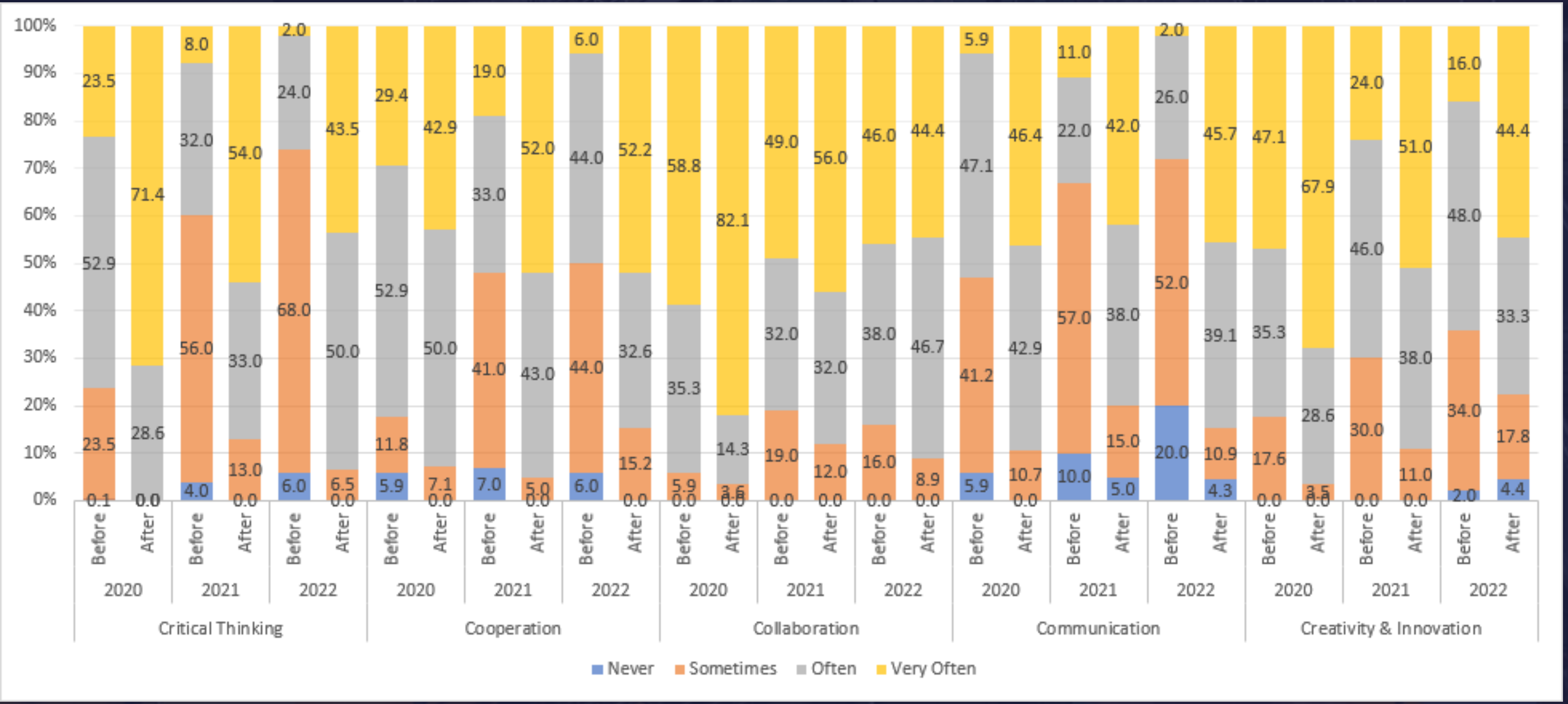

Figure 4. Survey results comparing the key transversal competencies trained before and after the course (2020 – 2021 - 2022).

5. Conclusions

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- ❑ The framework introduced is explained with a case study of an engineering course involving the process and design of a mechatronic product.

- ❑ This course was chosen as a practical example of implementing a highly complex course on multi-campuses and surveying students in the same major but with different educative backgrounds. Moreover, the course format facilitated interaction among students from different campuses and disciplines, creating active learning environments with synchronous and asynchronous teamwork activities.

- ❑ Throughout the three different delivery modalities (face-to-face, hybrid, remote), the course demonstrated adaptability and flexibility in response to varying circumstances. The consistent positive outcomes across modalities indicate that the Education 4.0 framework is robust enough to accommodate diverse teaching and learning needs while maintaining high-quality education.

5. Conclusions

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- The results showed that aligning the learning goals with the key competencies to be trained and applying correct learning methods supported by adequate ICTs of 4.0 Technologies and infrastructure made it possible to generate product ideas and conceptual products and create physical and working prototypes. It demonstrated that students could implement the acquired knowledge and integrate core concepts in this engineering area. Likewise, this new class format allowed students to interact with others from different campuses and disciplines and generate active learning environments with synchronous and asynchronous teamwork activities.

- Finally, this paper encourages further investigation of the Education 4.0 framework across various disciplines, levels, and cultural contexts. By examining the framework in diverse environments, researchers and educators can enhance understanding of its potential and limitations, ultimately guiding best practices and policies for future teaching and learning.

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