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A Laboratory-Based Multidisciplinary Approach for Effective Education and Training in Industrial Collaborative Robotics

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Abstract: The rapid evolution of robotics across various sectors, including healthcare, manufacturing, and domestic applications, has underscored a significant workforce skills gap. The shortage of qualified professionals in the labor market has had adverse effects on production capacities. Therefore, the significance of education and training for cultivating a skilled workforce cannot be overstated. This research work presents the development of a pedagogical approach centered on laboratory infrastructure designed specifically with multidisciplinary technologies and strategic human–machine interaction protocols to enhance learning in industrial robotics courses. Progressive competencies in laboratory protocols are developed, focusing on programming and simulating real-world industrial robotics tasks, to bridge the gap between theoretical education and practical industrial applications for higher education students. The proposed infrastructure includes a user-configurable maze comprising different colored elements, defining starting points, endpoints, obstacles, and varying track sections. These elements foster a dynamic and unpredictable learning environment. The infrastructure is fabricated using Computer Numerical Control (CNC) machining and 3D printing techniques. A collaborative robot, the Universal Robots UR3e, is used to navigate the maze and solve the track with advanced computer vision and human–machine communication. The amalgamation of practical experience and collaborative robotics furnishes students with hands-on experience, equipping them with the requisite skills for effective programming and manipulation of robotic devices. Empowering human–machine interaction and human–robot collaboration assists in addressing the industry's demand for skilled labor in operating collaborative robotic manipulators.

Keywords: robotics; industrial robotics; robotics in education; collaborative robotics; UR3e; laboratorial protocols; infrastructure to support teaching

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1. Introduction

In recent years there has been a significant advance in robotics and automation, both in household tasks and in medicine, industry, armed forces, and the list goes on. The main objective goal of this evolution is that there is an adaptation of "*the functions of robots with human needs* (p. 1)" [1]. Nowadays, robotics is part of everyday life; however, there is a misconception that the more robotics take over human tasks, the more unemployment will increase. For an uninformed society, this can be an obstacle to the existing deficit in the advances of robotics [1,2]. This evolution will have a "*positive impact of industrial robots on employment*" (p. 1). The International Federation of Robotics (IFR) predicts that about 4 to 6 million jobs will be created due to robotics. However, if we consider the number of jobs that will also be created indirectly, the number rises to 10 million [1,2].

This rapid advancement of robotization and automation of systems has created a high demand for professionals with specialized training in the field of robotics. This demand must be met by the qualification of new professionals, where education and training in robotics systems will play a fundamental and pivotal role in the high demand/need for professionals in the area. The American Society for Training and Development (ASTD) reported that organizations in the United States of America spend about USD 164.2 billion on employee training [1,2]

Today, there is still a large discrepancy between education and the needs of people, more specifically, in industry. However, if we can bring the two approaches closer together, it will be a plus both for those who seek to take advantage of education, in this case, university higher education, and for those who employ graduates with this background. These employers will feel more comfortable hiring an employee without having to worry about the extra expense and time spent training them to be fit for the job. It is known that specific training will always have to exist due to the constant evolution of science and technology. Still, if we reduce this training, however small the reduction may be, it will be an asset for both the employee and the employer in terms of less time being wasted [2–4].

When thinking about educational robotics, it is necessary to consider a multidisciplinary approach, as it touches fields such as mechanics, electronics, programming, automation, and so on. STEM (science, technology, engineering, and mathematics) is an educational method that aims at interdisciplinarity, among other aspects, addressing various areas of study, including mathematics, science, and technology, and offering new benefits in education at all levels. This approach interconnects all the areas of study necessary for a better approach to industrial robotics, adding that industrial robotics stimulates problem-solving skills, communication skills, teamwork skills, independence, and creativity [3,5–8].

It is estimated that there has been an 18–25% growth in the implementation of industrial robots. For this growth, the demand for new employees with appropriate training and skills is expected to increase. There will also be a need for many employees with robotics skills, with a great capacity for evolution in technology, and with the ability to give short training to workers [2].

The main objective of this paper lies in the development of a protocol with various degrees of difficulty of laboratory work involving programming and testing in real systems of industrial robotics applications, to provide a greater understanding and a smaller discrepancy between educational robotics and industrial robotics in higher education students.

To fulfill the main goal, the following objectives are defined:

- Conduct a literature review on the topics under study—robotics, industrial robotics, educational robotics, and STEM;
- Project an infrastructure and a teaching support system adaptable to various curricular units;
- Develop a laboratory activity and create two laboratory protocols with various degrees of difficulty, based on functions that replicate tasks that are observed in an industrial environment;
- Analyze and discuss the results obtained.

The essence of collaborative robots is that a human being joins their strengths in collaboration with those of the robot, that is, it is a symbiosis between the robot and the human, as shown in Figure 1. This procedural approach offers numerous advantages as robots are capable of continuous operation without any degradation in performance or precision. In contrast, human operators exhibit distinct characteristics. Over time, human workers experience fatigue, leading to a reduced capacity to sustain focus on tasks. This diminished focus results in decreased precision and efficiency, which, for a company, translates into potential profit losses or increased operational expenses [9,10].

In terms of ergonomics, the human capacity to bear weight is constrained by factors such as body size and load-bearing capabilities. These constraints not only prevent the execution of specific tasks but may also lead to fatigue and potentially debilitating musculoskeletal injuries that are challenging to recover from. In the context of bearing loads, robots exhibit their own set of limitations. However, these limitations are primarily related to the maximum load they can bear. Adapting a robot's load capacity to the specific load it is designed to handle is typically sufficient. In contrast to the physical limitations of humans, one of the advantages of utilizing robots lies in their ability to consistently bear loads without interruptions [9,11].

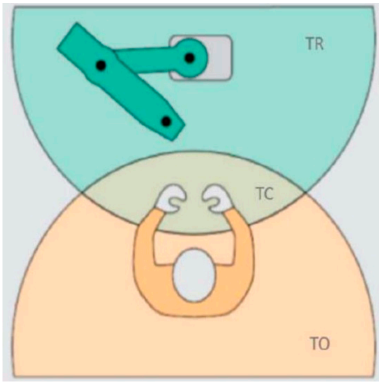


Figure 1. Collaborative workspace. Legend: TR-robot working space; TC-shared workspace; TO-operator workspace (adapted from [10]).

Nonetheless, collaborative robotics presents a multifaceted landscape characterized by a spectrum of advantages, drawbacks, and inherent challenges. This field remains a subject of ongoing research and advancement, offering significant prospects for further exploration. As delineated in Table 1, collaborative robotics presents notable advantages, particularly within industrial contexts. These advantages encompass economic viability, streamlined programming, reduced human effort, resilience to stress, enhanced safety, ergonomic benefits for human workers, facilitation of human–robot collaboration, and a high degree of versatility. Conversely, certain disadvantages, such as variability in operational efficiency, limitations in speed, and occasional constraints on load-bearing capacity due to reduced robustness, are observed.

Table 1. Advantages, disadvantages, and challenges of collaborative robotics (adapted) [10,12].

Advantages	Economic viability
	Human–robot collaboration
	High versatility
	Security
	Ease of programming
	Increased ergonomics
Disadvantages	Low speed
	Low load capacity
	Uncertainties about operational effectiveness
Challenges	Division of tasks
	Adaptability

Regarding challenges, it is imperative to recognize the perpetual potential for advancements in overcoming these challenges. Consequently, the field of collaborative robotics remains in a state of continual development and evolution [10,12].

Education plays a pivotal role in the development of a society, as it is an educated workforce that lays the foundation for the advancement of a nation. The attainment of education can be pursued using a diverse array of methodologies. However, within the context of this article, the focus is directed toward higher education. In an academic setting, the educational process is contingent on a multitude of variables, including (1) the prevailing environment, (2) the specific field of study under consideration, and (3) the level of complexity and rigor required, among other determinants. These very factors assume a central role in determining the pedagogical approach to be used. This encompasses decisions regarding the type of classes to be offered (be they practical or theoretical), whether the educational experience takes place in a field or within the institutional infrastructure, and whether the learning paradigm is oriented toward problem-based self-directed study or guided instruction by an educator. The permutations in educational methodologies are manifold, offering a spectrum of possibilities for educational delivery [1,13].

Using robots in education can be a valuable tool due to its multidisciplinary nature. It covers various subjects like physics, biology, geography, math, electronics, and mechanics. Learning in these areas not only imparts knowledge but also enhances skills such as writing, reading, research, teamwork, critical thinking, decision-making, problem-solving, communication, design, and computational thinking [14].

When researching multidisciplinary robotics in education, the acronym STEM (science, technology, engineering, and mathematics) always comes up as it is related to a multidisciplinary approach in education. Some authors argue that interdisciplinarity is very important in education today as this approach helps students to be better prepared for the constant technological evolution [6–8].

Typically, advancements in industrial robotics are first adopted within the industrial sector before being introduced into educational environments. This precedence is primarily due to the industry's continuous pursuit of increased efficiency, which provides a competitive edge [1].

Educational institutions aspire to reduce the disparity in skills between academia and industry, yet they encounter impediments such as financial constraints, resistance to curriculum updates, and logistical complexities in establishing experiential learning frameworks with industrial collaborators. These hurdles impede students from acquiring practical insights into the industry and gaining hands-on experience with potential work-related challenges, thereby impeding their readiness for their careers [15].

An alternative approach is to reform teaching methodologies within educational institutions, a change principally within the purview of these establishments themselves. Such innovation, however, needs to be an ongoing process, given the constant evolution of the robotics field. As robotics technology continues to advance and find applications in new areas, there will be a growing demand for multidisciplinary skills. Thus, the education sector must keep pace with these developments, consistently updating and expanding its curriculum to prepare students adequately for these emerging opportunities [15,16].

2. Materials and Methods

In the pursuit of developing a protocol within the domain of industrial robotics, we established a robust support infrastructure, which included the creation of a dedicated track. The central focus of this approach revolves around crafting engaging add-ons using 3D printing technology and creating a versatile workspace, both of which play pivotal roles in facilitating a wide array of educational activities. The overarching objective is to actively foster heightened engagement and promote a profound acquisition of knowledge among our students. The infrastructure enables the assembly of a track meticulously designed to be constructed by the robot while obeying the following rules: The pathway, defined by various pieces, was designed for the robot's analysis and construction. The green piece marks the starting point, while the red pieces serve as obstacles that should be avoided during construction. The blue piece designates the endpoint. The track's structure includes pieces of varying lengths. After assembly, the robot places a marble at the initial point, which then traverses the entire track to reach the endpoint. The activity is assembled in a base that has a grid of fittings to allow for precise positioning of the parts that compose both the setup and the track assembly. Figure 2 shows a possible configuration to solve a random setup.

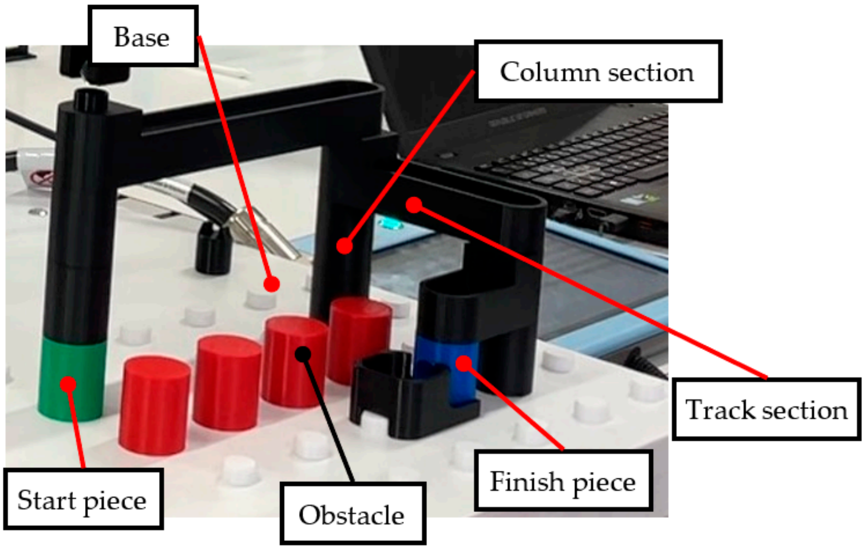


Figure 2. An example of a track constructed with the UR3e. The colored pieces define the path, along with the track made up of black pieces.

The development of the track involved several concepts and phases. In the initial phase, CAD drawings of the track were created, followed by 3D printing for prototyping and testing.

During this initial phase, it was important to test the dimensions of the track, as well as the tolerances for fitting and threading, to better understand which option best met the desired requirements.

The base of the track was developed to support all the fittings that make it up while also serving as a storage location for all the pieces and obstacles developed for this purpose. As shown in Figure 3, the developed base has a configuration to facilitate the manipulation of the parts by the robot and holes that allow the storage of all the parts involved. Its configuration is justified by the robot's working area being circular.

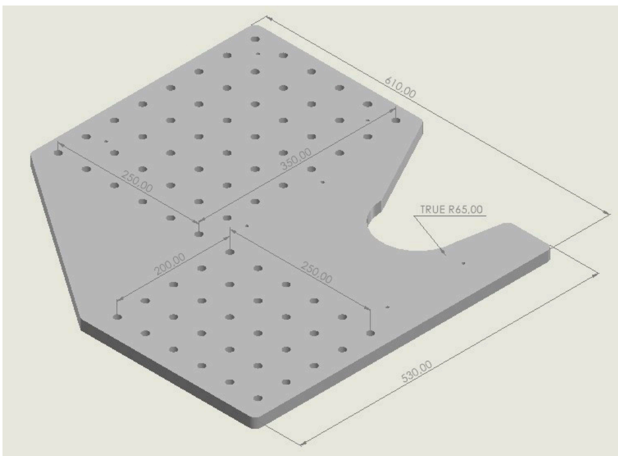
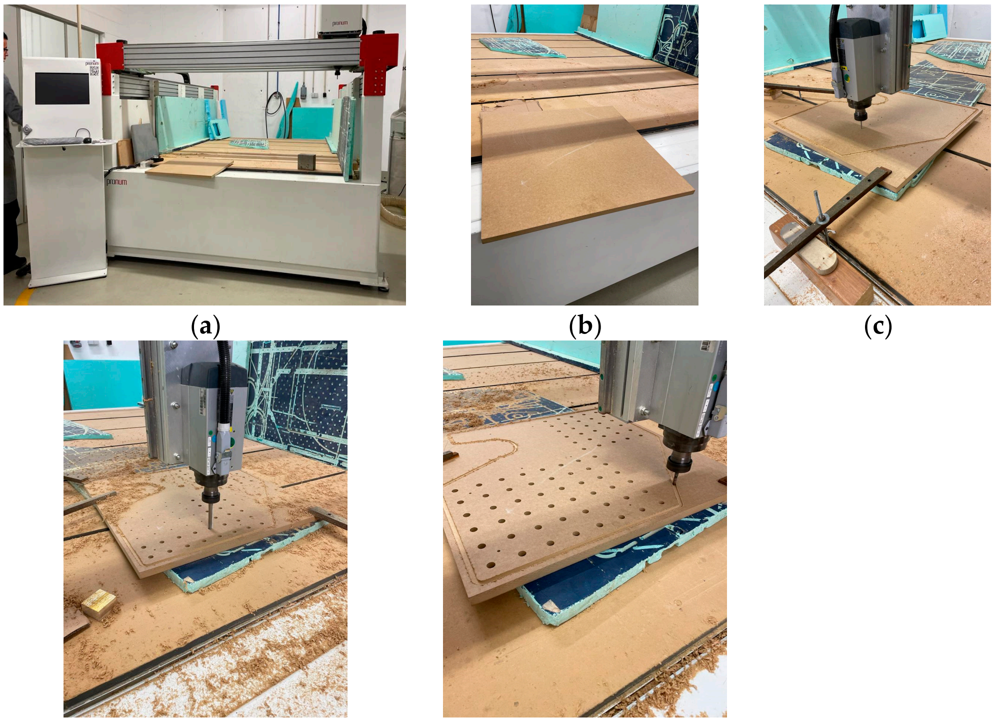


Figure 3. The track base and storage are designed to be adapted to the UR3e framework.

The chosen material for the base of the track was medium-density fiberboard (MDF). It was machined using a Pronun CNC router. The following images depict the machining process: Figure 4a is the Pronun CNC router; Figure 4b shows the wooden board (MDF) 650 mm × 650 mm × 18 mm; Figure 4c shows the drilling machine with a 5 mm diameter; Figure 4d shows the finishing drilling machine with a 13 mm diameter; and Figure 4e shows the milling of the outer contour.



(**a**) (**b**) (**c**) (**d**) (**e**)

Figure 4. The manufacturing process of the wooden board: (**a**) Pronun CNC router; (**b**) wooden board (MDF), 650 mm × 650 mm × 18 mm; (**c**) drilling with a 5 mm diameter; (**d**) drilling with a 13 mm diameter; and (**e**) milling of the outer contour.

Next, the wooden board underwent a surface treatment process to provide greater durability, as shown in Figure 5a. The following images illustrate the surface treatment process after machining: Figure 5a shows the raw wooden board; Figure 5b shows the sanding of the wooden board; Figure 5c shows the application of pore filler on the board; Figure 5d shows the application of paint on the board; and Figure 5e shows the finishing process of the application of matte varnish on the board.

Finally, pins were created, as shown in Figure 6a, to assist with the positioning of the track. These pins were inserted into the holes in the base, as shown in Figure 6b. Several tolerance tests were conducted for the pins, ranging from 12 mm to 13 mm in diameter. The diameter of 12.2 mm proved to be the best fit, as it had a tight fit and required some force to remove, which was perfect for its intended purpose.

One of the final elements created to complete the track was the marble holder support, as shown in Figure 7. It was designed to be fixed in place, with the lower peg allowing the robot to easily retrieve the marble. The detail of this component is that the marble rests on two elements that ensure it remains centered on the piece, facilitating its positioning.

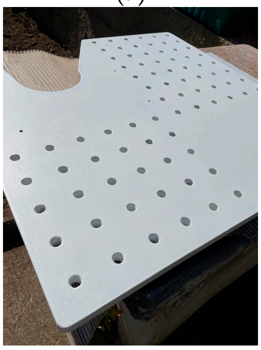
All the pieces have the same height about the z-axis, which facilitates the assembly. Therefore, they are truly differentiated by the length of the track sections. There are 5 different track sections ranging in length from 78 to 263 mm. However, what matters in terms of overall length is the distance between their fittings, as shown in Figure 8, which ranges from 50 to 250 mm with increases of 50 mm in each piece to match the space between the fittings in the base.

In Figure 9, an example of a track assembly of this version with all the elements can be seen. However, there were some issues, such as the fittings not all being the same and the marble not being able to pass through the heights, which would have been advantageous in terms of versatility.


(**a**)


(**b**)


(**c**)


(**d**)

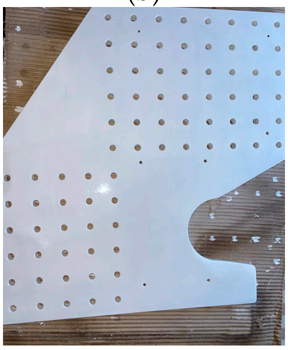
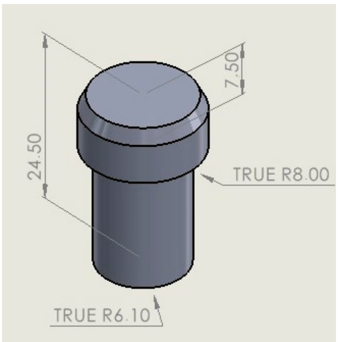

(**e**)

Figure 5. Treatment process: (**a**) raw wooden board; (**b**) sanding the wooden board; (**c**) application of pore filler on the board; (**d**) application of paint on the board; and (**e**) application of matte varnish on the board.



(**a**)

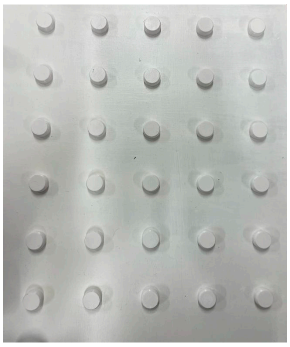

(**b**)

Figure 6. Pin: (**a**) pin and its measurements and (**b**) pins placed in the base.

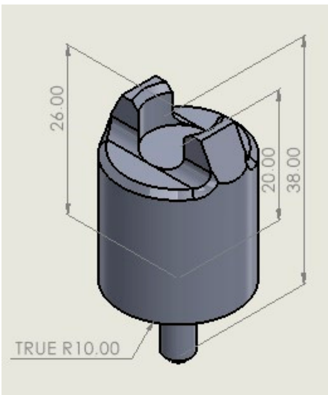


Figure 7. Marble support used in the track.

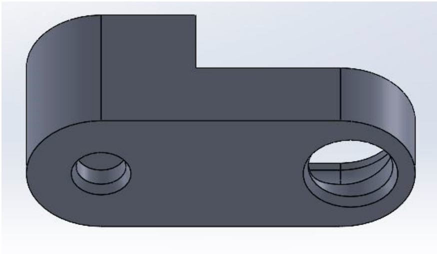


Figure 8. Track section fittings.

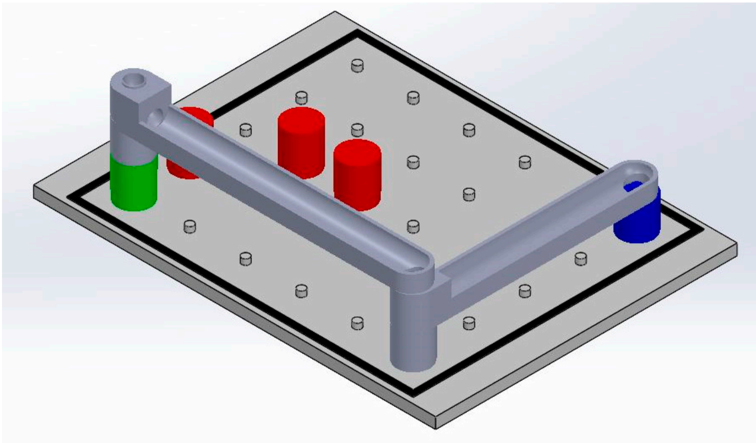
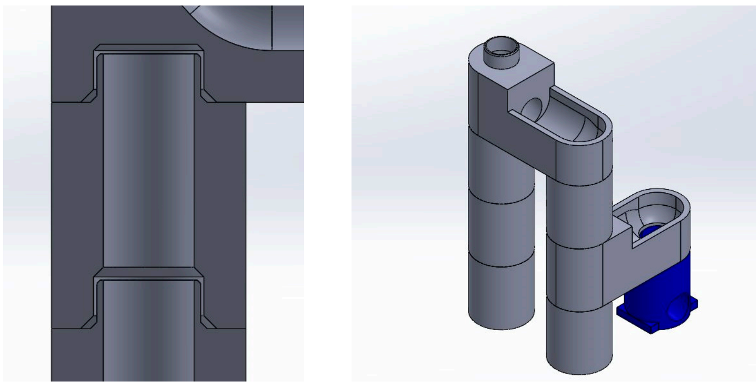


Figure 9. CAD model for a track assembly within the developed framework.

The column section has an interior hole, as shown in Figure 10a, that allows the marble to transition not only from one track section to another but also from a track section to a column section and then to another track section, as depicted in Figure 10b.



(**a**) (**b**)

Figure 10. (**a**) Height tunnel—cross-sectional view. (**b**) Straight to height to straight passage.

It can be observed that the track section fitting shown in Figure 11a enhances the stability of the track. The bottom fittings of this version are all the same, which allows for greater versatility and avoids any stability problems during assembly. The inner tunnel of each track section, as shown in Figure 11b, begins and ends tangentially to the surface of the component, allowing for smooth movement of the marble.

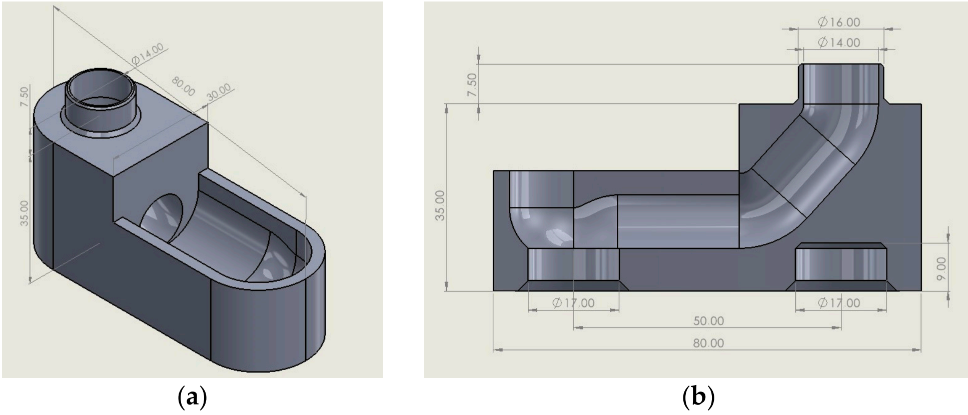


Figure 11. (**a**) Track section 1. (**b**) Fittings of track section 1.

The final piece, as shown in Figure 12a, was designed so that the marble, upon reaching the end of the track, stops in the transport piece, as shown in Figure 12b. The transport piece has a round concavity in its center to minimize the movement of the marble during transportation. It also has lateral tabs that serve as guides when it meets the final component, as depicted in Figure 12c,d.

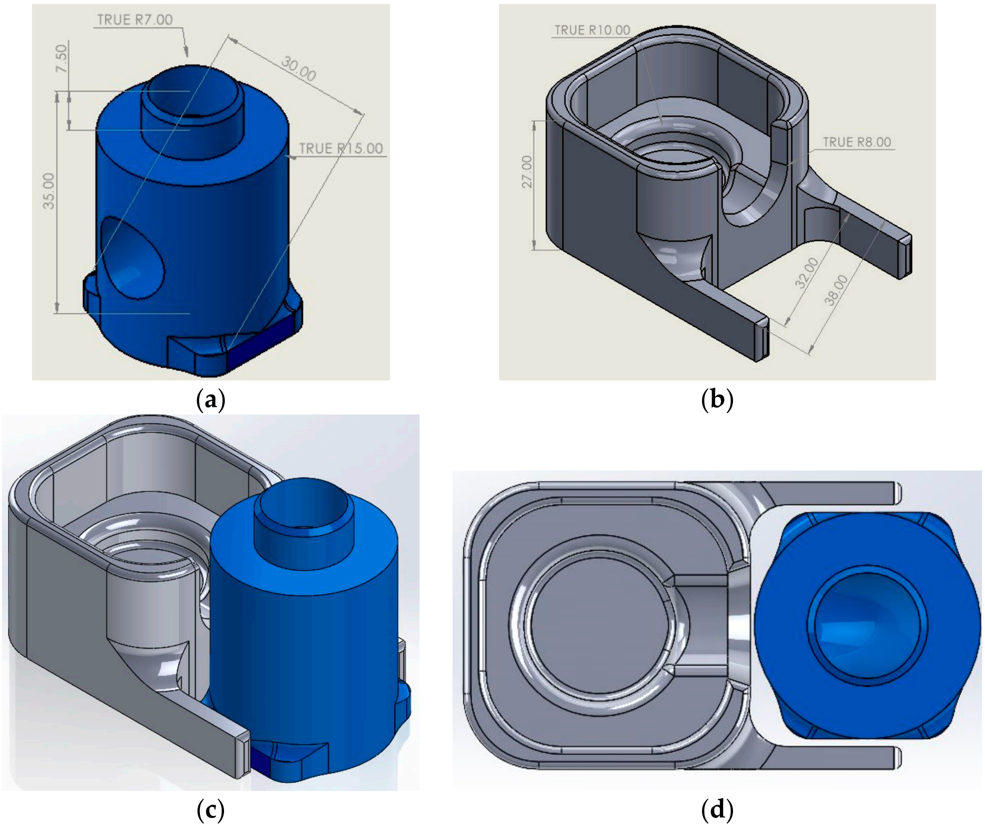
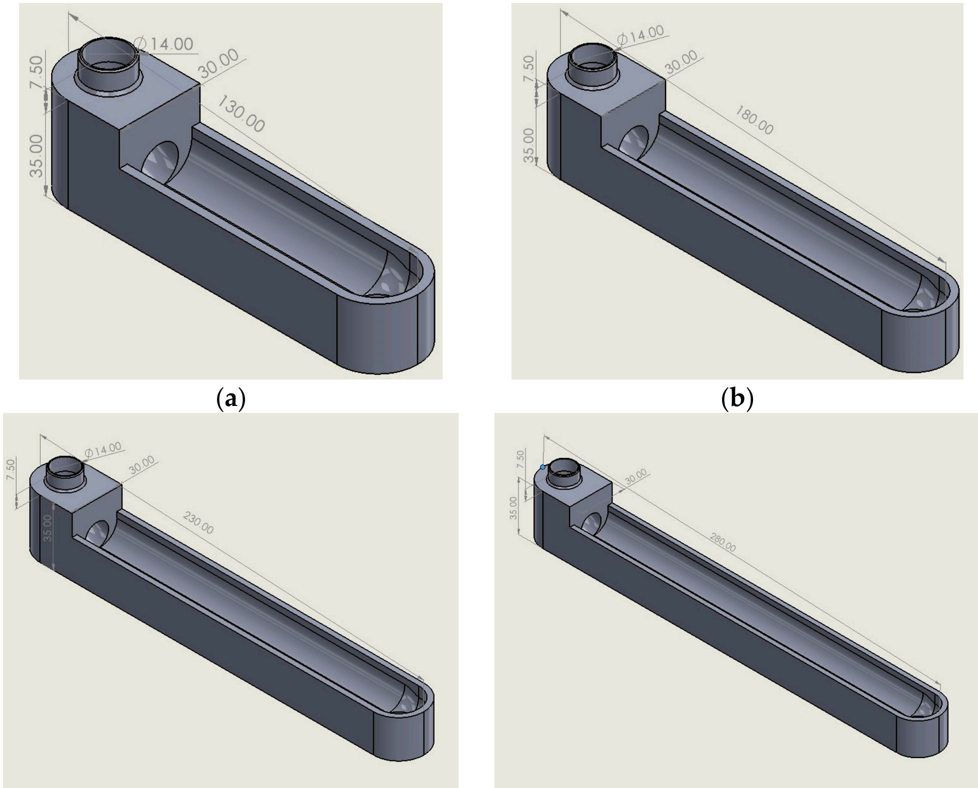


Figure 12. (**a**) Transport component. (**b**) Final component. (**c**) Fitting of the final component and the transport piece. (**d**) Top view of the fitting of the final component and the transport piece.

The remaining sections of the track, namely, section 2, shown in Figure 13a, section 3, shown in Figure 13b, section 4, shown in Figure 13c, and section 5, shown in Figure 13d, are identical to Figure 13a. The only difference lies in the length between the fittings at the bottom, which varies between the intervals of 50 mm, 100 mm, 150 mm, 200 mm, and 250 mm, respectively.



(**a**) (**b**) (**c**) (**d**)

Figure 13. Version 2 of the track sections: (**a**) track section 2, (**b**) track section 3, (**c**) track section 4, and (**d**) rack section 5.

The fittings were modified because they were too small and did not provide sufficient stability. To improve the stability of the track and to avoid the problem of the track falling out during its assembly, the fittings were increased from approximately 2 mm to 7.5 mm, as shown in Figure 14. This increase allowed for a larger contact area, ensuring greater stability.

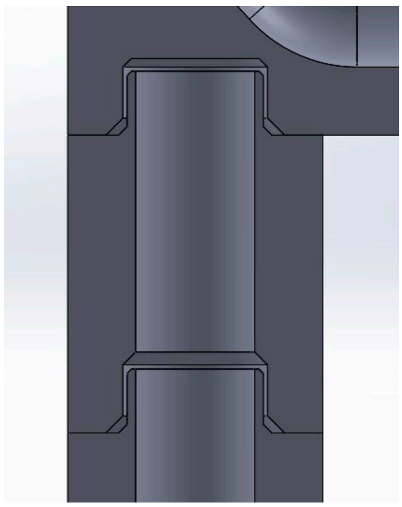


Figure 14. Cross-sectional view of the fittings.

With these components presented, it was possible to assemble the track, as shown in Figure 15. This version was tested and deemed to meet the desired requirements.

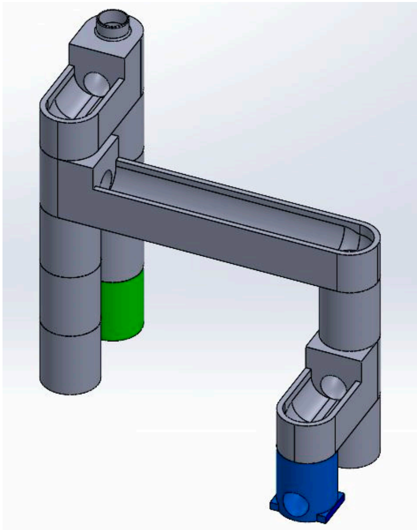


Figure 15. The track built with five iterations, which is the most complex type of path that UR3e can build in this framework.

3. Results

In this section, the procedures and phases entailed in accomplishing the task are explained.

3.1. Infrastructure—Analysis of Stages

The primary objective of this work is the establishment of infrastructure bridging industrial robotics and robotics in education. This infrastructure, as elaborated earlier, underwent multiple iterations to achieve a versatile version suitable for students of varying levels of complexity. The ultimate iteration is capable of not only constructing the shortest path while circumventing obstacles but also offers adaptability for navigating obstacles along the shortest route.

Furthermore, the foundational structure designed to facilitate the assembly and storage of track components can be readily customized with new elements and configurations to accommodate diverse activities. For instance, it can be used for simulating assembly line operations and assessing defects in specific components in terms of their shape, finish (e.g., painting, coating), or welding processes. The potential avenues for advancing this work are limitless.

During this project, a teaching support system was created, which could be the starting point for initiatives in industrial robotics courses or even for more dynamic and interactive demonstrations for students. With some modifications and adaptations, this support material can also be used for other disciplines in the field of industrial automation, which would be an interesting combination from an industrial perspective, as many industries integrate automation with robotics.

3.2. Laboratory Protocols

The two developed protocols are attached. They will differ in terms of their level of difficulty, with the second protocol being the most complex.

The first protocol has four activities designed for students to familiarize themselves with the UR3e robot. This protocol involves assembling the track using the robot pendant and guiding the marble through the track.

The first activity involves arranging the pieces—the initial piece (green piece), final piece (blue piece), and red pieces—in a pre-determined position, and the robot must pick them up and place them in the designated location according to the protocol.

In the second activity, the pieces are placed on a conveyor belt in a known sequence, and the robot must retrieve them from the conveyor belt and assemble them in the predetermined location.

In the third activity, the robot must retrieve the pieces from the conveyor belt, where they are randomly placed, and differentiate them by color using the wrist camera.

The last activity is the building of a track for a predefined and manually assembled challenge. The various components forming the maze are assembled with the manipulator, which needs to be programmed specifically for this manipulation task, demanding heightened complexity due to the precision and orientation requirements of the pieces.

The second protocol, deep in advanced robot programming, provides the student with an approach to research activities. Python implementation is essential to derive an algorithm capable of planning the most efficient path.

Figure 16 displays the layout sequence followed in both protocols. In the first protocol, students create a fixed challenge, meaning the programmed solution only works with that specific challenge layout. However, the second protocol allows for flexible challenges. In this protocol, changes to the challenge layout are accommodated in each attempt, enabled by the integration of a shortest-path planning algorithm.

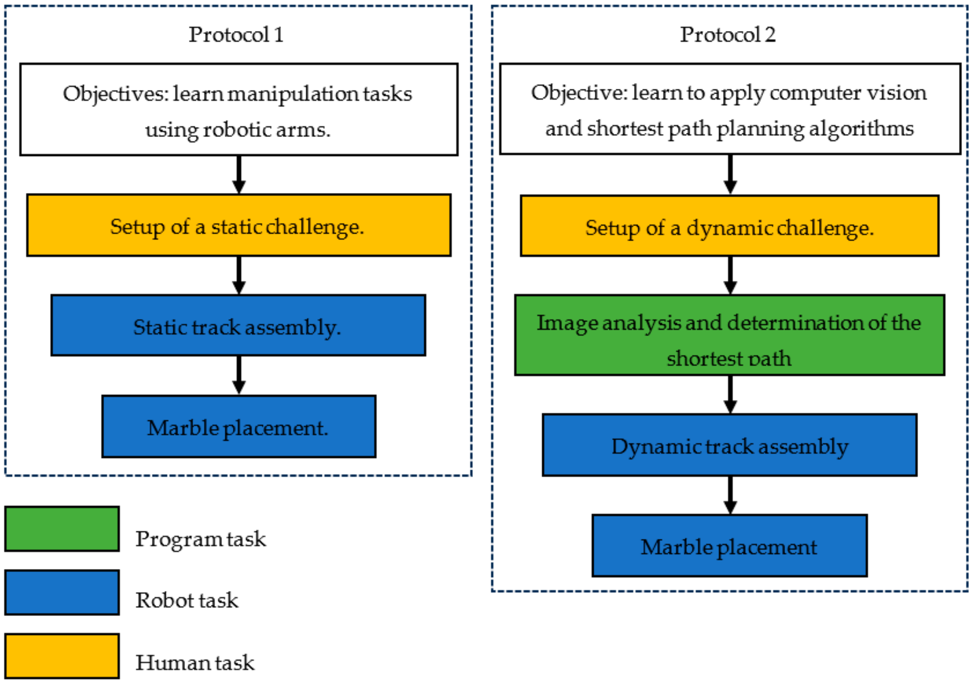


Figure 16. Comprehensive diagram illustrating the protocols developed.

Figure 17 shows a simplified diagram of the program logic. The track can have three possible configurations: a track with one straight piece, a track with two straight pieces and a curve, or a track with three straight pieces and two curves. The arrangement of the pieces in the photograph determines the type of track to be assembled.

When observing the assembly of a track with only one straight piece, it is evident that the fastest path is a straight line, which facilitates the assembly process. However, there can be multiple paths depending on the arrangement of the obstacles and the start and finish pieces. By analyzing Figure 18a, the fastest path between the initial and final points can be determined, as shown in Figure 18b. For this assembly, only one straight piece is required, as shown in Figure 18c. The robot then places the marble at the starting point (green piece) to follow the shortest path through the track to the endpoint (blue piece), as depicted in Figure 18d.

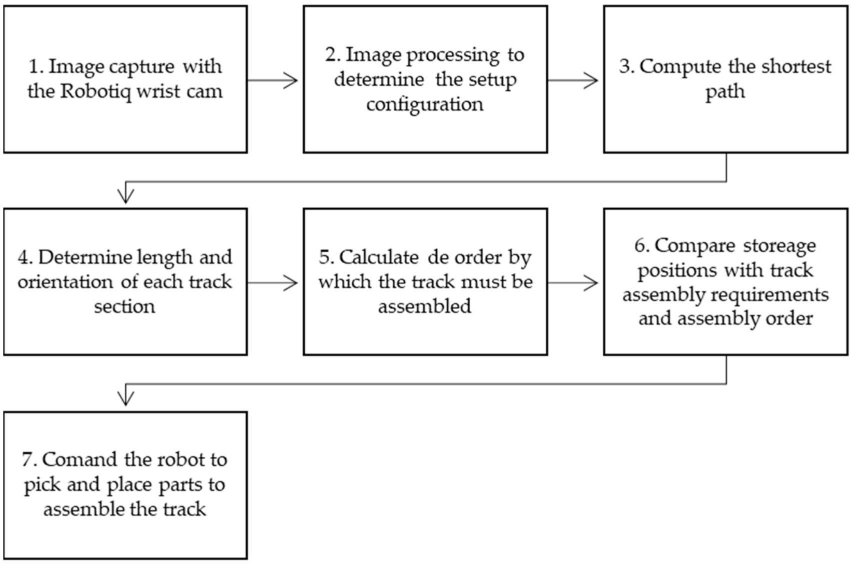


Figure 17. Program flowchart that enables track analysis and assembly.

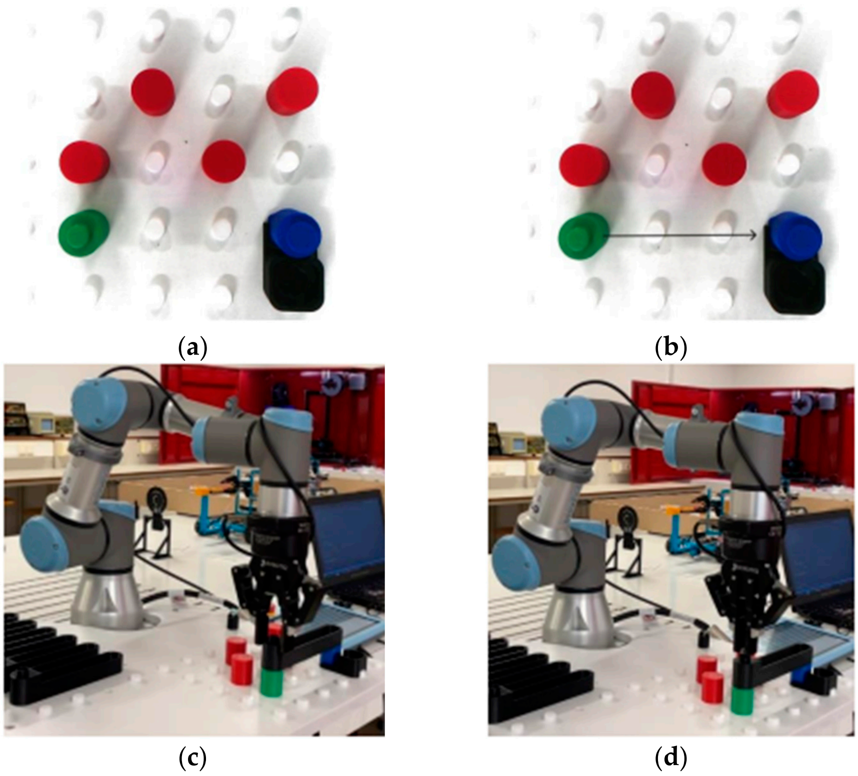


Figure 18. Movement sequence of Protocol 2—track with a single straight. (**a**) Example of piece arrangement. (**b**) Shortest path. (**c**) Assembly level 1. (**d**) Marble placement.

In a track with two straight pieces and a curve, the situation can be different because the arrangement of obstacles can lead to two possibilities of a shorter path. In the example shown in Figure 19a, it is easy to visualize the shortest path, as shown in Figure 19b. For the assembly of this version, four pieces are required: two heights and two straight pieces, divided into three levels of height. In level 1, a height piece is placed, as shown in Figure 19c. In level 2, the final straight piece and a height piece are placed, as depicted in Figure 19d. Finally, in the last level, level 3, the initial straight piece is placed, as shown in Figure 19e. Then, the robot places the marble at the starting point (green piece) to follow the shortest path through the track to the endpoint (blue piece), as shown in Figure 19f.

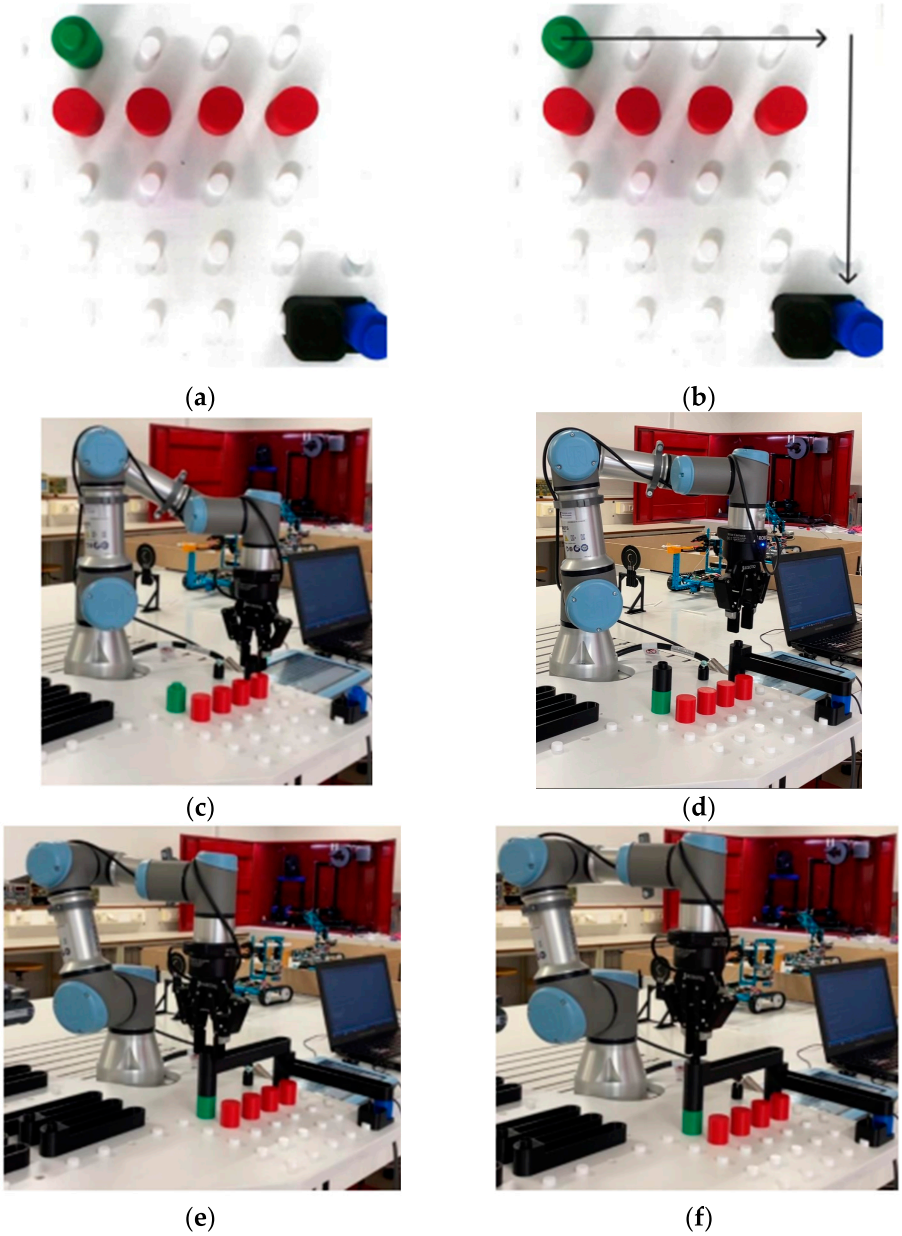
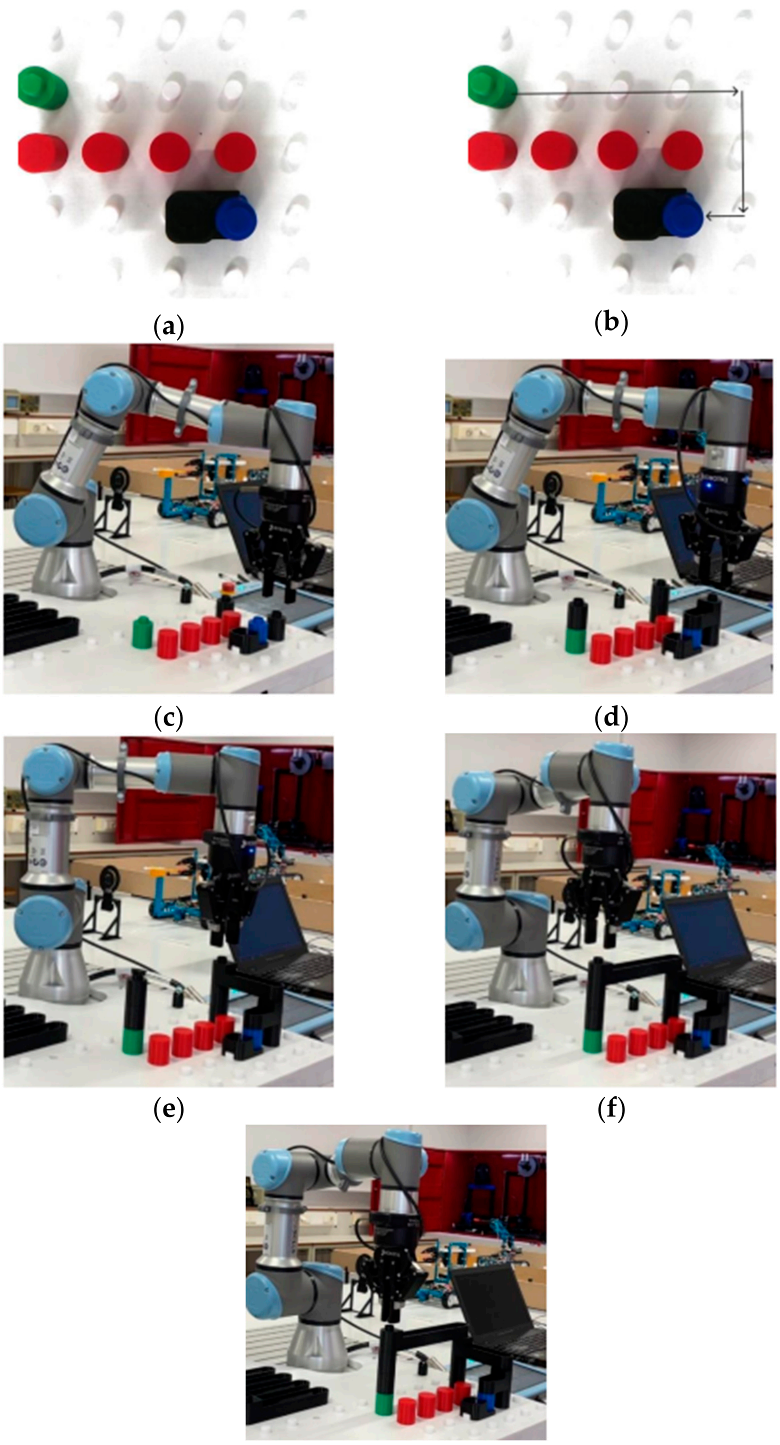


Figure 19. Movement sequence of Protocol 2—track with two straight sections and one curve. (**a**) Setup example. (**b**) Shortest path. (**c**) Assembly level 1. (**d**) Assembly level 2. (**e**) Assembly level 3. (**f**) Placing the marble to travel.

In a path with three tracks and two changes in direction, depending on the arrangement of the obstacles, there can be two possible paths. The following example, Figure 20a, illustrates the shortest path, as shown in Figure 20b. For the assembly of this version, eight pieces including five heights and three straight sections are required, divided into 4 levels. In level 1, two heights are placed, as shown in Figure 20c. In level 2, the final straight section, the intermediate height, and the initial height are placed, as shown in Figure 20d. Then, in level 3, the intermediate straight section and an additional height in the initial position are added, as shown in Figure 20e. In the final level, level 4, the robot places the initial straight section, as shown in Figure 20f. Finally, the robot places the marble to traverse the track from the initial point (green piece) to the final point (blue piece) following the shortest path, as depicted in Figure 20g.



(**a**) (**b**) (**c**) (**d**) (**e**) (**f**) (**g**)

Figure 20. Movement sequence of Protocol 2—track with three straight sections and two curves. (**a**) Example of piece arrangement. (**b**) Shortest path. (**c**) Assembly level 1. (**d**) Assembly level 2. (**e**) Assembly level 3. (**f**) Assembly level 4. (**g**) Placing the marble to traverse the track.

To establish the practical relevance of the proposed activities within industrial contexts, a panel of field specialists analyzed the suggested protocols. During interactive sessions and practical demonstrations, these experts supported the significance of the pick-and-place tasks, highlighting their adaptability to real-world operational scenarios encountered in the industry. They pointed out that, while the activities are designed with a generalist approach, they serve as an essential foundation for implementing specific task modifications in diverse industrial applications. Additionally, some interest was expressed in incorporating these protocols into their training modules, acknowledging the efficacy of the multi-disciplinary methodology proposed for educational and training programs in the domains of automation and robotics.

4. Discussion

Currently, industries face rising pressure to meet consumer demands efficiently and economically. To stay competitive, industries are investing heavily in streamlining production processes to support increasing raw material costs.

This evolution in industries demands a parallel shift in educational paradigms. Educational institutions must renew their approaches, exemplifying theoretical knowledge using more practical and advanced teaching methods. This ensures better-prepared students for the dynamic challenges awaiting them in the professional sphere upon course completion.

The main objective was fully achieved, which was the creation of a support system for education, linking industrial robotics and robotics in education. With the creation of this work, it will be possible for students to participate in didactic learning in a way that is close to the reality of the job market. It allows students to finish their training with minimum knowledge so that when they enter the job market, they are prepared for the problems that may arise. Python's inclusion in the last activities of Protocol 1 and Protocol 2 is primarily due to its widespread use as a requirement in advanced robotics, especially when integrated with computer vision. Throughout the completion of this work, and particularly in the development of the track, there were several iterations. The result was optimized in terms of versatility and ease of use. This version was able to solve the problem of height differences, allowing the track to be assembled without any level differences between the start and end of the straight section. Another problem solved was the absence of curved pieces, which was achieved based on the direction of the track section. For the assembly of the track by the robot, a program was developed where, in the initial phase, all necessary positions were defined and added to the position libraries. Subsequently, this same program analyses the picture taken with the robot arm's camera, detecting the shortest path, upon which the robot assembles the track accordingly. This entire process is determined by the laboratory activity protocols, which present various levels of difficulty. The first protocol involves a series of progressively challenging activities. It begins with simpler tasks focused on assembling parts for the track using the robot's pendant. Subsequently, the second and third activities introduce increased complexity with the integration of sensors and vision, respectively. These activities aim to familiarize students with fundamental robotics concepts and enhance their comfort in operating a robot's pendant. However, to complete all tasks, the utilization of the robot's learning console and an external Python program becomes necessary.

The fourth activity aims to solely use the pendant, consolidating the concepts learned in the preceding activities. This phase encompasses the entire process executed using the pendant interface, thus emphasizing and reinforcing comprehension of previously acquired knowledge.

5. Conclusions

This research highlights the relevant role of a pedagogical approach centered on the development of a specialized infrastructure tailored for collaborative robotics, human–machine interaction protocols, and advanced robotics programming. The establishment of these protocols not only enriches the learning experience within the robotics curriculum but also fosters a platform for future research endeavors and project engagement within the existing laboratories. By emphasizing real-world robotic task programming and simulation, this approach enhances students' skills in programming industrial robotics, thereby fostering their preparedness for the dynamic demands of the industry. As this work progresses, new concepts and themes arise, leading to new questions and ideas for applying the main objective of this work, as well as the development of additional protocols for other applications of robotics in the industry, such as welding, defective material separation, etc. Additionally, the improvement and optimization of the track assembly program, optimizing its size and attempting to make the assembly process faster, will be developed in future work.

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References

1. Do, H.D.; Tsai, K.T.; Wen, J.M.; Huang, S.K. Hard skill gap between University education and the robotic industry. *J. Comput. Inf. Syst.* **2022**, *63*, 24–36. [CrossRef]
2. Sergeyev, A.; Alaraje, N.; Parmar, S.; Kuhl, S.; Druschke, V.; Hooker, J. Promoting industrial robotics education by curriculum, robotic simulation software, and advanced robotic workcell development and implementation. In Proceedings of the 11th Annual IEEE International Systems Conference, SysCon 2017, Montreal, QC, Canada, 24–27 April 2017.
3. Santos, F.C.; Júnior, G.A.S. A dimensão da robótica educacional como espaço educativo. *Dialogia* **2020**, *34*, 50–65. [CrossRef]
4. Uslu, N.A.; Yavuz, G.Ö.; Koçak Usluel, Y. A systematic review study on educational robotics and robots. *Interact. Learn. Environ.* **2022**, *31*, 5874–5898. [CrossRef]
5. Sergeyev, A.; Alaraje, N. Promoting robotics education: Curriculum and state-of-the- art robotics laboratory development. *Technol. Interface J.* **2010**, *10*, 111–115.
6. Gao, X.; Li, P.; Shen, J.; Sun, H. Reviewing assessment of student learning in interdisciplinary STEM education. *Int. J. STEM Educ.* **2020**, *7*, 24. [CrossRef]
7. Li, Y.; Wang, K.; Xiao, Y.; Froyd, J.E. Research and trends in STEM education: A systematic review of journal publications. *Int. J. STEM Educ.* **2020**, *7*, 11. [CrossRef]
8. Navy, S.L.; Kaya, F.; Boone, B.; Brewster, C.; Calvelage, K.; Ferdous, T.; Hood, E.; Sass, L.; Zimmerman, M. Beyond an acronym, STEM is...: Perceptions of STEM. *Sch. Sci. Math.* **2021**, *121*, 36–45. [CrossRef]
9. Hägele, M.; Nilsson, K.; Pires, J.N.; Bischoff, R. Robots at work. In *Springer Handbooks*; Springer Science and Business Media B.V.: Berlin/Heidelberg, Germany, 2016; pp. 1385–1421.
10. Soares, R.; Lucato, A.V.R. Robótica colaborativa na Indústria 4.0, sua importância e desafio. *Rev. Interface Tecnológica* **2021**, *18*, 747–759. [CrossRef]
11. Kirgis, F.-P.; Katsos, P.; Kohlmaier, M. Collaborative Robotics. In *Robotic Fabrication in Architecture, Art and Design*; Springer: Cham, Switzerland, 2016; pp. 448–453.
12. Marques, A.L.; Santos Carrijo, R.; Silva De Morais, A. collaborative robotic: Importance and challenges. In Proceedings of the Conferência de Estudos em Engenharia Elétrica, Uberlândia, Brazil, 7–11 December 2020.
13. Shmatko, N.; Volkova, G. Bridging the skill gap in robotics: Global and National Environment. *SAGE Open* **2020**, *10*, 2158244020958736. [CrossRef]
14. Eguchi, A. Bringing robotics in classrooms. In *Robotics in STEM Education: Redesigning the Learning Experience*; Springer: Cham, Switzerland, 2017; pp. 3–31.

15. Almaleh, A.; Aslam, M.A.; Saeedi, K.; Aljohani, N.R. Align my curriculum: A framework to bridge the gap between acquired university curriculum and required market skills. *Sustainability* **2019**, *11*, 2607. [CrossRef]
16. Mcmurtrey, M.E.; Downey, J.P.; Zeltmann, S.M.; Friedman, W.H. Critical skill sets of entry-level IT professionals: An empirical examination of perceptions from field personnel critical skill sets of entry-level IT professionals. *J. Inf. Technol. Educ.* **2008**, *7*, 101–120.

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