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Enhancing Engineering Education through Digital Twins and Interdisciplinary Collaboration

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Abstract

In the current educational environment, the tripartite collaboration between the Department of Industrial Engineering (DIE), the Department of Mechatronics (DIM), and a globally recognized automation company has been fundamental in improving student learning. This project enabled the development of digital twins for the logistics cell, which is currently operated manually. Using the Emulate3D tool, the activities developed in this project aimed to transform this cell into an automated cell with Industry 4.0 elements. The tool facilitated students in creating innovative proposals that enhance their use and improve the teaching methodology. Implemented in the Industrial Automation course, the project not only automated the cell's processes but also enriched the practical and experiential learning of the students, demonstrating the effectiveness of interdisciplinary cooperation in educational settings. Currently, these proposals are being evaluated by DIE professors for future incorporation into courses that use the logistics cell.

Keywords: *Interdisciplinarity, digital twins, collaboration, higher education, educational innovation.*

1. Introduction

In higher education, interdisciplinarity is crucial for preparing students to meet the demands of an increasingly complex and technology-oriented industry (Glänzel & Debackere, 2022; Kolmos et al., 2024). The integration of advanced tools, such as digital twins, exemplifies how interdisciplinary methods can connect theoretical knowledge with practical applications. Digital twins, virtual representations of physical systems, allow students to simulate and analyze real-world scenarios in a safe and controlled environment. Their implementation fosters active learning, enhances technical competencies, and promotes collaboration across disciplines, making them an invaluable resource for engineering education (Pathak & Upadhyay, 2024).

However, the adoption of interdisciplinary and technology-oriented approaches faces significant challenges. Educators encounter barriers such as lack of experience with advanced tools, limited resources, and the need for a shared vision among collaborators (Van den Beemt et al., 2020). Addressing these obstacles requires fostering collaboration, continuous professional development, and integrating emerging technologies into the curriculum.

This study addresses two important elements in engineering education reflected in the following research questions: What are the advantages and disadvantages of interdisciplinary collaboration between departments in engineering education? What adjustments are necessary to implement projects using new and unfamiliar technological tools for both teachers and students?

The collaboration took place between the Departments of Industrial Engineering (DIE) and Mechatronics (DIM) and Rockwell Automation, a globally recognized automation company. The tool used was Emulate3D (Emulate 3D, 2024), which allows the creation of digital twins of processes. Mechatronics students developed practical exercise proposals using Emulate3D, which will be applied by industrial engineering students in a logistics cell to enrich their learning activities and advance towards Industry 4.0. These proposals are designed to enhance the academic experience and practical learning of industrial engineering students and are currently being evaluated by the professors of the Department of Industrial Engineering for implementation in courses that use the logistics cell. This collaboration enabled the creation of shared visions and the acquisition of interdisciplinary skills, addressing the research question: How does the use of digital twins' impact practical learning and student motivation in engineering? Digital twins allowed the design of experiences that simulate real situations, thereby improving students' mastery of competencies.

2. Methodology Project Description

The project was conducted in the Industrial Automation course during the sixth semester of the Mechatronics Engineering program. It involved two groups of 16 students each, forming four teams per group. At this stage in their studies, students possess a solid knowledge base in electronics, computing, mechanics, control, and automation. The course spans 120 hours, including 80 hours of core topics and a 40-hour final project based on the challenge-based learning (CBL) technique. In this approach, students propose solutions to real-world problems by researching, analyzing, proposing, and implementing appropriate solutions. This method actively involves students in industrial contexts, with an industry partner collaborating on the challenge, providing valuable experience and preparing them for their professional careers (Leles et al., 2024).

This semester's challenge was the development of digital twins using Emulate 3D software, a platform for modeling and simulating production systems, from assembly lines to logistics networks. Emulate 3D allows users to create a detailed virtual representation of their production environment. The use of this tool was made possible by the support and sponsorship of an automation company that has consistently supported the university. Both students and the course instructor were initially unfamiliar with Emulate 3D, adding an additional layer of learning and adaptation.

At the beginning of 2024, Industrial Engineering professors sought support to automate their logistics cell, which currently operates manually. Their goal was to add technological elements to transform it into a cell with Industry 4.0 features, enhancing its utility and positively impacting student learning.

This problem was presented to Mechatronics Engineering professors, who saw an opportunity to link the course challenge with the logistics cell of Industrial Engineering to create its digital twin. Preliminary meetings were held before the course began, involving engineers from the automation company and professors from DIE and DIM. The objective was to establish a work plan and develop a project proposal achievable within the course's timeframe. The initial scope was limited due to high costs associated with acquiring necessary equipment and materials, as well as the course duration constraints.

The problem defined and presented to the students on the first day of class was: Automate the logistics cell process in the Industrial Engineering laboratory by implementing a digital twin using Emulate 3D® software from Rockwell Automation. The goal was to improve efficiency and present economically viable proposals, including a budget table for the Industrial Engineering department to consider for implementation.

2.1. Course Framework and Initial Challenge Presentation

The challenge was presented on the first day of the course, along with deliverables and evaluation methodology. To maintain a formal atmosphere, the engineer from the automation company and the professor from the Department of Industrial Engineering were invited to the presentation. An overview of the automation company was provided, followed by the students' first contact with the logistics cell through a practical exercise to identify problems and potential solutions. They were given an activity manual to understand how to submit their practice proposals. During the challenge development, the engineer from the automation company provided training sessions on the software. The professor from DIE offered guidance on using the logistics cell, while the professor from DIM coordinated the challenge development and taught the course.

The course strictly follows the curriculum, with the challenge playing a fundamental role. The total evaluation is divided into two sections: the course itself (60% of the final evaluation) includes exams, practical laboratory exercises, and quizzes; the challenge (40% of the evaluation) has two key evaluation points, at the middle and end of the course.

Due to inexperience with the software, the last laboratory practice was sacrificed to help students complete the challenge. This highlights the main challenge of this technique: accurately measuring the time required for both the course and the challenge. The nature of the challenge and lack of experience with the tool complicated time estimation, necessitating adjustments to meet industry partner requirements.

2.2. Final Project Assessment: Digital Twin Solutions

On the last day of classes, the eight final projects were presented in the presence of the industrial training partner, professors from both departments, and invited professors to evaluate the work. The requirements for the final deliveries were:

1. Problem Identification and Improvement Proposals: Based on knowledge acquired during practical sessions in the logistics cell, students identified a problem and made two improvement proposals:

   Low-Budget Proposal: Solutions that do not involve significant costs, utilizing and reorganizing existing materials within the Industrial Engineering laboratory space.

   New Elements Proposal: Solutions that include acquiring new elements or desirable products for a manufacturing laboratory with Industry 4.0 elements.

2. Integration of Existing Elements: Incorporate resources already available in the logistics cell for the new production and distribution process proposal.
3. Selection of Appropriate Equipment: Choose components that meet the specific requirements of the simulated process.
4. Technologies Used: Employ specialized software (Emulate 3D), communication modes, and technology to simulate, program, and visualize the entire process.

While taking this course, students also take the Flexible Manufacturing course, which is why all proposals in the second category included industrial robots. Additionally, students were required to provide the costs of the equipment used and reference websites where the equipment could be purchased. Another requirement was to develop a practical user guide for Industrial Engineering students to follow their proposed work.

The projects ranged from identifying bottlenecks in a production line, measuring delay times in raw material handling and manufacturing, to automotive transmission assembly projects, seeking to optimize processes and obtain performance metrics for production lines. Students applied knowledge acquired in the logistics cell to identify bottlenecks and optimize production processes, using digital twins to simulate and evaluate their proposals in a safe environment.

3. Project-specific examples

3.1. Automated 3D Printing Farm

The "Automated 3D Printing Farm" project uses 3D printers (3DP) to enhance student interaction with the production process, emphasizing data collection and generation in Industry 4.0. 3DP technology, increasingly adopted in educational institutions, enhances teaching and learning across disciplines by allowing students to design and create solutions for real-world problems, improving their visual and technological literacy (To, Al Mahmud, & Ranscombe, 2024). Integrating additive manufacturing (AM) and 3DP in engineering education fosters essential skills such as CAD modeling, problem-solving, critical thinking, and teamwork, promoting creativity, innovation, and multidisciplinary collaboration (Tripathi et al., 2024).

In the project, 3D printers serve as adaptable production machines in the logistics cell, enabling students to create and customize designs, thus combining manual work with automated activities. For example, students can compare creating paper shirts in origami with 3D printing to evaluate the impact on their learning.

A new laboratory practice involves using 3D printers to produce T-shirts of different sizes and storage boxes, aiming to maximize production speed and quality. Students collect data to predict the time required to produce 1000 T-shirts for a client. The price of a 3D printer is approximately 215 US dollars, and the filament package costs 25 dollars, making this an attractive investment for the laboratory.

3.2. Use of Virtual Reality in PCB Assembly Training

According to Scorgie et al. (2024), one of the significant advantages of the digital twin is that, supported by Virtual Reality (VR) tools, it allows for direct operator training without the need to read a manual or halt production. This proposal is based on VR, which has revolutionized various industries by offering immersive and realistic experiences that surpass traditional methods. Safety training, crucial for preventing workplace accidents, has traditionally relied on passive methods such as videos and manuals, which can be less effective. With the transition to Industry 4.0, digital technology, including VR, is increasingly used to enhance safety training, providing a more interactive and engaging learning experience.

This project focuses on the production subprocess of printed circuit boards (PCB) assembly and soldering. The objectives are to test the immersive experience of VR in recreating a PCB assembly process and facilitate learning with VR tools. For the proposed practice in the Logistics Laboratory, the digital twin of the logistics cell created in Emulate3D software is provided. This model illustrates how an operator, using VR, assembles PCBs with soldering technology. The exercise, tested and handled by a professor during the final course evaluation, involves the user taking PCBs from the storage system and placing them in the through-hole component assembler, following instructions in the immersive VR environment. This activity requires augmented reality glasses; the Oculus Quest 2 was used, costing $485. Additionally, Emulate3D software is necessary for developing virtual environments, raising the initial investment cost.

3.3. General Comments

The skills developed through these projects, including CAD modeling, problem-solving, critical thinking, and teamwork, are highly applicable to future learning and industry. Students gained hands-on experience with advanced manufacturing and digital technologies, preparing them for careers in fields that require technical proficiency and innovative thinking. The projects demonstrated significant improvements in student motivation and understanding complex industrial concepts. The use of digital twins and virtual reality created engaging and immersive learning environments, which enhanced students' practical and technical skills. These findings highlight the effectiveness of integrating advanced technologies in engineering education and their potential to improve learning outcomes.

Figure 1. Professor using Virtual Reality tool for PCB assembly training exercise

4. Current challenges and plans

Lack of Experience with Software: The inexperience of both students and the professor with Emulate 3D software led to adjustments in planning, including the elimination of a laboratory practice focused on advanced simulation techniques. This can negatively impact the learning of other course content and hinder the project's completion. To address this, additional training sessions and workshops on Emulate 3D are recommended to build proficiency and confidence in using the software. Providing access to online tutorials and resources can also help bridge the knowledge gap.

Challenges in Time Management: The methodology highlights the difficulty in accurately measuring the time required to complete both the course and the challenge. This can result in excessive workloads for students and limit the time available for other important course activities. To avoid sacrificing content, it is proposed to add greater flexibility to the schedule, with contingency times or additional sessions if students require more support to solve their challenge. Implementing a more detailed project timeline and regular progress check-ins can help manage time more effectively.

Dependence on External Resources and Budget Constraints**:** Implementing the digital twin and automating the logistics cell requires financial and material resources, such as specialized software, hardware, and training materials, which can be challenging to secure. This limitation restricts the project's scope and may result in some elements remaining theoretical without practical implementation. Nevertheless, the Department of Industrial Engineering has shown interest in the 3D Printing project and has recently acquired 3D printers to support this initiative. To mitigate this limitation, seeking additional funding sources and partnerships with industry could be beneficial.

Key Findings: The project demonstrated significant improvements in student motivation and understanding of complex industrial concepts. The use of digital twins and virtual reality created engaging and immersive learning environments, which enhanced students' practical and technical skills. These findings highlight the effectiveness of interdisciplinary collaboration and the integration of advanced technologies in engineering education.

5. Conclusions

This work has addressed the importance of interdisciplinarity and industry collaboration to enhance teaching in the field of Engineering. By utilizing digital twins and virtual reality, the project created active and safe learning environments that allowed students to develop practical and technical skills while facing real-world challenges. Projects such as the automated 3D printing farm and the modeling of processes in virtual reality proved effective in enhancing student motivation and their understanding of complex industrial concepts.

Additionally, the work highlights the need to address limitations related to software inexperience and time management. Future projects should incorporate additional training sessions and detailed planning to optimize outcomes. The collaboration between the Departments of Industrial Engineering and Mechatronics, supported by Rockwell Automation, has been fundamental to the success of these initiatives.

In future work, it is anticipated that the Department of Industrial Engineering (DIE) will acquire the necessary devices to implement the 3D printing farm proposal and other advanced project ideas. This will allow for a more comprehensive evaluation of the project's impact and strengthen the alliance between academia and industry to design authentic and relevant learning experiences. The integration of advanced technologies such as digital twins and virtual reality not only elevates student training but also prepares future engineers to address the multifaceted challenges of modern industry.

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