Integrating Project-Based Learning and Design Thinking: an innovative approach to enhancing hard and soft skills in industrial robotics education

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***Abstract*— This innovative practice full paper presents an approach to industrial robotics education, based on the practical integration of Project-Based Learning (PBL) and Design Thinking (DT) methodologies. This approach aims to improve both hard and soft skills among engineering students. The PBL/DT methodology is conceptually based on the hands-on learning philosophy and combines an educational methodology with an innovation development method to enhance the acquired skills. The methodology was implemented in a partnership between the Federal Institute of Amazonas (IFAM) and LG Electronics Factory, located in Manaus, Amazonas/BR. Manaus, situated in the heart of the Amazon Rainforest, is home to numerous electronics factories due to a Brazilian government policy aimed at promoting sustainable economic alternatives and preventing deforestation. Despite this, the city's isolation from other developed regions has led to a shortage of professionals skilled in advanced technologies. Consequently, there is a need for Manaus to transition its production processes to align with Industry 4.0 standards, including advanced industrial robotics technology. In response to the government's limited investment in education and technology, LG Electronics and IFAM launched a project to train engineering students in advanced industrial robotics skills. The project was structured in three main phases: (i) designing the PBL/DT methodology; (ii) building an industrial robotics laboratory, including equipment; and (iii) conducting a four-month training in industrial robotics using the PBL/DT methodology. The training involved practical classes at the university and at the factory environment, as well a hands-on project to apply the knowledge to solve real industrial challenges and to give meaning to classes to consolidate the acquired knowledge. The project, which was executed in 2023, aimed to train two groups of undergraduate engineering students from various public and private universities. The results were highly encouraging. All students successfully completed the training, the methodology was positively evaluated, and the university-industry partnership was deemed a success, effectively achieving the project's proposed objectives. This innovative teaching practice not only impacts technical knowledge but also fosters a structured, logical, and creative way of thinking, preparing students for the real-life challenges using industrial robotics.**

Keywords*— *Project-Based Learning, Design Thinking, Industrial Robotics, Academic-industrial partnership Introduction (Heading 1)

I. Introduction

In engineering area, particularly in technological teaching such as industrial robotics and similar, students are accustomed to a banking education that, according to Paulo Freire [1], is the teaching and learning process that is characterized by being "an act of depositing, in which the students are the depositories and the educator, the depositor". Therefore, the first module (Multiple Competencies & Hands On) precisely worked these issues of multiple intelligences and competencies, the importance of developing cognitive (hard skills) and socio-emotional (soft skills) skills, using the PBL/DT methodology.

Indeed, training for the real-life job cannot be exclusively technical. According to the World Economic Forum [2], the main skills needed for the world of work in 2027 can be summarized in Figure 1. Note that these skills are divided between soft and hard skills, that require diversified skills from the student.

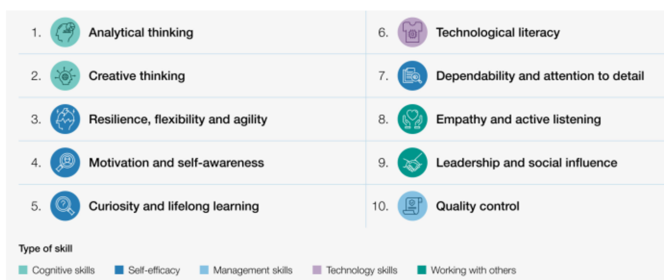

Fig. 1. The future of job competencies for 2027.. From [2].

Manaus, the capital of Amazonas, is a significant city in the Brazilian Amazon rainforest. It has tax incentives for the tech industry due to a territorial occupation policy, aiding forest protection. However, its isolation and lack of intellectual capital pose challenges for these industries, especially in forming high-tech human resources for Industry 4.0 [3].

To improve engineering teaching and learning, many universities use active methodologies combined with technologies, such as the use of educational robotics. However, most of the time they are still far from the needs of the work life.

The partnerships between universities and industries are crucial for innovation in the Manaus Industrial Pole (PIM). They are key components of innovation ecosystems, enhancing research processes and business innovation.

Particularly in industrial robotics training, these partnerships enable teachers and students to tackle real-world problems, preparing students for the job market. Robotics can transform learning, making it more engaging and introducing students to the scientific field.

This job focuses on a practical teaching methodology, where the student will learn by doing, where the main contribution is a new teaching and learning methodology that combines Project-Based Learning and Design Thinking. Developed through a partnership between LG Electronics and the Federal Institute of Amazonas, it focuses on advanced industrial robotics training. The teaching and learning method used includes expertise from both academia and industry.

II. INTEGRATION OF DESIGN THINKING WITH PROJECT-BASED LEARNING METHODOLOGY

Influenced by Finland, Canada, and Australia, Brazilian education researchers have sought ways to enhance Brazil's professional education system. They've expanded the use of active methodologies to bridge gaps in the current school system. These methodologies emphasize not only technical skills but also socio-emotional skills, crucial for professional knowledge enhancement.

Innovation-oriented training is vital in today's competitive world, demonstrating the possibility of sustainable growth through robust intellectual capital.

In 2018, the Federal Institute of Education of Amazonas (IFAM) initiated the LAPASSION project in collaboration with various European, Latin American, and Brazilian institutions. Funded by the European Union's Erasmus Plus Program, this project aimed to foster students' social skills and address challenges posed by partnerships with private or public companies and government agencies [4].

The LAPASSION project effectively utilized Project-Based Learning and Design Thinking concepts, not yet integrated, but focusing on a hands-on teaching methodology that uses these active and innovative methodologies [5].

A. *Project-Based Learning*

Project-Based Learning (PBL) is a teaching and learning approach where students actively engage in real-world projects that hold personal significance. In PBL, students undertake a project over a specified duration, which could range from a week to a semester or more. These projects involve solving a real-world problem or answering a complex question. Through these projects, students demonstrate their knowledge and skills by creating a service or product, which is then presented to an audience beyond just the academic community [6].

PBL encourages student autonomy, providing them with a voice and decision-making power in the development of solutions. It incorporates meaningful content and promotes collaboration, communication, technological proficiency, creativity, and time management. Consequently, students acquire a deep understanding of the content and develop critical thinking skills, collaboration, creativity, and communication, among others.

PBL stands apart from merely "doing a project" as it necessitates critical thinking, problem-solving, collaboration, and diverse forms of communication. To respond to a guiding question and produce high-quality work, students must do more than merely recall information. They need to employ thinking skills to search for, interpret, utilize, and transform this information, and learn to collaborate effectively as a team [7].

B. *Design Thinking*

Design Thinking (DT) is a dynamic methodology that enhances problem-solving by understanding user needs and incorporating their feedback when creating a product or service. It's not a specific method, but an approach that stimulates decision-making and knowledge pursuit through the organization of ideas. It's widely employed in the product and service industry.

DT prioritizes the end user and customer experience, emphasizing empathy for user challenges. It aims to boost productivity, even if it means compromising profit margins and efficiency metrics. The methodology follows five steps to devise an innovative solution: empathize, define, ideate, prototype, and test. This involves observing real-life contexts, analyzing data to better comprehend user needs, and fostering a creative mindset for idea generation and solution testing [8].

Contrary to traditional product and service design thinking, DT goes beyond merely creating something desirable or aesthetically pleasing. It aims to design something that considers these aspects but also emphasizes cost efficiency and sustainability [9]. We will employ a condensed version of the DT methodology, comprising three steps: immersion (empathy and definitions), ideation, and prototype (including tests).

C. *The PBL/DT Methodology*

Design Thinking (DT) is a dynamic methodology that enhances problem-solving by understanding user needs and incorporating their feedback when creating a product or service.

Design Thinking and Project-Based Learning play a pivotal role in advanced STEM (Science, Technology, Engineering, and Mathematics) education. Design Thinking employs strategies to comprehend design needs and opportunities, visualize and generate innovative ideas, and plan, analyze, and evaluate these ideas against success criteria. It can be particularly useful in understanding and unpacking the STEM problem identified within project-based learning.

Using DT, the students can generate ideas and refine a design through iterative evaluation and testing, thereby developing their skills (both soft and hard) with each iteration.

In a Project-Based Learning environment, students gain knowledge and skills by investigating and responding to a

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complex question, problem, or challenge. PBL addresses interdisciplinary content through rigorous, authentic, practical, and interactive learning experiences. It engages students in opportunities to solve rich and authentic problems, fostering innovation, critical and creative thinking strategies, and collaborative teamwork.

Figure 2 illustrates the proposed integration of PBL and Design Thinking. As depicted, Design Thinking is incorporated as an organizing method for the development of an innovative product within the PBL framework. This provides students with opportunities to develop various skills such as autonomy, leadership, resilience, conflict management, responsibilities, collaboration, communication, and critical thinking, among others [10].

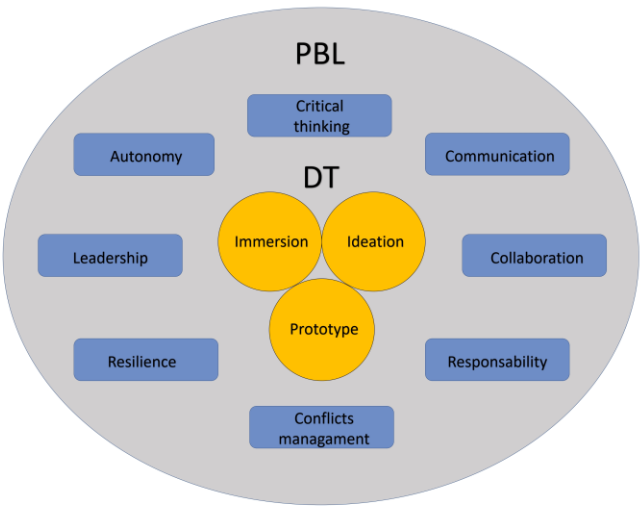

Fig. 2. Integrated PBL-DT teaching and learning methodology. From [10].

It's not a specific method, but an approach that stimulates decision-making and knowledge pursuit through the organization of ideas. It's widely employed in the product and service industry.

III. THE IFAM/LG INDUSTRIAL ROBOTICS TRAINING PROJECT

In Manaus, factories within the Industrial Pole face significant challenges in recruiting professionals skilled in emerging technologies. The disconnect between real-world experience and the demand for technical and social skills can impede these professionals' ability to operate in production areas or oversee production processes. This often mirrors a technological divide between professional practices and academic practices in university laboratories.

In the academic setting, the methodologies employed to facilitate learning in engineering courses are tailored to the educational institutions' environments. They align with the requirements of laboratories designed to aid students in comprehending the content and practices outlined in the course curriculum, thus fostering a more academic practice. It's crucial to note that technological advancements aren't necessarily tied to learning methodologies or curriculum content. Rather, they're frequently driven by the necessity to modernize industrial processes and enhance a company's competitiveness. This results in a gap between the teachings at the university and the practices in the industry.

Academic institutions often struggle to adopt new technologies due to constraints in financial and human resources, which are needed to modernize laboratories with advanced equipment and provide technological training. This is particularly true in remote regions like the Amazon, where Manaus, its largest industrial hub, is geographically isolated from the rest of the country.

To address this, the Brazilian branch of LG Electronics and the Federal Institute of Amazonas have collaborated to initiate the "Advanced Training in Industrial Robotics (ATIR)" project. This project, which runs from March to December 2023, is funded by LG Electronics and includes the establishment of an advanced industrial robotics laboratory. The IFAM has offered a course under the Initial and Continuing Training (FIC) modality, employing an innovative methodology to train two cohorts of students or graduates in automation and control engineering or related fields. The course focuses on advanced industrial robotics applied to real industrial challenges.

LG Electronics invested approximately US$700,000.00 in the ATIR project, mediated by the IFAM Support Foundation (FAEPI), which can be divided into three main stages.

A. *Infrastructure and equipments*

The initial phase, which spanned approximately three months, encompassed the establishment of the Industrial Robotics Laboratory (IRL) and the procurement of furniture and equipment. The laboratory was strategically located adjacent to the IFAM Innovation Pole building.

The Figure 3 showcases the external area, both during construction and post-completion. Internally, it features designated areas for student teams equipped with computers, as well as a separate section housing robots and industrial equipment.

Fig. 3. Industrial Robotics Lab: layout. From Authors (2023).

The laboratory is ingeniously tailored for the PBL/DT methodology, featuring an internal layout that enhances active learning. The area is seamlessly divided into two distinct sections by transparent glass windows, ensuring unobstructed visibility across the space.

The first one consists in a learning and design environment, that is equipped with hexagonal tables designed to accommodate six individuals, forming cohesive teams, promoting student collaboration, and providing a personal space for study, research, and devising solutions to challenges.

The second one is dedicated to the practical application and realization of the proposed solutions, that is furnished with four top-tier industrial robots from Epson, Yaskawa, Staubli, and Universal Cobot, along with Programmable Logic Controllers (PLC), laptops, conveyor systems, sensors, cameras, spare parts, and additional tools necessary for hands-on experiences.

This configuration fosters a dynamic and interactive educational atmosphere, where students can seamlessly transition from theoretical learning to practical technology application.

B. Training's Curriculum and teaching qualifications

The phase involved the selection and training of teachers in the application of the proposed methodology and the equipment (the robots) installed in the lab. Figure 4 showcases the six modules of the training: Multiple Skills and Hands-On (40h), Introduction to Industrial Robotics (40h), Robotics Programming (60h), PLC Programming (60h), HMI Programming (60h), and Computer Vision (60h). Alongside these modules, the Hands-On Journey runs parallel, where student teams develop an innovative solution (DT) while learning the content by developing a project (PBL). The training was focused on the operation and programming of proprietary hardware/software systems, as industrial robots and PLC's.

The teachers underwent training that involved both the PBL/DT methodology to be used throughout the project, as well as specific training on the installation and use of laboratory equipment, in particular industrial robots. Then, the teachers, accompanied by an educational and pedagogical researcher, redefined (adjusted) the contents of each module and prepared teaching plans.

It's crucial to highlight that the initial module "Multiple Skills & Hands-On" was responsible for introducing the students to the PBL/DT methodology and outlining how the entire training would be developed, based on this methodology, culminating with the presentation of the project results on Demoday (a day dedicated to presenting to guests to showcase the achieved results).

C. Student selection and training execution

The third and concluding phase entailed the recruitment of students via a public announcement, succeeded by a three-month training period. The announcement welcomed applications from undergraduate students in related disciplines who had completed at least four semesters, as well as recent engineering graduates from both public and private institutions. The training was organized into two groups, each comprising 15 students, with one group attending in the afternoon and the other in the evening.

Following a comprehensive three-month preparation period, the training program was successfully launched in August 2023. This preparatory phase encompassed the construction of the laboratory, its setup, procurement and installation of necessary equipment, curriculum development, and class organization. This rigorous preparation ensured a smooth transition into the training phase, facilitating an effective learning environment for the participants.

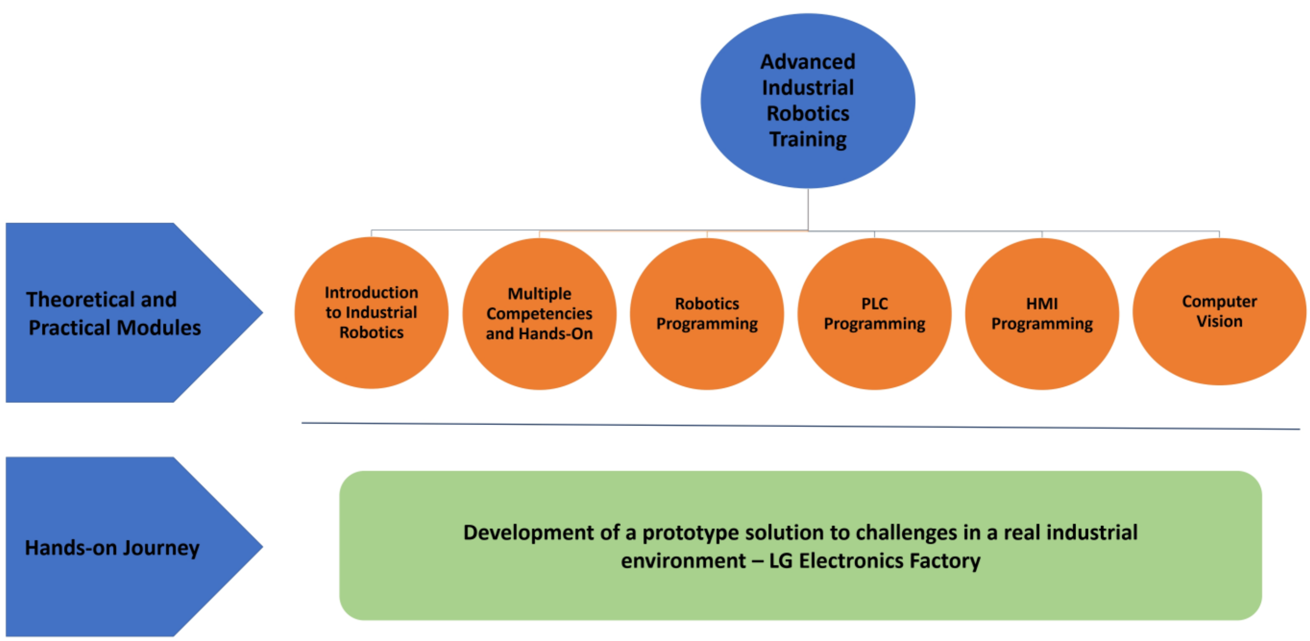

Fig. 4. The industrial robotics training curriculum organization. From Authors (2024).

IV. RESULTS AND DISCUSSIONS

In the context of this paper, while there are several significant aspects such as the partnership with LG Electronics and the challenges of navigating Brazilian bureaucracy to procure equipment and construct a laboratory, our primary focus is on the implementation of the Project-Based Learning/Design Thinking (PBL/DT) Methodology.

Following the acquisition of the necessary equipment, including robots, we initiated the technological training of teachers. Subsequently, we proceeded with their training in the PBL/DT methodology.

This sequential approach ensured a comprehensive understanding and effective application of both the technology and the methodology.

To align the teachers with this methodology, the project's educational researcher facilitated an 8-hour workshop. This workshop offered a blend of theoretical knowledge and practical understanding of the methodology, harmonizing concepts and disseminating tools.

A significant aspect of this training was the transformation of the teacher's role from merely importing knowledge to facilitating learning, acting as a mentor who directed the students' studies and practical actions, without acting as a transmitter of content. The Figure 5 depicts two pivotal moments in the teacher training - the imparting of theoretical knowledge and its practical application.

Fig. 5. Teacher training in PBL/DT methodology. From Authors (2023).

The two classes were divided, each one, into six multidisciplinary teams, that is, diversifying the student's knowledge, and they developed the PBL/DT method stages throughout the training and to present a solution to a real problem presented by LG Electronics. Figure 6 presents moments of this training where they used the methodology.

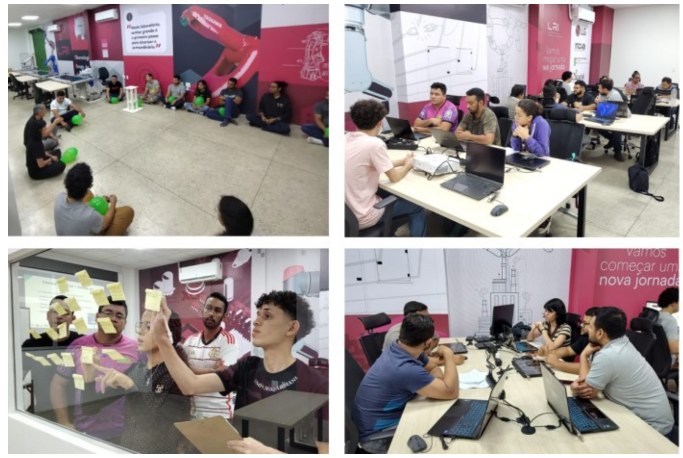

Fig. 6. Teacher training in PBL/DT methodology. From Authors (2023).

With each module developed in the curriculum sequence, the teams progressed in their challenge solutions, utilizing the phases of Design Thinking (DT) within the scope of Project-Based Learning (PBL). The teachers played the role of learning facilitators, sometimes conducting theoretical/practical classes, but primarily acting as mentors to the students.

Throughout the training, we employed formative assessment, which is intrinsically linked to the teaching-learning process. It forms an integral part of the whole and is not merely its end goal. It does not aim to measure learning in quantitative terms, but rather assumes an objectively pedagogical character about what was learned, with a greater emphasis on the process [11].

Upon completion of the modules, the teams had an additional 20 days to finalize their challenge solutions. All project solutions to the challenges were showcased at Demo Day at the conclusion of the training. Figure 7 depicts four teams at Demo Day presenting their proposed solutions to the management, the training teachers, and the partners from LG Electronics.

Fig. 7. Demo Day - presentation of challenges solutions on the Hands On Journey. From Authors (2023).

Upon the completion of each training module, students filled out questionnaires to evaluate the respective module. These evaluations confirmed the positive reception and effectiveness of the employed methodology. However, we will not present these evaluations module by module here due to text limitations and to maintain focus on the overall assessment.

In this questionnaire, a self-perception evaluation was conducted at the end of the entire training via Google Forms. The educational researcher was present to guide the questionnaire process and clarify any doubts from the students. The questions were categorized into three main blocks: evolution of cognitive skills (hard skills), development of socio-emotional knowledge (soft skills), and a general evaluation of the methodology. Figure 8 illustrates the learning performance in the cognitive competencies developed during the training.

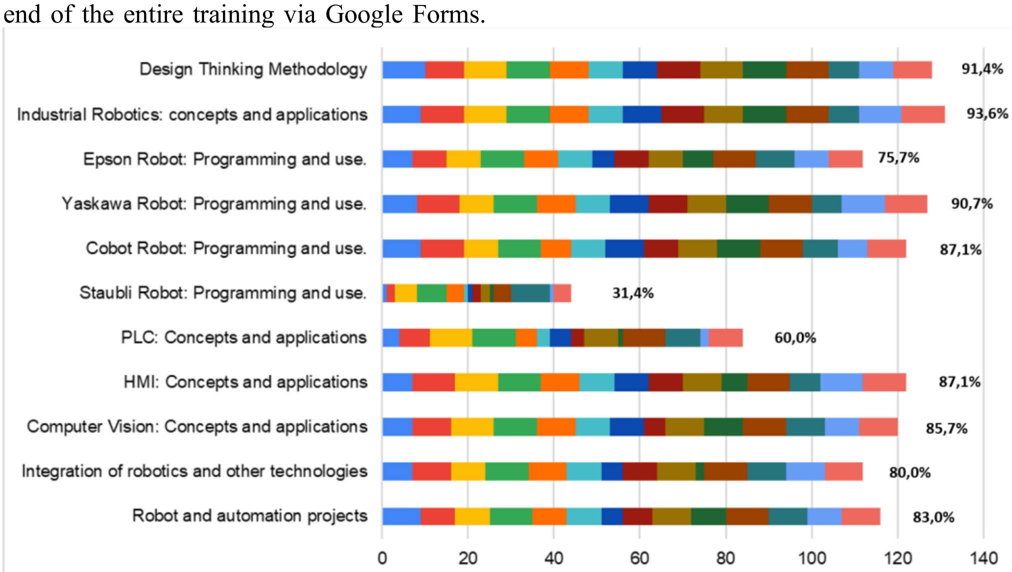

Fig. 8. The learning in cognitive (hard) skills in the main contents. From Authors (2024).

It's noteworthy that most competencies exhibited a performance between 80.0% and 93.6%, indicating a high level of learning. The exception was the learning of PLC, which achieved a moderate performance (60%). This reflects, to some extent, the evaluation of this module, where a more traditional teaching approach by the instructor, who is an engineer and not a career teacher, was identified.

The learning of the Staubli Robot is an outlier due to its delayed delivery to the laboratory, which occurred after the robotics modules. This delay was anticipated. Nevertheless, the students were able to interact with the equipment and achieved a learning rate of 31.4%, without the module classes and solely through self-learning with the PBL/DT methodology applied in the development of each team's project.

The Figure 9 illustrates the average learning performance in the main socio-emotional skills (soft skills) developed during training. These skills were defined with reference to the report "The Future of Job Reports" [2], which describes the skills required for professionals by 2027, from which we chose 13 soft skills.

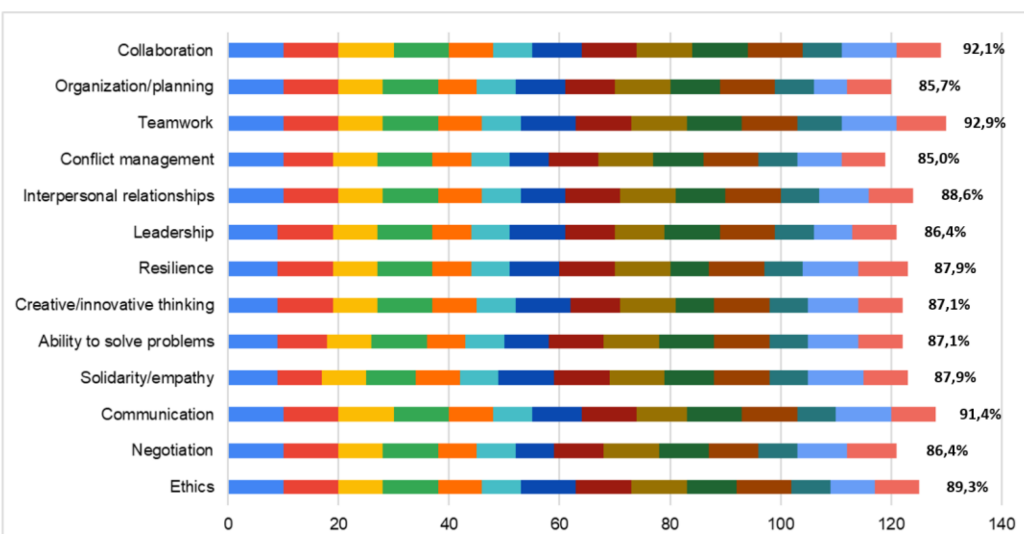

Fig. 9. The Learning in socio-emotional (soft) skills. From Authors (2024).

Relative to the inquiries about the methodology and the training, the questionnaire incorporated two open-ended questions, where the students were free to answer as they want. We had initially planned to employ a Textual Analysis Method [12]. However, given that the responses to the two questions were unanimously positive, we have chosen to present only a selection of these responses in Table 1. These responses serve as evidence of the approval of the PBL/DT Method and the training.

TABLE I. QUALITATIVE ASSESSMENT OF THE METHODOLOGY/TRAINING

Question	Table Column Head
What did you think about the training methodology?	- "I was satisfied with the course, with good modules and teachers too". - "Very good and had great teachers". - "Sensational project". - "I found the training great". - "A great impact on my academic career". - "It incredibly complemented my degree, in which there was not, for example, the methodology of teamwork and hands on". - "I found it excellent, it exceeded expectations". - "Very good, it added a lot to my professional and personal career". - "It will be of extreme importance in my works". - "Great period of learning and personal development". - "Very good, I liked the didactics of the teachers a lot". - "We had many theoretical and practical parts too, which helped us and helped to understand, the real sense of theory". - "The volume of knowledge acquired was extremely high". - "A great opportunity to get to know new learning methodologies".
What skill do you think you developed the most and that was important to you?	- "Teamwork". - "IHM and computer vision". - "Programming of robots" (3 students)". - "Design Thinking and IHM". - "Learn to work in cooperation". - "The skill that I developed the most was in the area of computer vision". - "Leadership and innovative thinking". - "Teamwork and task management". - "Programming techniques and integration between different hardware". - "Teamwork and collaboration with the team". - "Resilience and teamwork".

Source: the authors (2024).

It's noteworthy that all competencies demonstrated a performance ranging between 85.0% and 92.9%, indicating a high level of learning. A significant observation is the visible growth in the socio-emotional maturity of the students, a development that was remarked upon by all teachers and attributed directly to the application of the PBL/DT methodology.

The second question revealed a balance between the perceived importance of cognitive aspects (hard skills) and socio-emotional aspects (soft skills) among the students. We observed seven mentions each in cognitive (hard) skills, with a focus on robotic programming and computer vision, and socio-emotional (soft) skills, with an emphasis on teamwork and innovative thinking.

Upon the successful completion of the training, the students were awarded their certifications in a grand ceremony. This event was graced by the presence of the Dean of IFAM and the Director of LG Electronics in Brazil, adding prestige to the occasion. This certification has empowered the students to work proficiently with industrial robotics.

The Figure 10 provides a visual representation of the ceremony, capturing the proud moments of the students, teachers, and training managers.

Fig. 10. The Students, teachers and management team at the certification ceremony. From Authors (2024).

We view the PBL/DT Methodology as promising for high-level training in Industrial Robotics. It fosters the development of both hard and soft skills in an environment that encourages student autonomy and leadership. The methodology provides a focused and organized approach to structuring innovative thinking, thereby enhancing the development of the process and its outcomes.

A strong indicator of the success of the methodology was the fact that despite the intensive nature of the course (with classes from Monday to Saturday, including four hours of class on Saturday), and the absence of any financial incentives (scholarships) for the students, we achieved a performance rate of 100%. No student dropped out, which is quite unusual for this type of technological training in Brazil.

The partnership between academia and industry synergistically enabled the achievement of the training objectives. It primarily facilitated the necessary investments for a laboratory environment suitable for the project and introduced real challenges from the perspective of meaningful education.

In fact, this project allowed the construction of a high-level laboratory in industrial robotics, trained teachers and students through modern teaching strategies that align with the needs of companies in the Manaus Industrial Pole, qualifying human resources and developing knowledge of new technologies and new teaching methodologies to teachers at the Federal Institute of Amazonas. This will produce short, medium, and long-term results that will impact the training of new professionals and meet the demands for solving industrial problems through industrial robotics. More specifically, the project achieved the following results:

- Conclude the training of 30 undergraduate students in Control and Automation Engineering, Mechanical or Mechatronics Engineering, or related areas.

- Developed and executed theoretical and practical activities for the training modules offered in the project.
- Students experienced collaborative work, resilience, defense of ideas, critical analysis of reality, socio-emotional intelligence, creativity, and other characteristics of soft skills.
- Developed proposals and Minimum Viable Product (MVP) to solve industry problems and identified opportunities for future projects.
- Created strategies for new teaching-learning methods in industrial robotics that align with the needs of the industry and qualify students in cutting-edge technologies for immediate placement of qualified engineers in the Manaus Industrial Pole.

The main contribution of this work was the use of two consolidated methodologies, PBL and DT, extracting the best from each in a positive symbiosis, and aligning it with a partnership between academia and industry that enabled the application and experimentation of PBL/DT in a real situation.

Furthermore, the collaboration with the company has fostered a strong bond with the university, paving the way for innovative technological and educational initiatives. This partnership has led to increased investments, further enriching the training programs in the field of control and automation engineering.

Acknowledgment

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