Teaching Cobots in a Workforce Development Environment

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Background

Since the landscape of industrial automation has undergone a significant paradigm shift with the emergence of Collaborative Robots (cobots), the authors decided to develop a non-credit cobots and automation course within a workforce development program. Contributions from the participants are also included in this paper. The authors conducted multiple ASEE Peer Paper Repository searches with the keywords, “cobots” and “cobots and workforce”, yielding 26 and 15 entries. After close examination, the authors realized that only a couple of papers focused on cobot-based efforts in workforce, and most other just mentioned that the cobots have a strong place in future workforce development efforts and in Industry 4.0/5.0.

The program was funded by Block Center for Society and Technology at Carnegie Mellon University after a grant competition, based on prior federal funding it received. This center was envisioned as an interdisciplinary research hub to ensure that technological progress benefits everyone, rather than just a few [1]. The center was built on two pillars: the future of work, and responsible AI and analytics. The future of work is the area where this project belongs. This area examines how automation, robotics, and AI are changing the labor market, while the center focuses on three actions [1]:

- Reskilling and Training: Finding ways to help workers transition into new roles.
- Economic Opportunity: Ensuring that the wealth generated by new tech is distributed equitably across different skill levels and regions.
- Human-Tech Collaboration: Researching how tools can empower workers rather than just replace them.

The program was envisioned as directly adhering to two of the three actions mentioned above, reskilling and human-tech collaboration. The course depicted in the article was the third one in a sequence, taught after Industrial Robots and Programmable Logic Controllers (PLCs). It was designed to be delivered in three stages in 60 hours: an introduction to cobots, interactive e-learning modules offered by the cobot maker, Universal Robots [2], and a hands-on complementary component that included fixed-goal programming and wiring exercises, as well as open-ended ones for workcell development.

Introduction to Cobots

The course was initiated with a brief introduction to collaborative robots, but only one participant of the course had taken the earlier Industrial Robotics course. Throughout the training the instructors made frequent comparisons to industrial robots to refresh the students’ memories , as well as to draw contrasts between them and cobots. This also allowed the participant who did not take the previous course to learn about industrial robots.

Unlike traditional industrial robots that operate behind physical safety cages to protect human workers, cobots are designed to work alongside humans in a shared workspace. The core principle of these systems was first introduced to address the need for robots that could guide human motion rather than replacing it [3]. This evolution is driven by the need for greater flexibility, safety, and cost-effectiveness in manufacturing environments, particularly within Industry 4.0.

The core value of collaborative robotics lies in the synergy between human cognitive abilities—such as problem-solving and adaptability—and the mechanical precision and endurance of robots. As defined by international safety standards, these systems utilize advanced sensors, power-and-force limiting technologies, and vision systems to ensure safe collaboration [4]. By removing the physical barriers of traditional robotic automation, cobots allow for more intuitive human-robot interaction (HRI). This shift is particularly important in assembly lines, where the cooperation between humans and machines can significantly improve workflows and ergonomics [5].

In the first stage, a variety of cobot applications were also introduced along with the content summarized above. The instructors focused on the lead-through programming (a.k.a. free drive) aspect of cobots early on during this stage, again comparing it to the online and off-line programming the participants learned in their industrial robotics course.

The project team had access to a UR5e (Figure 1) [6] cobot purchased through another effort which was completed recently. This robot came with a Robotiq Hand-E Adaptive Gripper (Figure 2a) [7]. A second UR5e cobot was borrowed from a local company along with a two fingered gripper, Robotiq 2F-85 (Figure 2b) Adaptive Gripper [8]. The team purchased a Robotiq Wrist Camera [9] through this project. Since the enrollment was limited to 7 students, two cobots are deemed to be enough for programming and wiring activities. The following section describes the features of this equipment:

Figure 1. UR5e cobot

The UR5e is a 6 degree of freedom (DOF) medium-duty cobot from Universal Robots designed to work safely alongside humans in shared workspaces. It features a 5 kg (11 lbs) payload capacity, an 850 mm (33.5 in) reach, and 0.030 mm (30 microns) repeatability [10] per the ISO 9283 standard [11], making it highly suitable for tasks like assembly and machine tending. Further details of the UR5e system can be found in Appendix A of this paper.

The team's access to the Robotiq Hand-E and 2F-85 adaptive grippers, specifically designed for cobots, enhanced the learning experience since these grippers allow their fingers to automatically conform to the specific shape, size, and geometry of an object without requiring complex programming for every unique item [12], [13]. Details of both grippers can be found in Appendix B.

Figure 2. Robotiq a) Hand-E b) 2F-85 Adaptive Grippers

The Robotiq Wrist Camera (RWC) is a compact plug-and-play vision system designed specifically for Universal Robots (UR). It mounts directly to the robot's wrist—often sandwiched between the arm's faceplate and a gripper—to give the cobot "eyes" for localization, picking, and inspection tasks. Details of this camera can be found in Appendix C of this paper.

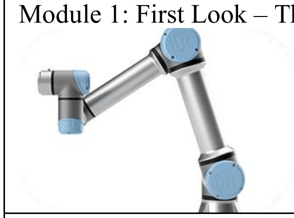
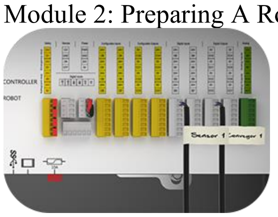
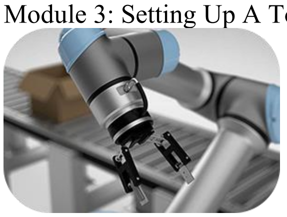
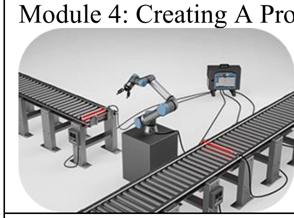
Figure 3. Robotiq Wrist Camera and Gripper

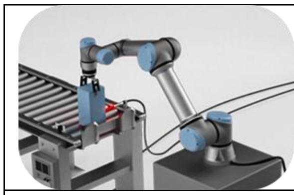
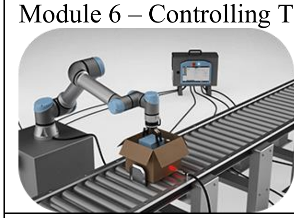
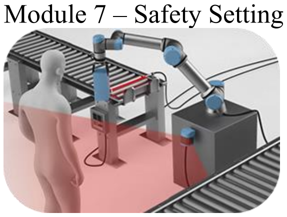
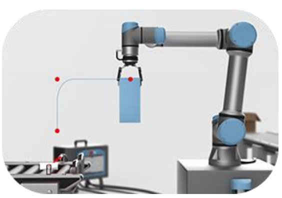
E-Learning

After a brief introductory lecture defining the cobot and contrasting it with industrial robotics and its applications, participants were enrolled in the cobot maker's portal and completed three tracks of modules under the supervision of the instructors. These tracks were: Core, Pro, and Application tracks [14], [15], [16]. The Core track modules included cobot at a first glance, preparing a task, setting up a tool, creating a program, interaction with external devices, controlling conveyors, safety content, and optimization. Building on the Core track, the Pro track offered program flow, feature coordinates, and force control information. Finally, the Application track encompassed handling of palletizing, screwdriving, and machine tending operations.

Core Track Modules were the first segment participants needed to complete to acquire the cobot fundamentals. It is summarized below in Table 1.

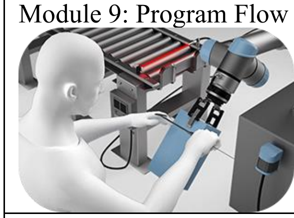
Table 1. Core Track Modules [14]

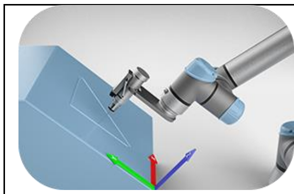
Module 1: First Look – The Robot At A Glance 	This module gives a short introduction to the robot, user interface, I/Os and functions. Key Subjects: Hardware Overview, Control Box, Protective Stop, Teach Pendant, Freedrive
Module 2: Preparing A Robot Task 	The participants will prepare the robot for a pick-and-place task by connecting an end-effector, and by connecting and configuring sensors and conveyors. Key Subjects: Tool connector, Connect sensors, Rename inputs, Application setup, Turn on end-effector, Connect conveyors, Safety control board
Module 3: Setting Up A Tool 	The participants will learn how to find and configure the tool center point (TCP), how to teach tool orientation, and how to teach center of gravity and payload. In the end of the module, they will configure the gripper for the pick-and-place application that was prepared in Module 2. Key subjects: End-effector configuration, Center of gravity, Payload, Tool center point, Orientation
Module 4: Creating A Program 	In this module, the participants will learn about the robot's different motion types, and they will program all the motions and waypoints needed for the pick-and-place application. Key Subjects: Motion types, Waypoints
Module 5: Interaction With External Devices	In this module, the participants will learn how to operate the gripper, how to interact with sensors, and how to change the payload by using set and wait commands. Finally, they will program all the set and

	wait commands needed for the pick-and-place application. Key subjects: Operate gripper, Wait command, Change payload, Set command
Module 6 – Controlling The Conveyors 	In this module, the participants will learn how to control the conveyors by using a thread. Key Subjects: Thread, Conveyors, Variables
Module 7 – Safety Setting 	The participants will learn how to apply different safety settings to the pick-and-place application: - How to trigger reduced mode using a safety scanner - How to trigger a safeguard stop using a safety scanner - How to connect and set up a safeguard reset button - How to connect and set up an external emergency stop button - How to define safety boundaries - How to set up a tool sphere Key Subjects: Safety scanner, Safeguard stop, Safety boundaries, External emergency stop, Reduced mode, Safeguard reset, Tool sphere
Module 8 – Optimizing 	The participants will learn how to optimize the pick-and-place application by adding blend radius to relevant waypoints, and by adjusting speed and acceleration. Key Subjects: Blend radius, Acceleration, Speed

Pro Track builds upon the skills learned in the core track but teaches more complex topics. If you do not already know how to operate a UR robot, Universal Robots strongly recommends that you complete the core track modules before starting the Pro track. Table 2 below summarizes the content of Pro Track modules [15].

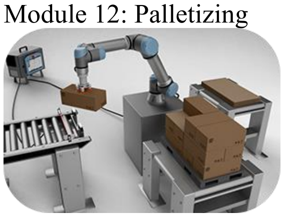
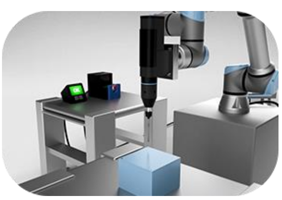
Table 2. Pro Track Modules [15]

Module 9: Program Flow 	The participants will learn how to use variables and if-statements to create a more advanced, non-linear program flow. Key Subjects: Variables, Else-if, Operator input, Subprograms, If-else, Expression editor, Pop-up.
Module 10: Feature Coordinates	In this module, the participants will learn how to create user-defined coordinate systems, how to program

	waypoints relative to a coordinate system, and how to move the robot in different coordinate systems. Key Subjects: Feature coordinates, Move feature, Move robot relative to feature, Create feature, Align robot with feature
Module 11: Force Control 	The participants will learn how to use the robot's force template to apply force in one or more directions. The force functionality is very useful in a number of applications such as polishing, deburring and assembly. Key Subjects: Force control, Deburring, Polishing

Application Track teaches specific knowledge and skills that are applicable to applications such as screwdriving, packaging, and machine tending. Table 3 below summarizes the Application Track's content.

Table 3. Application Track Modules [16]

Module 12: Palletizing 	The participants will learn how to use the pallet template to easily create a palletizing program with different patterns, multiple layers and separators between the layers. Key Subjects: Pallet template, Layers, Patterns, Separator
Module 13: Screwdriving 	The participants will learn how to use an external screwdriver with a UR robot. They can download the entire "Screwdriving" program for URsim by clicking the "Download materials" from the UR link given. Key Subjects: Communication between UR robot and screwdriver, Screwdriving command, TCP and orientation
Module 14: Force Control 	In this module, the participants will learn how to work with dual grippers for maximum efficiency, and how to set up the necessary signals between the robot and a CNC machine. Finally, they will learn how to create a flexible machine tending program that can handle all possible situations: unloading and loading the machine at the same time, loading the machine without unloading a finished part first, or only unloading the machine when there isn't a new part to be loaded in the machine Key Subjects: Dual grippers/TCPs, Communication between robot and machine, Subprograms, Flexible program flow that can handle all possible situations

Hands-On Laboratory

Hands-on labs gave participants the opportunity to gain experience setting up and programming a cobot in a similar way as done in the industry.

Lab 1. Installing a cobot
The participants installed a UR5e cobot shown in Figure 4 loaned from the industry for this course. Students had the opportunity to install and handle the robot themselves. The participants marked the location of the mounting bolts on a wooden table in the lab and drilled the holes, then the robot was attached to the table with the cobot's supplied bolts. The participants experienced how easy it is to move and fully install a cobot, which shows a major advantage of cobots over industrial robots.

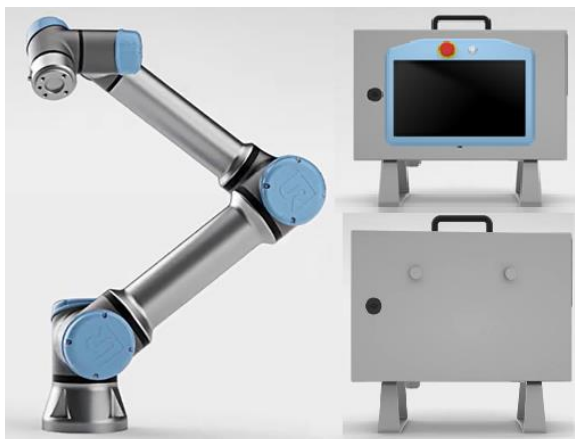


Figure 4. Cobot (showing flange at the end of last link), controller and its teach pendant.

Lab 2. Updating the operating system
Participants realized there was an update available for the operating system (Polyscope) and proceeded to update the operating system by:

- Downloading the operating system from the Universal Robots webpage into a USB drive
- Following the instructions: Setup robot > Update robot > Search (Choose File) > Update Software > Start

The participants realized how easy it is to update the operating software of UR cobot. However, they also had to reset the robot and its settings like the tool frame after the update.

Lab 3. Duplicating some of the critical parts from the online training
After the first two tracks, the hands-on work was gradually introduced, and students learned how to power on and off the cobot, bring it to its home position and manually jog the cobot once the cobot is operational, pushing the free drive button at the top of the teach pendant in Figure 5 allows it to manually move all links of the robot.

Afterwards participants started following content from the e-modules by setting up the cobot, including its tooling (gripper), and writing and executing simple programs.

To set up a gripper it is necessary to define the tool center point (TCP) and the center of gravity (CG). Both locations must be measured from the tool flange of the cobot. In this case, it is very easy to define the TCP as the distance needed can easily be measured in the normal direction of the flange to the midpoint of the points of contact between the load and the gripper. The payload and center of gravity can be easily determined using the cobot's user-friendly program made for this purpose. To do so select Installation > Payload > Next > Set Position > Measure and follow the procedure to select four different positions of the cobot, needed to set up both the payload and CG.

Figure 5. Teach pendant.

Lab 4. RWC installation

Wrist cameras are effective and common tools to locate objects. The participants installed and calibrated the camera following the instructions given in earlier e-learning modules. The video in the link https://www.youtube.com/watch?v=TjlX6mQlEQU&t=62s presents the steps to install the Robotiq wrist camera (RWC). The steps to calibrate the RWC are presented in https://www.youtube.com/watch?v=znRHYE-iAzQ. Appendices A and B include a list with the step by step of these procedures.

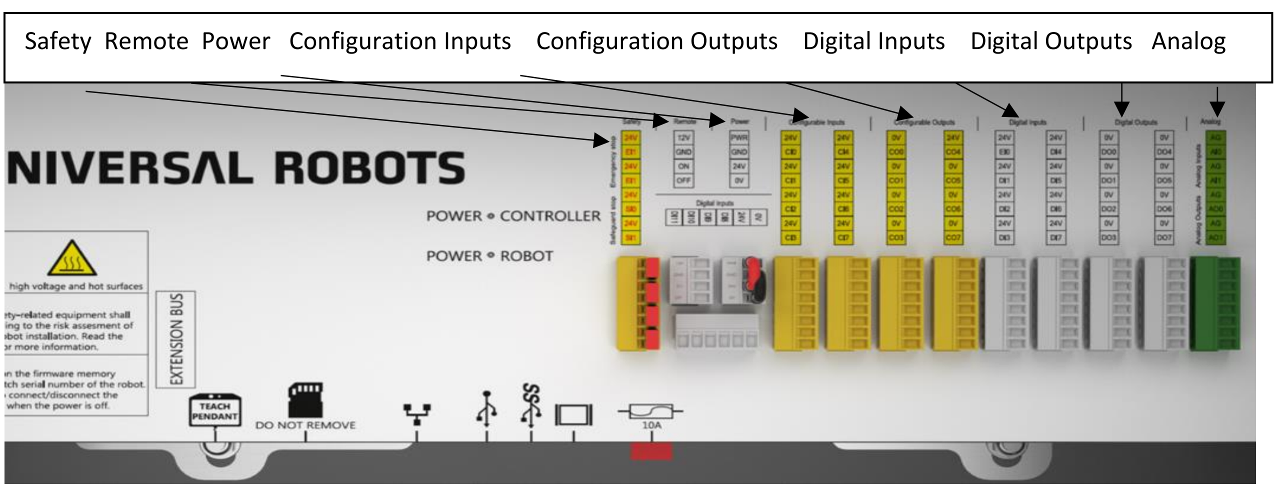


Figure 6. Cobot's controller I/O interfaces.

Lab 5. Building a LEGO tower using VEX sensors to identify color

In this lab participants built a LEGO tower using blocks of size 2 x 2 employing the cobot's interfaces and sensors (Figure 6). The tower is built using three LEGOS with a specific color sequence: red (bottom), blue (middle), and green (top). Blocks of many different colors and two sizes were placed manually on the left of the VEX conveyor (Figure 7). At the end of the conveyor, there is a metal rod that keeps the block on the conveyor, there is also an optical sensor (sensor 1) that sends a signal to the VEX controller to stop the conveyor. This ensures that blocks do not pile up, since the conveyor belt would otherwise constantly be constantly running. When the conveyor stops a signal from the VEX controller is sent to the cobot to pick up the block and hold it in front of two optical sensors (sensors 2 & 3) placed next to each other to determine if the block is 2x2 (only one sensor DI4 detects a block) or 2x4 (both sensors DI4 and DI5 detect a block). 2x4 blocks are sent to a "trash" pile and 2x2 blocks are moved by the cobot to a VEX color sensor (sensor 4). VEX controller's color sensors produce digital signals identified as "DI[1]" (red), "DI[0]" (blue), or "DI[2]" (green). Then, the cobot's controller checks if the color of the block is the one needed to build the tower with the correct color sequence, if it does the block is used to build the tower, otherwise is placed at the beginning of the conveyor. It is necessary to have counters for the red and blue blocks to keep track of which block color is currently needed and to place the block at the appropriate height. When the green block is placed the tower is completed and the program ends.

Each signal from the VEX controller was conditioned using a relay. The students not only analyzed and understood the cell's design and its operation but also learned about I/O wiring and analog and digital signals. Figure 7 below shows the conveyor; blocks are fed on the left and the bar at the right keeps the blocks on the conveyor.

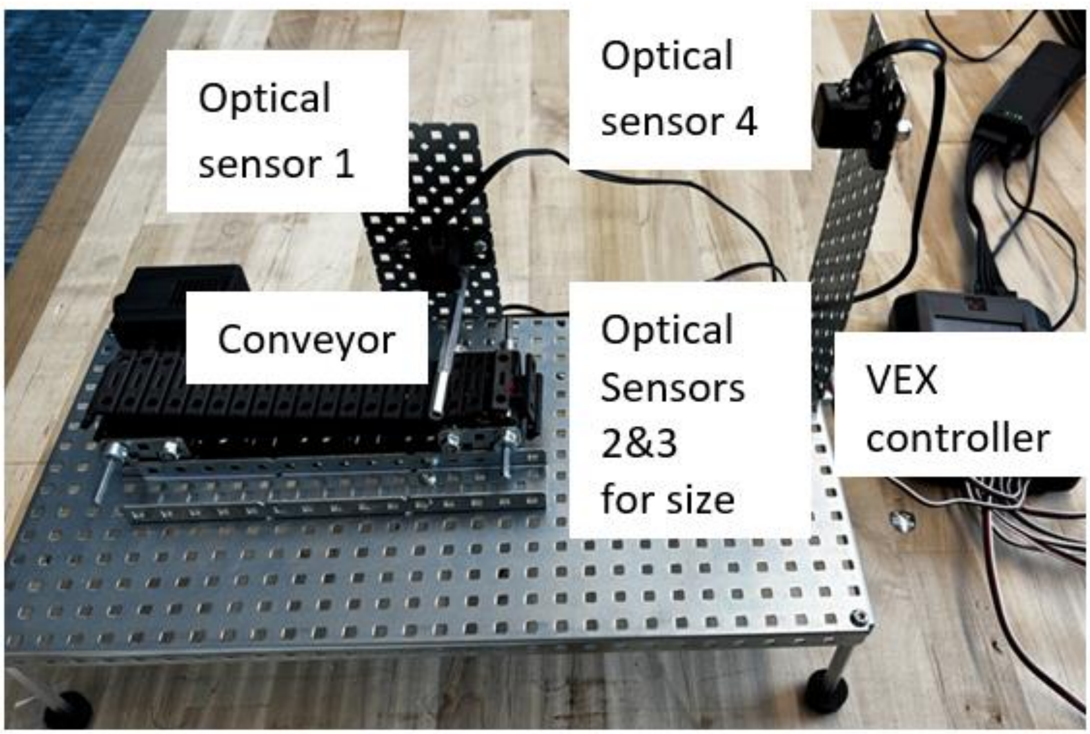


Figure 7. VEX conveyor system

The wiring between the VEX controller and the URe5 controller is shown in the Figure 8 below. The black wire on the right of the VEX controller is the power cable, and the three wires on the top left of the VEX controller power optical sensor 1, conveyor and optical sensor 4.

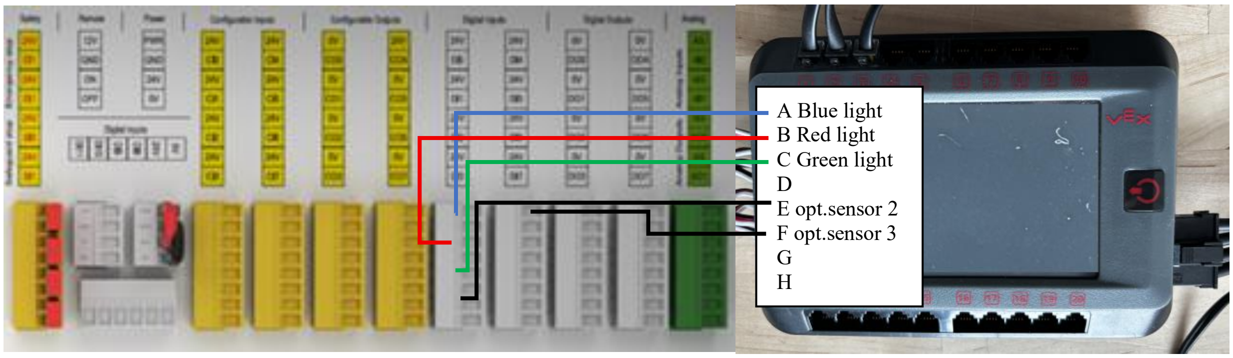


Figure 8. Input wiring schematic

Lab 6. Building a LEGO tower using the cobot's camera to identify color
The objective of this lab was to replace the VEX color sensors with the cobot's vision system. Thus, the same VEX code and hardware were used, but there was no need to send signals to identify the color of the blocks to the cobot's controller. The cobot's path to build the LEGO block is given in Figure 9 below with each critical point being labeled with a number. Figure 10 also shows the logic behind the cobot program that accomplishes assembly of the blocks.

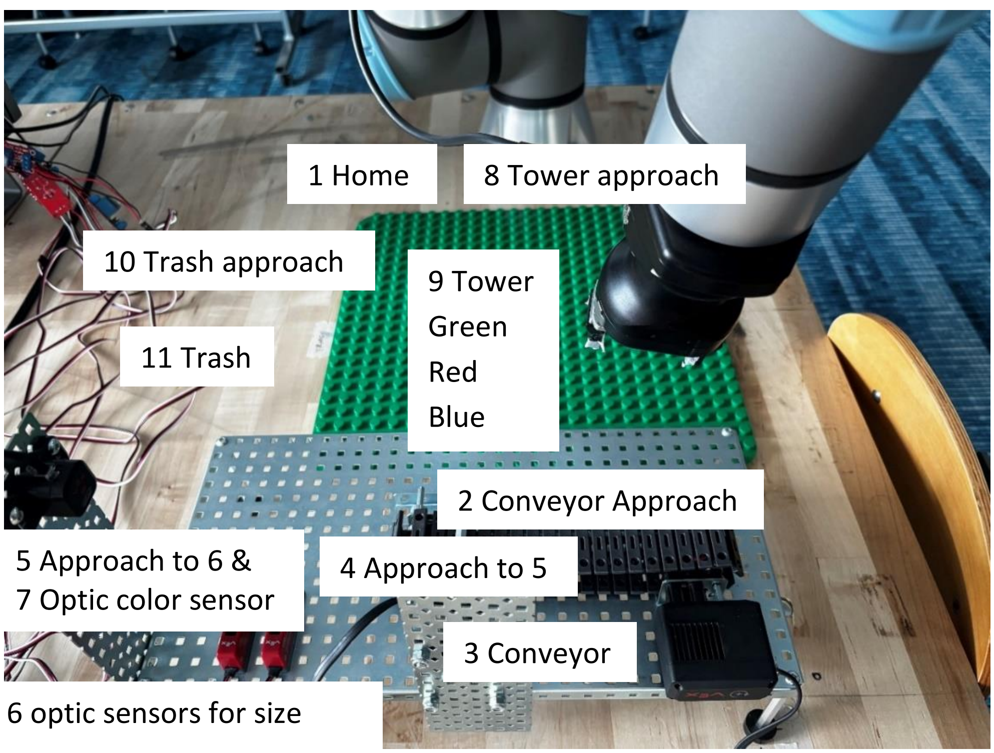


Figure 9. Cobot's path

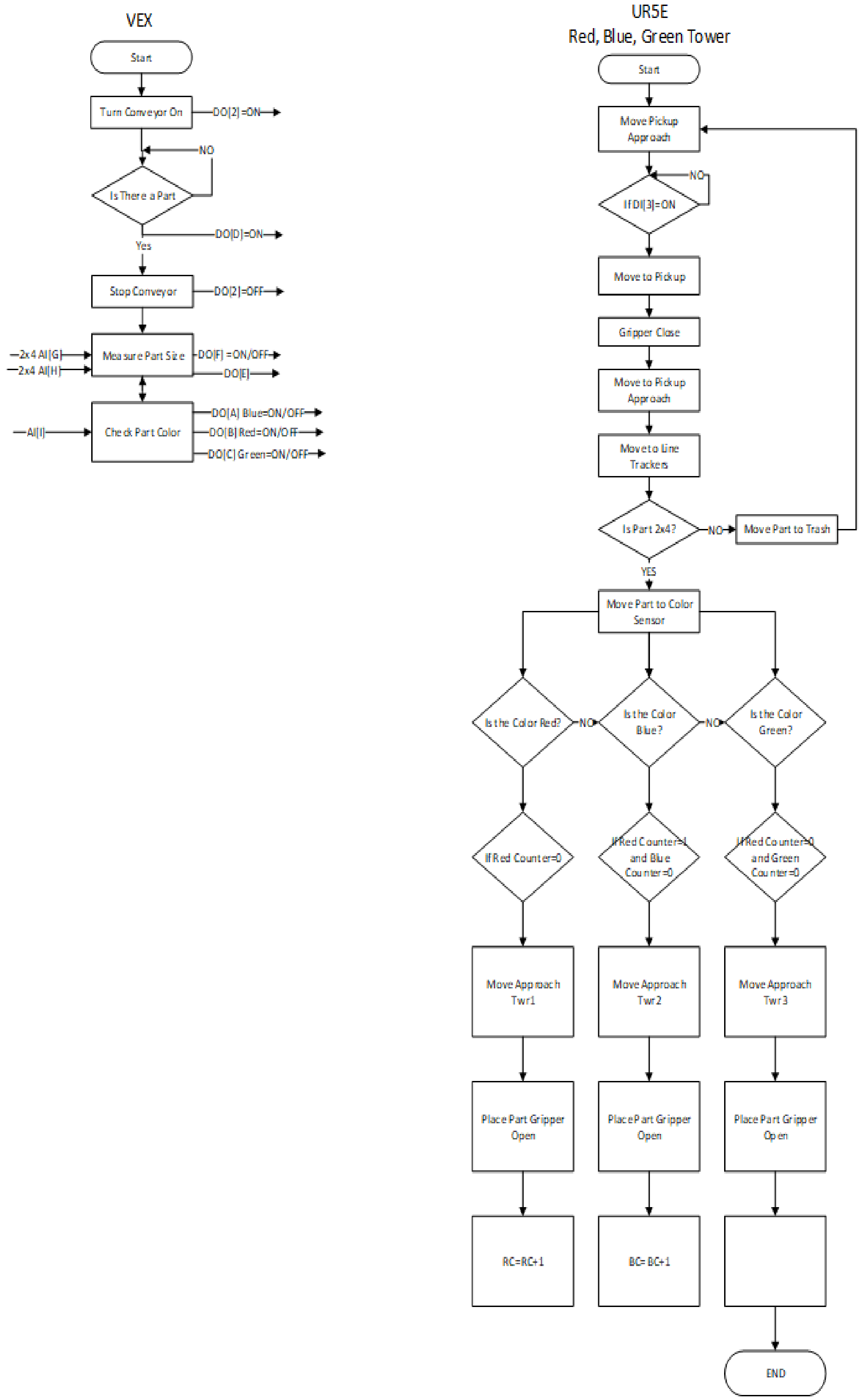
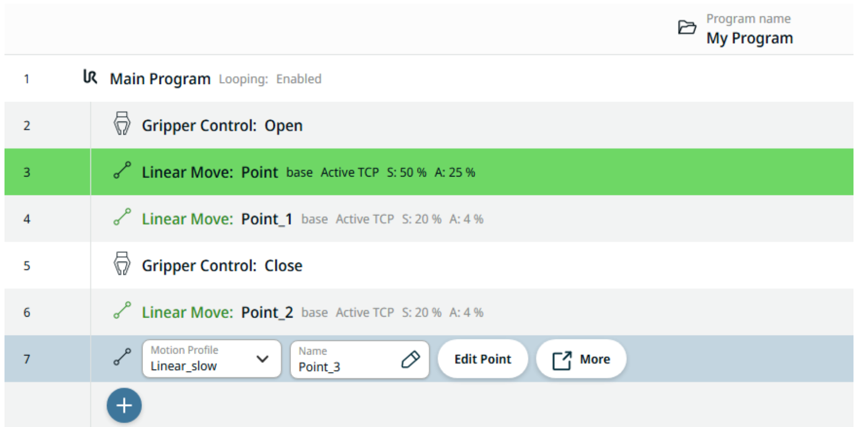


Figure 10. Flowchart for the logic of the LEGO block assembly (tower) with a VEX controller and its sensors including both controllers' contribution

Lab 7 OFFLINE Programming and Simulation with UR Studio
Students used the Universal Robots software UR Studio for offline programming and simulation of the cobot. An example of a short program and simulation screenshots are given in Figures 11a and 11b below.



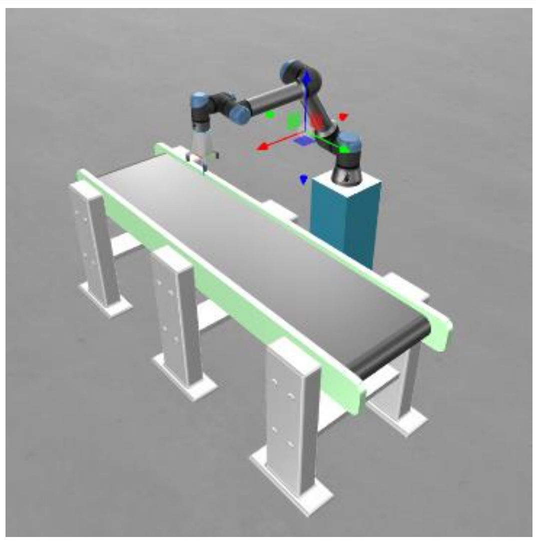


Figure 11. a) UR Studio program example and b) screenshot of the simulation.

Assessment Based-on Participant Feedback

The participant feedback for the UR5e cobot training was overwhelmingly positive, highlighting a successful blend of theory, hands-on hardware interaction, and real-world industrial applications. Summary of the key themes emerging from the participants' responses is presented below:

Technical Skills
Students gained comprehensive expertise in the UR5e platform, specifically focusing on:

- Logic and Programming: Mastering subroutines, program nesting, and "offline" development using UR Studio.
- Vision Systems: Utilizing a wrist-mounted camera for color, shape, and size recognition to perform complex "pick-and-place/assembly" operations.

- Hardware Integration: Configuring end-effectors (grippers), calibrating TCP (Tool Center Point) coordinates, and integrating peripheral systems like VEX controllers.
- Safety Protocols: Implementing Digital/Analog I/O (DI/DO, AI/AO) and collaborative modes to ensure safe human-robot interaction.

Pedagogical Effectiveness
The "flipped classroom" model was cited as a major strength. By using UR Studio for offline simulation and online modules for interface familiarization, students could:

- Test logic and prevent hardware collisions before touching the physical robot.
- Maximize in-class time for high-value tasks like full hardware disassembly, operating system (OS) updates, and troubleshooting.
- Visualize complex automation flows using flowcharts in Visio.

Industrial Relevance & Industry 4.0
Participants noted that the training bridged the gap between the classroom and the workforce:

- Efficiency & Ergonomics: Students learned how cobots optimize production by taking over repetitive or taxing tasks, allowing humans to focus on cognitive problem-solving.
- Professional Impact: One student specifically mentioned using the course's "program structuring" techniques to reduce code complexity and increase reliability at their current job.
- Real-World Exposure: The inclusion of industrial case studies and a site visit to a local business helped students see the UR5e operating in a high-mix, low-volume manufacturing context.

Overall Student Sentiment
The feedback describes the course as "transformative" and "essential." It successfully catered to both beginners—who were introduced to a field they otherwise wouldn't have explored—and experienced professionals seeking to refine their technical toolsets for modern automation.

Conclusions and Future Work

This program is a combination of theoretical content on cobots, handled with an introduction, followed by e-learning modules supplied by the cobot maker (UR) and complemented by the hands-on laboratory exercises. It presents a good integration of theoretical and hands-on components for training, and two of the laboratory exercises were real-life problem-solving projects, where the participants had to assemble LEGO bricks using either simple VEX sensors and their controller or employ a RWC along with its vision software, the URCap. These two exercises involved some open-ended components, where the participants had to make certain decisions about the logic of the process control.

Participants were from military (U.S. Air Force, Navy, Department of Veterans Affairs), and industry. Only one participant out of the seven had previous knowledge about cobots. Six participants completed the training, and each participant earned 3 certificates, one from each track of the Universal Robots e-learning modules. Based on the feedback given in the previous section, the authors can summarize the feedback as follows:

- The participants reported a high level of satisfaction with the UR5e cobot training, consistently highlighting the successful blend of theoretical simulation and practical, hands-on application. A strong feature of the program was the use of UR Studio and a flipped classroom model, which allowed them to master programming logic and offline development along with engaging with physical hardware. This approach maximized in-class efficiency, enabling students to dive deep into complex tasks such as full hardware disassembly/assembly, operating system updates, and Tool Center Point (TCP)/gripper calibration. Students particularly valued the progression from basic VEX sensors to advanced vision-guided systems, culminating in a sophisticated Lego-sorting project that utilized wrist cameras for color and shape recognition.
- Beyond technical skill acquisition, the feedback also emphasizes the "real-world" impact of the course. Participants gained a robust understanding of Industry 4.0/5.0 principles, specifically how collaborative robots improve ergonomics, productivity, and safety in high-mix, low-volume manufacturing. Industry-aligned learners specifically noted that the training in subroutines, I/O safety protocols, and program nesting directly improved their professional workflows, making their industrial cells more reliable and less complex. The inclusion of site visits and the physical installation of new units provided a comprehensive view of the technology's lifecycle, leaving participants feeling confident and inspired to further their studies."

In terms of further discussion about the assessment, this is a skill-based program that also includes theoretical components. The participants not only had to get robot programs running, understand wiring of multiple devices and accomplish handshaking, use and calibrate vision systems, or set a robot gripper with force feedback up and operate it. They also had to take quizzes supplied by the UR company to complete this training successfully. End results will be presented during the conference based on the competencies developed by the participants, possibly by the participants, also including project videos.

Future work will involve offering similar courses that span into the Artificial Intelligence/Machine Learning (AI/ML) area as well as Mixed Reality (ML). The participants already are interested in taking these courses along with additional applicants. There are also plans to purchase lower cost cobots like (UFACTORY equipment) and Intel's RealSense cameras to scale the effort into our undergraduate programs, including the Computer Science Program.

Acknowledgements

The work presented in this paper was supported by Southwestern Pennsylvania New Economy Collaborative using Federal funds under award 01-79-15316 URI 121596 from U.S. Economic Development Administration, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of the U.S. Economic Development Administration or the U.S. Department of Commerce.

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Appendix A – Specifications of UR5e

- The system includes 17 configurable safety functions, such as stopping time/distance, joint force and torque limits, joint position/speed limits, tool position (TCP)/speed which comply with the ISO 10218-1 foundational safety standard for industrial robots [17]. Furthermore, it is certified to Performance Level d (PLd) Category 3 under ISO 13849-1 [18]. This certification indicates that a single technical failure will not lead to the loss of safety functions, providing reliability equivalent to Safety Integrity Level 2 (SIL 2).
- While the robot itself is covered by general standards, ISO/TS 15066 provides specific "rules of engagement" for human-robot interaction [19]. This technical specification defines biomechanical limits for force and pressure on the human body and establishes the Power and Force Limiting (PFL) collaborative mode used by the UR5e. When the safety system is triggered, the UR5e utilizes stop types defined by the IEC 60204-1 standard [20]: a Category 1 stop for emergencies, and a Category 2 stop for safeguards.
- Biomechanical Limits: These standards define the maximum permissible forces and pressures that can be safely applied to different regions of the human body. For example, they specify how much impact force a robot may exert on an arm versus the chest before there is a risk of injury. This ensures that any physical contact between a robot and a human remains within medically safe thresholds.
- Collaborative Modes: The standards also outline four recognized modes of human–robot collaboration. The UR5e primarily operates under the *Power and Force Limiting (PFL)* mode, in which the robot's speed, torque, and applied force are carefully restricted. This ensures that, if contact occurs, it remains non-hazardous to nearby personnel.
- Workspace Restrictions & Safety Boundaries (Safety Planes): Collaborative robots can be programmed with virtual safety boundaries—often referred to as safety planes or restricted workspaces—that define areas the robot is not allowed to enter. These boundaries act as invisible walls within the robot's operating environment, preventing the cobot from crossing into unsafe or unauthorized zones. Using the robot's safety configuration software, authorized users can define multiple planes in three-dimensional space. Each plane can be assigned specific rules, such as completely stopping motion, limiting speed, or restricting tool orientation when the robot approaches the boundary. This allows the system to enforce physical separation between the robot and sensitive areas, such as human walkways, control panels, or delicate equipment. Safety planes are especially important in collaborative environments where humans and robots work in close proximity. By restricting the robot's motion to a defined "safe zone," the risk of accidental contact or interference is significantly reduced. If the robot attempts to move beyond the allowed workspace, the controller will automatically prevent the motion or trigger a safe stop. This virtual "plane of existence" ensures that the cobot operates only within approved regions of the workspace, maintaining predictable behavior and enhancing overall system safety without the need for physical barriers.

Table A1. When the safety system is triggered, the UR5e uses specific stop types defined by the IEC 60204-1 standard

Feature	Stop Category	Description
Emergency Stop	Category 1	A controlled stop where power is kept to the motors to decelerate quickly, then removed once stopped.
Safeguard Stop	Category 2	A controlled stop where power is maintained to the motors so the robot can resume work immediately once the safety signal is cleared.

In summary, the UR5e offers three distinct advantages: intuitive lead-through programming, integrated force/torque sensing at the tool flange for high-precision tasks, and a lightweight 20.6 kg design in a small footprint that allows for flexible deployment across the factory floor.

Appendix B – Specifications of Robotiq Hand-E and 2F-85

Even though it only has a safety rating of IP 40, this versatility is well demonstrated by the 2F-85, which utilizes a specific finger design to transition between parallel gripping, clamping flat surfaces, and an encompassing grip, wrapping around cylindrical or irregular objects [17]. While the 2F-85 is the world's best-selling gripper for general-purpose high-flexibility tasks with an 85 mm stroke, the Hand-E is engineered for higher precision and durability [21], [22]. Featuring a 50 mm stroke and an IP67 rating, the Hand-E is ideal for harsh industrial environments like CNC machine tending where exposure to dust or fluids is common [23]. Both models integrate seamlessly with cobots through "Plug + Play" software, allowing operators to control grip force and speed to safely handle everything from heavy metal parts to fragile components [21], [23].

Appendix C – Specifications of Robot Wrist Camera

The RWC is lightweight (160 g), IP67-rated vision system that integrates directly into the cobot's tool flange. It utilizes a 5 MP color sensor with adjustable focus to perform part localization and inspection [21]. The camera is suited for flexible manufacturing because it does not require fixed external mounting; instead, it moves with the robot to view parts from multiple angles. The hardware is controlled via URCap, which is a software "plugin" for the Universal Robots PolyScope operating system. Much like a smartphone app, a URCap simplifies complex automation by providing:

- Installation Nodes: For hardware configuration and calibration.
- Program Nodes: "Drag-and-drop" command (e.g., "Camera Locate") that replace manual scripting.

The RWC URCap enables the robot to identify parts through three primary methods: Automatic (teaching by showing a part), Parametric (defining geometric shapes), and CAD Import (using .dxf files for complex geometries) [24], [25]. Two standout features include:

- Visual Offset: Using a "Robotiq Tag," the camera can detect if a workstation has shifted and automatically recalibrates the robot's entire program to match the new position.
- Traceability: The system can read 1D and 2D barcodes, allowing the robot to perform data logging and sorting based on serial numbers during the production cycle [24].

Appendix D - Lab 4. RWC installation

The following steps are necessary to install the camera based on the instructions given in earlier e-training modules:

a) URCap files were downloaded from robotiq.com/support webpage and extracted in a USB drive.
b) The camera was mounted on the robot with the proper alignment
c) The gripper was mounted to the camera
d) The wire of the camera was secured to each link of the robot. This wire has a USB and red and black wires.
e) The red wire of the camera was connected to the cobot's controller using a 24V terminal connector (top left of the configurable inputs section – Figure 6)
f) The black wire of the camera was connected to the cobot's controller using a 0V terminal connector (top left of the configurable outputs section. See Figure 6)
g) The USB cable was connected to the supplied four port USB hub. The USB with the vision server and the USB vision server's license dongle were also connected to the four port USB hub. Then the USB four port hub was connected to the controller.
h) The robot was turned on. In the triple bar icon and the following selections were made Settings > System > URCap > + > usbdrive > downloaded file > Open
i) To check proper installation the following selections were made: Installation icon > URCaps > Camera > Dashboard > Install vision server > Update camera firmware > Start Camera

Appendix E. Lab 4. RWC calibration

The following steps are necessary to calibrate the camera based on the instructions given in earlier e-training modules:

a) Select Installation > URCaps > Camera > Snapshot > +
b) Write a name.
c) Select Full Calibration
d) Place the robot in such a way that the calibration board is in the camera's view.
e) Select Hold to Align the Axis
f) Select the Calibrate button. The robot will take 36 pictures. Select Accept.
g) Place the object to be recognized on the camera, filling at least one square of the grid. Select Hold to Align Over. Save the calibration position. Then save the calibration. There are other options to improve the calibration not included in this work.