The Teaching of Industry 4.0 Technologies in Brazilian Professional Education

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Teaching Industry 4.0 technologies in Brazilian professional education significantly impacts the training of specialized labor for the job market. This research examined how two educational institutions prepared their manufacturing students for the digital technologies of Industry 4.0 and what the leading technologies used in the students' projects. The case study method was used, and 35 projects were analyzed. Digital technologies were used in the projects with a particular emphasis on simulation systems aided by 3D modeling competence IoT and augmented and virtual reality.

Keywords: Industry 4.0, Digital Technologies, Professional Education, Brazil

1. Introduction

Digital technologies of Industry 4.0 are being applied in several areas of knowledge, not only in manufacturing. Technologies like the Internet of Things (IoT), cloud computing, additive manufacturing, virtual and augmented realities, simulation, and systems integration can be highlighted. These technologies contribute to the proliferation of digital technologies in the industry and their vertical and horizontal development. The fact that they are recent technologies, there are still few industries that adopt them and thus need specialized labor that needs to be formed and trained in the market, opening an extensive training and education market for institutions such as vocational training technical schools, technology colleges, universities, and training companies. However, it is essential to emphasize that the teaching and training of these digital technologies require an infrastructure of equipment and digital laboratories that can supply students with the practical part of each technology, approaching the actual use that it will have in the professional market and that these laboratories and spaces maker requires a considerable investment in their installation. Another point noted is that students from educational institutions, regardless of their level, must apply their knowledge in realistic projects that simulate the job market and apply the techniques learned to solve simulated problems. In this research, the projects studied were course conclusion works, where students developed theoretical projects and implemented the prototypes. Given this context, this research aimed to verify how two educational institutions prepared their manufacturing students for the digital technologies of Industry 4.0 and the leading technologies used in the students' projects. This article includes this introduction; the next topic addresses the literature review. Section 3 presents the scientific methodology used. Section 4 presents the results and discussions; the last section concludes the paper.

2. Literature Review and Hypothesis Formulation

2.1 Industry 4.0

The world has experienced continuous transformations, somehow changing human trajectory and history. We can explain the first and second industrial revolutions and the information revolution. The introduction of the Internet of Things and Services in manufacturing began the Fourth Industrial Revolution: Industry 4.0 (Okano, 2017).

Industry 4.0 is a strategic initiative recently introduced by the German government, and its objective is the transformation of industrial manufacturing through digitization and exploration of the potential of new technologies (Rojko, 2017). According to Rojko (2017), an Industry 4.0 production system is flexible and allows individualized and personalized products.

In recent years, due to the rapid development of the fourth industrial revolution and new information technology platforms, smart systems have received widespread attention in many sectors and have brought the potential to improve the efficiency of the construction industry (Kozlovska et al., 2021).

According to Pereira & Romero (2017), this emerging concept of Industry 4.0 is an umbrella term for a new industrial paradigm that encompasses a set of future industrial developments related to Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), Robotics, Big Data, Cloud Manufacturing, and Augmented Reality.

2.2 Key Digital Technologies

The following items detail the leading digital technologies surveyed and which were significantly associated with the projects.

• Simulation Systems

Digitization is the first step applied to simulation systems, which includes using digital technology to change production processes and product development or business models. The 3D modeling of the objects in the environments aims to optimize the efficiency of the process under analysis (Portal da Indústria, 2023). Digital transformation encompasses phases such as digital planning, detection, design, and implementation of data processing. The results are obtained through computers and software that present a complex environment between the variables in the system, thus interactively imitating the real-world process (Fortino et al., 2020).

• Systems Integration

The integration of vertical and horizontal systems in Industry 4.0 aims to create an interconnected, collaborative, and efficient business environment in which systems, processes, and business partners work together to achieve greater productivity, quality, and agility in industrial business, involving the connection between the different hierarchical levels within an organization, from the factory floor to senior management (Borrego et al., 2020).

• Additive manufacturing

It is manufactured by a digital design (made from three dimensions), which is superimposed on the thin layer of material from the 3D printer. You can use plastic, metal, metal alloys, ceramics, and sand materials (Portal da Indústria, 2023).

For Pereira (2022), additive Manufacturing is one of the enabling technologies of Industry 4.0. In recent years, its use has been increasing in industries worldwide, both in the prototyping phase of a product and in the final production phase.

• Virtual and Augmented Reality

For Jerald (2015), virtual reality (VR) is a computationally generated digital environment that can be interactively experienced as if it were real. Virtual reality can create surrogate reality by computing the technology, simulating the real environment and systems, and making experiences in a virtual environment (Hounsell et al., 2020).

Augmented reality (AR) technology has recently attracted much attention and has become mature and strong in all areas of human knowledge (Tori et al., 2020). For Azuma et al. (2001), AR is a system that supplements the real world with computer-generated virtual objects appearing to coexist in the same space and having the following properties.

• Internet of things

The Internet of Things (IoT) refers to the network of massive physical objects, things equipped with sensors, actuators, and small computers for sensing and communicating with each other (Ren et al., 2021). The introduction of the Internet of Things and Services in the manufacturing environment is starting a fourth industrial revolution: Industry 4.0 (Okano, 2017).

According to Botta et al. (2016), IoT is generally characterized by small real-world things that are widely distributed with limited storage and processing capacity, which involves concerns about reliability, performance, security, and privacy.

• Cloud Computing

Cloud computing is a consolidated and mature digital technology; it has solved most of the IoT problems and has infinite storage resources and processing power (Botta et al., 2016).

Atlam et al. (2017) consider that cloud computing provides on-demand, convenient, and scalable network access, which enables the sharing of computing resources; in fact, this allows for the dynamic integration of data from multiple data sources. According to Sadeeq et al. (2021), the integration of cloud computing with IoT offers various advantages for numerous IoT applications with, for example, data capture and access from anywhere and at any time, processing and real-time analysis of data collected by devices, in addition to the possibility expanding and managing many IoT devices.

2.3 Industry 4.0 Technologies Related to Education in the World

According to Drath (2014), in Germany and North America, industry 4.0 addresses the application of cyber-physical systems to industrial production, describing the basic industrial requirements that need to be met for its success, addressing not only the technologies but also the qualification of those who have contact straight to the topic.

According to Oztemel (2020), the relationship between the pillars of Industry 4.0 and technological education addresses some principles such as project design, virtualization objective orientation during development, and modularity to tend to the needs of projects. These principles can be observed in projects scripted from digitization to completion, applied in production processes, and generated in a practical library for academics and industry professionals.

To overcome the complexity of integrating the technologies present in Industry 4.0 into the educational scenario, the concept of a learning factory was proposed, where real scenarios are presented to students so that they can work on skills inherent to the challenges of different types of projects in an integrative way (Erol et al., 2016).

The lack of qualified professionals and the high cost involving industry 4.0 technologies require studies involving industrial and academic environments to smooth the impacts on the transition of new methodologies that must be adopted when gradually introduced in companies (Benešová & Tupa, 2017).

In several schools around the world, it is possible to perceive that some technologies such as additive Manufacturing, IoT, robotics, and integrated systems between real and virtual environments are trends that enable the employability of operators so that they can implement intelligent manufacturing on the factory floor through projects technicians (Ahuett-garza & Kurfess, 2018).

The perspective of researchers, companies, educational institutions, and students regarding the multi-disciplinary contained in projects involving industry 4.0 technologies is essential due to the scope of the subject in the industrial and academic environment, in addition to directing future research in software operations management, devices, methodologies, and learning (Ivanov et al., 2021).

Courses that train technicians and technologists must be updated with industry 4.0 technologies, with laboratories providing practical activities. In this way, new professionals experience solid professional development skills and meet the current industry’s challenges (Silva et al., 2020).

According to Brasil (2023), professional and technological education (PTE) is an educational modality provided for in the Law of Guidelines and Bases of National Education (LDB) with the primary purpose of preparing “for the exercise of professions,” contributing to those citizens can insert themselves and act in the world of work and life in society. To this end, it includes qualification, technical and technological qualification, and postgraduate courses, organized in such a way as to provide continuous and articulated use of studies.

In this study, two types of institutions were analyzed: a vocational training technical school that offers professional technical courses at the secondary level and a technology college that offers professional courses at the undergraduate level.

Generally, institutions that participate in professional and technological education (PTE) maintain an infrastructure of laboratories and workshops to offer the practical part of the technologies involved, not just theory.

The teaching of technologies and techniques is carried out in theoretical and practical classes, and at the end of the courses, students must design and develop in practice a project that simulates a problem in the professional market.

3. Research Methodology

The methods used in this research were:

• Bibliographic research for the elaboration of the theoretical framework presented in section 2 or literature review.

• The case study’s methodology highlights the importance of understanding the context in which projects are carried out and guides planning, conducting and analyzing qualitative research (Yin, 2021). In addition to aspects such as case selection to data collection and analysis, emphasizing the importance of exploring the complexity and uniqueness of individual cases (Stake, 2010).

The selected cases were a Technical School of Vocational Training and a College of Technology, both publicly accessible and having medium-level technical courses and undergraduate classes in mechatronics, automation, and control and manufacturing, respectively.

Participatory observation in the factory environment was used as a research instrument, together with the team responsible for the implementation of mechatronic projects, from meetings, monitoring the planning, installation, and operation of the projects, as well as presentations of the works to a bank of professors and professionals from the area. In the observations, it is possible to observe the technologies contained in Industry 4.0, the challenges encountered, the interactions between team members, the performance of the systems, and the benefits obtained with the integration of technologies.

Another instrument used was an interview with a script of open and closed questions with the guiding professors and students of the projects, in addition to the reading of the written projects developed by the groups of students, seeking to obtain insights and perceptions of those involved with the mechatronic projects related to Industry 4.0.

The objective of applying these mentioned methodologies is to identify the areas of application of each project, the technologies of industry 4.0 used in each mechatronic project/advanced manufacturing, to understand the importance of the interaction between these technologies and professional training, the contribution of environments for activities practices in the use of technologies in each project, in addition to the challenges, benefits found during the creation, development, and implementation of these projects.

A total of 35 projects were analyzed, 29 of which were developed at the technical vocational training school and six projects developed at the technology college, involving 130 students and eight teachers. The research period was from February 2020 to April 2023. Then, a questionnaire containing eight questions involving mechatronic projects/advanced manufacturing was applied:

1. What is the area where your mechatronics design/advanced manufacturing is being applied?

2. What Industry 4.0 technologies are applied in this mechatronics/advanced manufacturing project?

3. Of the technologies in Industry 4.0 addressed throughout the mechatronic project/advanced manufacturing, can you associate them with importance in your professional training?

4. Did the practical activities developed in Fablabs and experiences in the industrial sectors help you better understand the technologies in Industry 4.0 when developing your mechatronic project/advanced manufacturing?

5. How did you handle cross-team collaboration during implementing mechatronics design/advanced manufacturing?

6. What are the main lessons from applying mechatronic design/advanced manufacturing involving industry 4.0 technologies?

7. How did mechatronic design/advanced manufacturing contribute to students' technical and professional training?

8. What are your future perspectives regarding applying mechatronic design/advanced manufacturing in Industry 4.0?

4. Statistical Analysis and Results

At the vocational training technical school, the choice of projects was aimed at groups containing an average of three members per activity. The application areas were divided into Product and Process Development, IT, Tooling, and Manufacturing. These subdivisions allowed a greater balance between the activities to be developed and an alignment with environments with up-to-date technologies and with Industry 4.0.

The division of groups in the technology college also adopted the criterion of an average of three members per project. The choice of projects was aimed at companies that seek to integrate their projects and processes with new technologies, divided into some areas such as Horizontal and Vertical Communication in industry and Industrial Processes.

Tables 1 and 2 present the results obtained in the research describing the project's theme, the application area, and the areas and technologies used, the first Table being from the vocational technical training school and the second from the technology college.

Table 1 *Results of the Survey with the Vocational Training Technical School*

Project	Theme	Application area	Technologies used
1	Case study: Induction tempering applied to dies	Tooling	3D Modeling in CAD
2	Case study: Logistics applied to the commissioning of standard parts	Tooling	Mechanical tests
3	Measurement and control system applied in stamping system	Stamping	3D Modeling in CAD
4	Circular interchangeable clamping device on B-pillars of motor vehicles	Frame	Logistics
5	A mechanical device for identifying bodywork positioning in the painting process	Painting	3D Modeling in CAD
6	The automated system i s applied to body positioning identification in the painting process.	Painting	Manufacturing Process Automation
7	Automation of the glue application system in automotive structures	Final assembly	3D Modeling in CAD
8	Wheel bolt tightening device in automotive vehicles	Final assembly	Additive Manufacturing
9	Analysis of interactive external movements in vehicles with an application of ergonomics and virtual reality	Product and Process Development	Ergonomics Virtual reality
10	Device to eliminate occurrences in stamping and welding processes	Product and Process Development	3D Modeling in CAD
11	Analysis of the types of fittings applied to projects developed through 3D printing	Product and Process Development	Virtual reality Additive Manufacturing
12	IoT application in electrical testing of mirrors	Product and Process Development	3D Modeling in CAD IoT
13	Automation of Didactic Press	Tooling	Bend Stamping

14	Welding device automation	Tooling	3D Modeling in CAD
15	Conveyor automation system	Tooling	Additive Manufacturing
16	Laser measuring system for checking stamped parts	Stamping	Linear guide automation
17	Interchangeable rectangular device for tightening central B-pillars of motor vehicles	Frame Area	IoT
18	Scanning of a windshield glue application device on an assembly line	Product and Process Development	3D Modeling in CAD
19	Integration of IoT with PLC in electrical tests of mirrors	Product and Process Development	Virtual reality PLC and IoT
20	Application for real-time data collection used in the automotive assembly line	Product and Process Development	Application Creation
21	Automation of didactic press applying the NR12 standard	Tooling	Internet of Things
22	Welding device automation	Tooling	Integration between PLC and IoT
23	Interchangeable rectangular device for tightening central B-pillars of motor vehicles	Frame	Additive Manufacturing
24	Mechanical device for applying glue to windshields on an assembly line	Final assembly	Application Creation
25	The automated system is applied in the windshield glue operation on the vehicle assembly line.	Final assembly	Manufacturing Process
26	Case study: Cybersecurity procedures applied to the network of large companies	IT	Data analysis Cybersecurity
27	Case study: Collaborative robot application in the bodywork glue application process	Frame	3D Modeling in CAD Collaborative robot
28	Case study: Application of augmented and virtual reality in the digitization of new products	Product and Process Development	Additive Manufacturing Augmented and Virtual Reality
29	Case study: 3D printing applied to new product development	Product and Process Development	Pneumatic Additive Manufacturing

Source: *Research Data*

The projects were divided into several manufacturing application areas; the project choices were up to the students themselves, with the development being directed by the guiding professor. Table 3 presents the projects according to the areas of application.

Table 2 *Results of the Survey with the Technology College*

Project	Theme	Application area	Technologies used
30	Application of augmented reality together with the MQTT and WEB SERVER communication protocol for industrial process monitoring through a supervisory application	Horizontal and Vertical Communication in Industry	3D Modeling in CAD Augmented Reality Internet of Things Integration between PLC and IoT Application Creation
31	Application of augmented reality in directing data in digital manufacturing processes collected via IoT	Horizontal and Vertical Communication in Industry	Application Creation Augmented Reality IoT
32	Process sheet scanned through augmented reality application	Industrial process- es	3D Modeling in CAD Augmented Reality Application Creation
33	Augmented reality applied to the assembly of electrical panels	Industrial process- es	3D Modeling in CAD Augmented Reality Application Creation
34	Data collection application for traceability of engine block machining in heavy vehicles	Industrial processes	Application Creation Manufacturing Process Data analysis
35	Autonomous robot applied to internal services of a restaurant	Horizontal and Vertical Communication in Industry	Application Creation 3D Modeling in CAD Augmented Reality IoT

Source: *Research Data*

Table 3 *Number of Projects by Application Area*

Application area	Projects
Product and Process Development	9
Tooling	7
Final assembly	4
Frame	3
Horizontal and Vertical Communication in Industry	3
Industrial processes	3
Stamping	2
Painting	2
IT	1
Total	**35**

Source: *Research Data*

The Product Development area was the one that had the most projects with a total of 9 practical applications, followed by Tooling, which held second place with seven applied projects.

It was noticed that an excellent incentive for choosing the Product Development area was the direct contact with new technologies contained in the pillars of Industry

4.0, in addition to the challenge of creating products and technological artifacts that sharpen the innovative vein of students.

The tooling area also stood out due to the number of skills required of students during the development of projects, together with the encouragement of the participation of mentors, helping with new technologies associated with the guidance of the mentor teacher.

Regarding digital technologies, Figure 1 presents all those used in the projects, emphasizing that a project may have applied more than one technology.

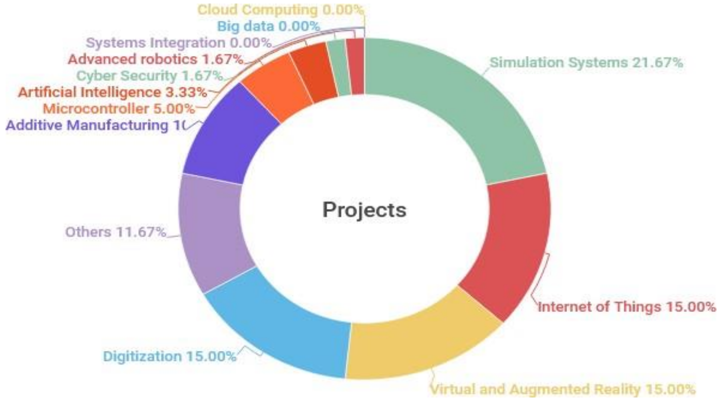

Figure 1 *Key Digital Technologies Used*
Source: *Research Data*

It can be seen in Infographic 01 that simulation systems, mainly 3D modeling in CAD, were most used with 13 projects, followed by three technologies tied with nine projects: Internet of Things, Virtual and Augmented Reality, and Digitization with application creation. On the other hand, cloud computing, big data, and systems integration were not indicated as the chosen digital technologies. Still, they were undoubtedly used in some projects as infrastructure and reference to enable their use.

Many activities could only be associated with industrial activities due to prototyped electronic development boards containing microcontrollers such as Arduino and ESP 32. Their technologies, having connections such as Bluetooth and Wi-fi, were essential for the association of PLCs and the application of some pillars such as IoT, Augmented Reality, and Additive Manufacturing.

It is worth noting that some projects developed at the vocational training technical school were developed in an integrated manner, namely, scanning of a device for applying glue to windshields on an assembly line, Mechanical device for applying adhesive to windshields on an assembly line, Automated system involved in the windshield glue operation on the vehicle assembly line and application for real-time data collection used on the automotive assembly line.

Given this scenario, the respective advisors highlighted and praised some skills, such as planning skills, synergy, empathy, communication skills, and knowledge transfer in the face of new technologies.

In the technology college, the application of augmented reality, together with the MQTT and WEB SERVER communication protocol for monitoring industrial processes through a supervisory application, gained notoriety due to being the most complete involving new technologies, in addition to being a pioneer in the integration of Horizontal and Vertical Communication in the industry.

5. Conclusions

The objective of this research was achieved, as it was verified that the two educational institutions prepared their manufacturing students for the digital technologies of Industry 4.0 with theoretical classes and course completion projects that apply the acquired knowledge.

Among all the technologies used throughout the project's development, simulation systems stand out due to their ability to model in 3D and the availability of environments intended for this activity.

IoT technology also gained prominence during the evaluation due to the use of programming and the reduction in the cost of prototyped boards available on the market, which are indispensable for communicating devices with the internet.

Augmented and virtual realities gained prominence by using 3D modeling skills and simulating different scenarios to obtain the final version of the projects.

Both schools have 3D printers, which also made it possible to speed up the creation time of the devices created, in addition to building design thinking about the usability of the products.

The importance of laboratories, workshops, and Fablab is highlighted to fill the gap in the practical part with the digital technologies applied in Industry 4.0 and to fix the knowledge presented in a theoretical way.

Another relevant factor observed is the commitment, satisfaction, and pride the students showed in their work and defended the projects as true market professionals, praised by the guiding professors and other market professionals.

This research proved that professional and technological education is on the right track to prepare students from technical and technological institutions at different levels for inclusion in the professional market, such as Industry 4.0.

In future work, we evaluate other professional and technological education levels and how this market acceptance of graduate students as employability is recommended.

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