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VEX V5 Workcell: Industrial Robotic Arm Model for STEM Education (Other)

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Introduction

The use of robotics in education has become an interdisciplinary, hands-on, authentic learning experience for students of all ages. Robots not only are interesting and engaging to students, but they also provide a physical representation of abstract concepts such as coding. With technology continuously evolving and programming becoming a desirable skill, secondary educational institutions are wanting to prepare their students for the workforce by introducing them to industrial robotics and manufacturing. Industrial robots are programmable machines that are designed to perform a specific task or function like assembly or welding[1]. Even though students are showing an interest in robotics and manufacturing, there are two main barriers when introducing industrial robotics to students in high school, a technical school, or postsecondary education. These two barriers are the high cost of industrial equipment and the barrier of entry for programming novices. Both of these problems result in a high barrier of entry for both educators and students, as well as limited accessibility to certain equipment. This paper discusses how the VEX V5 Workcell may be a solution to introducing industrial robotics in an educational setting.

Finding Affordable Reconfigurable and Scalable Robotic Systems for Educational Settings

As technology advances, more and more students are becoming interested in robotics as a career. Robotics can also spark student interest in the science and mathematical fields, as well as give students the opportunity to practice problem solving and logical thinking[2]. However, there are limitations to bringing industrial robots into an educational setting to prepare these students to be successful in a manufacturing career. It is costly to not only purchase, but also costly to maintain a working robotic arm. These cost issues can limit the number of robots that the students can interact with and consequently, limit the amount of student independent hands-on engagement[3]. Industrial size robotic arms also require a great amount of space, and there is always a safety risk when working with industrial robots. Inexperienced students could accidentally harm themselves, the equipment, or others[3]. Because of these factors, educational institutions are turning to smaller, safer, and more cost-effective industrial robot models.

> "While the handling of large robots requires constant supervision and has to be done in dedicated robotic cells, many universities are now opting to purchase additional desktop-size robots that allow students to work independently. As these machines are programmed the same way as the larger robots the results can be immediately applied to the large machines for full scale applications"[4].

Multiple literature reviews were conducted on use of reconfigurable and scalable modular robotic systems in teaching industrial robotics and automation. The results showed a limited number of studies where a reconfigurable and scalable modular system being used in teaching industrial robotics and automation at a pre-college or college level:

- Hsieh has been teaching reconfigurable and scalable systems projects while applying a comprehensive approach that addresses multiple learning styles and integrates knowledge and skills[5]. Most intriguing part of Hsieh's research is the use of Fischertechnik, which is a modular construction system that can be used in building and simulating industrial robotic work-cells and machines, including industrial and mobile robots, as well as punching machines, indexing lines, pneumatic processing centers, and automated warehouses.
- In another effort, Xiao et al.[6] also used the Fischertechnik system to cultivate mechanical innovation through projects after teaching the basics behind creativity, innovation, and ideation. Student works built with these modular blocks were submitted to the National Undergraduate Mechanical Innovation Design Competition in China and included industrial machines such as machining centers or garbage cleaning machines.
- In a recent effort, Sirinterlikci et al.[7] focused on development of industrial robot configurations for teaching students from a variety of levels including pre-college and college. MOSS modular robotics system was chosen but not found adequate for most of the industrial robot configurations, excluding the articulated robot arm. Additional components were designed and made to be interfaced with the existing MOSS modules to accomplish configurations like selectively compliant articulated robot arm (SCARA).
- Lai-Yuen in her work[8], employed LEGO block assembly in simulating the micromanufacturing processes used in making micro-electromechanical-system (MEMS) components as well as well LEGO mobile robots to mimic automatically-guided vehicles (AGVs) in manufacturing material handling.

Similar approaches were carried out as described below[9,10] but they were based on a custom build manufacturing system and were not scalable nor reconfigurable alike the previously described efforts [5,6,7,8]:

- Yip-Hoi and Pasek developed a manufacturing system handling LEGO blocks[9]. Their paper focused on a general concept for a computer integrated manufacturing (CIM) environment intended for the design and assembly of 'products' built out of LEGO blocks. The 'products' are designed within a Lego CAD System. Process and trajectory planning software was utilized to determine the build sequence and robot program for assembling the products directly from the CAD models. The robot program is downloaded into a cell controller to perform the physical build of the "product". The set-up included a robot gripper, a block sorting mechanism, and an assembly planning system integrated with the CAD system and the physical assembly cell.

- Creasy and Otte also focused on introducing manufacturing processes, systems, and their automation environments to high school students to help prepare them for relevant technical careers[10]. Their work is also noteworthy, but not scalable nor reconfigurable alike Yip-Hoi and Pasek's work. The authors used standalone machines, and robots with customized tooling.

VEX V5 Workcell System

The VEX V5 Workcell is a smaller, safer, and cost-effective industrial robot environment, that is modular and small enough to be placed on a classroom desk and with a recommended three students to one robot ratio, allows students the opportunity for hands-on engagement with the robot. The V5 Workcell is safer by being a smaller size, as well as having the ability to program a Bumper Switch that functions as an emergency stop if needed. VEX V5 Workcell also allows students to engage in a building experience that otherwise would not be possible. Students that are engaged with professional industrial robotic arms gain valuable knowledge and skills programming them, but may not understand how they move and operate because they were not involved in the building process. Being involved in the building process not only gives students the opportunity to make a stronger connection between the hardware and software, but also allows students to gain more foundational knowledge of how the robot physically works. This opportunity can give students the knowledge and building experience they need in order to troubleshoot the hardware more effectively as well as problem solve[11].

> "Building robots is a popular project choice for the implementation of problem-based learning (PBL) in classrooms. The reason why it is such a popular choice can be explained by the multidisciplinary nature of the topic: robotics requires many different scientific, technical and technological skills, such as physics, electronics, mathematics and programming. It is an ideal subject because so many different courses can be linked to it. Additionally, robots themselves capture the imagination of children and teenagers, providing inspiration and motivation"[11].

Students build the V5 Workcell out of parts from the VEX Robotics V5 System. The V5 Workcell Kit is just under twenty-five hundred dollars with all parts included and just under nineteen hundred dollars without the V5 Control System. The list of included and excluded parts are shown below:

V5 Workcell Kit (276-7900)

- (1) V5 Brain & Battery
- (12) V5 Smart Motors
- (18) V5 Sensors
- (1) V5 Electromagnet
- (36) Weighted Discs
- (3) Storage Bins
- (3) Storage Trays
- (3) Storage Bin Lids
- (3500) Construction components

V5 Workcell Kit (No Control System) [276-8655]

- (8) V5 Smart Motors (5.5W)
- (18) V5 Sensors
- (1) V5 Electromagnet
- (36) Weighted Discs
- (3) Storage Bins
- (3) Storage Trays
- (3) Storage Bin Lids
- (3500) Construction components

The following parts found in the V5 Workcell Kit (276-7900) are ***NOT*** included:

- USB Cable (228-2785)
- V5 Robot Brain (276-4810)
- V5 Robot Battery (276-4811)
- V5 Robot Battery Charger (276-4812)
- V5 Battery Clips (276-6020)
- V5 Power Cable (276-4817)
- 4x V5 Smart Motor (276-4840)
- V5 Smart Cables (Starter Pack) (276-6364)

Most other smaller and more cost-effective industrial robot models come pre-assembled and they may only be built for one function. An advantage of the V5 Workcell hardware is that students are not limited to one robot build. The V5 Workcell has numerous different builds including the basic function of the robot arm (shown in Figure 1a), changing the end-of-arm-tooling (EOAT), and adding multiple conveyors and sensors (shown in Figure 1b). This gives students experience in not just building the robot arm itself, but the entirety of a small sized manufacturing workcell model.

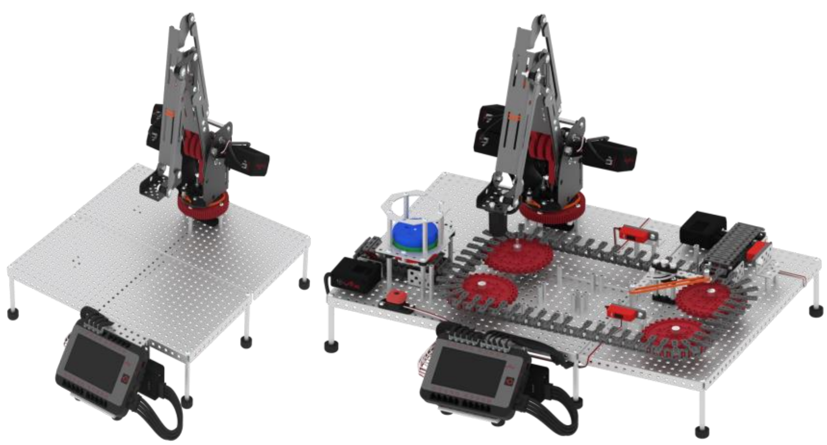

Figure 1a: The Lab 1 Build (the robotic arm), 1b: The Lab 11 Build (the robotic arm as well as the conveyors and sensors)

The different builds are provided in Build Instructions that guide the user through step-by-step building (shown in Figure 2). This makes the barrier of entry low for those that may not have any experience building in general, building with metal, or using tools. Table 1 below summarizes the 12 laboratories associated with VEX V5 Workcell, also presenting learning objectives and outcomes of each laboratory exercise. Each laboratory builds on what was experienced and learned in a previous laboratory exercise prepping the teachers and students to the completion of an automated manufacturing work-cell and a consequent classroom challenge.

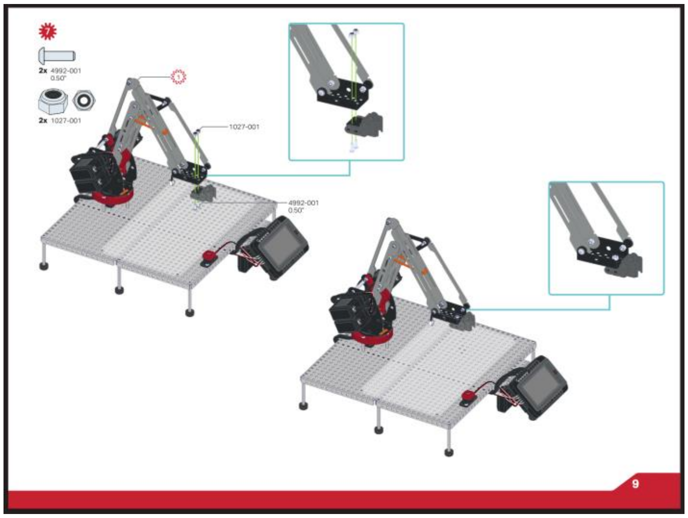

Figure 2: A step from the Lab 4 Build Instructions

Table 1: VEX V5 Workcell Laboratory Sequence

Laboratory Sequence	**Laboratory Title**	**Learning Objectives (Student will understand)**
1	Industrial Robotics	A variety of production systems and their layouts, and available automation types along with fundamentals of industrial robots and their place in industrial automation.
2	Safety	Industrial robots and safety in the workplace, safety mechanisms and precautions as well as co-bots.
3	Manual Jogging of Robots	Industrial robot configurations, calibration and definition of robot movements, and actuators used in robot movements
4	Robot Programming of Movements	Robot controllers, operating systems, and programming as well as robot frames, kinematics, and dynamics.
5	Variables in Robot Programs	Joint positions as well as linear ones
6	End-Effectors	Non-servo and servo robotic motion, end-of-arm-tooling (EOAT) and hand-exchange mechanisms, and accuracy and repeatability of industrial robots
7	Pick and Place Operations, and Material Handling	Dropping off objects picked by the end-effector and palletizing operations
8	Conveyor Systems	Transporting of objects using different handling systems
9-10	Sensors	Sorting good and bad parts using sensors and diverters in addition to different forms of material transfer mechanisms (i.e. continuous, intermittent) and associated tooling as part positioners, jigs, and fixtures
11	Automated Work-Cell Support Systems	Digital and analog input and output signals, handshaking between different controllers (collaborative systems) as well as material storage mechanisms and associated concepts
12	Classroom Competition	Plays the role of a capstone

The curriculum also provides student assessment. Not only are there rubrics that educators can use to assess student understanding throughout the labs, but there is also a challenge at the end of each lab where students are given the opportunity to demonstrate their learning – Figure 3.

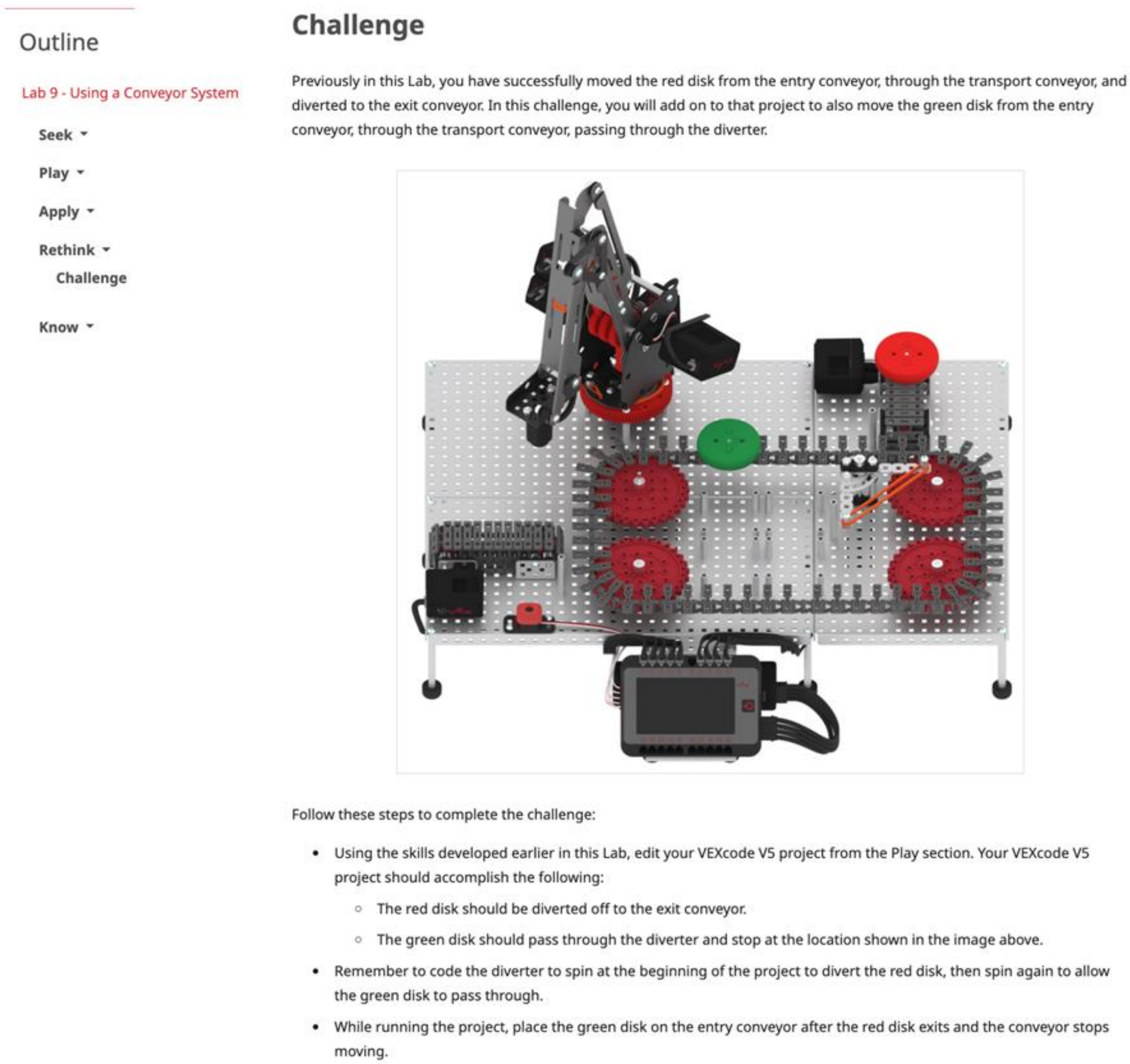

Figure 3: A challenge used in gauging student competencies

Not only will students have the opportunity to demonstrate their learning using engineering and coding concepts, but they can also be formatively or summatively assessed using the provided questions at the end of each lab – Figure 4.

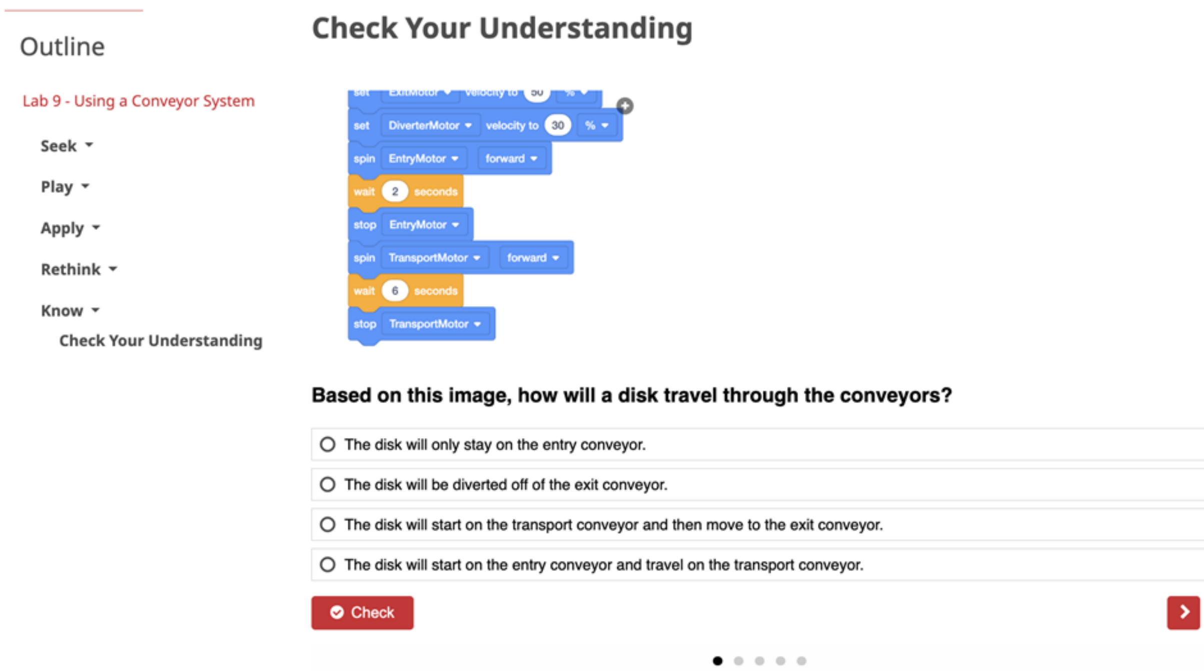

Figure 4. End of lab questions employed in formative or summative assessment

Teaching Programming

With technology advancing at exponential rates, many manual labor jobs in industrial manufacturing are now being supplemented with automation[12]. This can complement labor, and even in some cases can create more demand for labor, but also requires workers to have a strong knowledge of programming in order to operate, repair, and maintain the automation[12]. Programming is a skill that can take years to become proficient, and most programming languages used in industry are complex and designed to be used by professional engineers[13]. This means that the programs that are necessary to have the robot perform even the most simple tasks require hiring a programming specialist, and that can get costly[13].

> "For example, manually programming a robotic arc welding system for the manufacture of a large vehicle hull takes more than eight months, while the cycle time of the welding process itself is only sixteen hours. In this case, the programming time is approximately 360 times the execution time"[14].

This also raises the barrier of entry and limits accessibility for students and educators wanting to learn about the programming fundamentals of industrial robotics, but have little to no programming experience.

> "Robot programming is time consuming, complex, error-prone, and requires expertise both of the task and the platform. Within industrial robotics, there are numerous vendor-specific programming languages and tools, which require

> certain proficiency. However, to increase the level of automation in industry, as well as to extend the use of robots in other domains, such as service robotics and disaster management, it has to be possible for non-experts to instruct the robots”[15].

Learning to program as a novice at any age is challenging[16]. Learning how to understand project flow on top of learning syntax can not only be overwhelming, but discouraging and even outright frightening. These factors set the barrier of entry high for novice programmers[17]. The barrier of entry needs to be lowered for novice programmers so that students and educators can gain programming experience by coding industrial robotics or industrial robotic models. This can be done by simplifying the programming language from traditional text-based languages. Simplifying a programming language has been successful in introducing and teaching young children how to program in different areas, including education[13]. Because of this success, a simplified programming language can be used to teach individuals the basics of programming industrial robots, and would allow them to build the foundational skills that they can later use to be successful in industry[13].

The VEX V5 Workcell allows users to program an industrial robotic arm model using VEXcode V5, a block-based language powered by Scratch blocks (Figure 5a). The user is able to program with VEXcode V5, a simplified programming language. Users can build a project to manipulate the Workcell successfully and also understand the purpose and flow of the project on a deeper level. Studies have shown that novices with no prior programming experience can successfully write block-based programs to accomplish basic industrial robotics tasks[13]. Studies have also shown that students report that the nature of a block-based programming language, such as VEXcode V5, is easy because of the natural language description of blocks, the drag-and drop method for interacting with the blocks, and the ease of reading the project[18]. VEXcode V5 also addresses points of concern to a block-based programming language compared to the more conventional text-based approach. Some of the identified drawbacks are a perceived lack of authenticity and being less powerful[18]. VEXcode V5 addresses both the perceived lack of authenticity and seeming less powerful by incorporating a tool known as the ‘Code Viewer’ (Figure 5b)’. The Code Viewer allows a user to create a blocks project, and then view the same project in text form in either C++ or Python. This conversion allows users to grow beyond the constraint of a block-based language.

A study done by David Weintrop to compare block-based and text-based programming in High School Computer Science classrooms found that students using the block-based language showed greater gains in their learning and a higher level of interest in future computing courses. Students using the text-based language viewed their programming experience as more similar to what programmers do in industry and more effective in improving their programming skills[19]. VEXcode V5 gives novice programmers the best of both worlds by allowing them to first build a strong foundation of programming concepts that they can then use when transitioning to C++ or Python, both text-based languages supported in VEXcode V5.

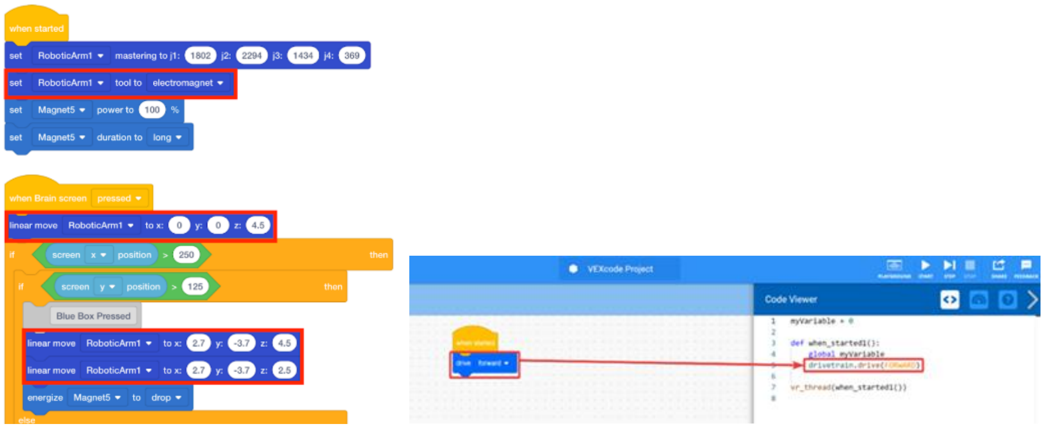

Figure 5a: A sample code in VEXcode V5 5b: Code Viewer

VEXcode V5 is an accessible and free block-based programming language for an industrial robot model to be used in educational settings, that makes programming robots accessible to students and educators who otherwise would not be able to use them. Manufacturing work environments are consistently changing with technology, block-based programming languages like VEXcode V5 may be able to better provide students who aspire to be future manufacturing workers[13].

Big Ideas and Conclusions

One of the biggest advantages of the V5 Workcell is that students are given the opportunity to learn and focus on larger concepts and basic principles that are foundational to not only programming, but also engineering and the professional field of industrial robotics. Focusing on a few larger concepts that can be applied in different settings and situations gives students the opportunity to gain a more in-depth understanding and deeper learning experience of those skills and topics. Halpern and Hackel suggest that, "an emphasis on in-depth understanding of basic principles often constitutes a better instructional design than more encyclopedic coverage of a broad range of topics"[20].

Students will investigate different concepts such as building with metal and electronics, the Cartesian coordinate system, how a robotic arm moves in 3D space, code reuse, variables, 2D Lists, sensor feedback for automation, conveyor systems, and many more. Students will gain foundational knowledge of these concepts that can be transferred and applied later in a wide range of fields such as mathematics, programming, engineering, and manufacturing. While gaining an introduction to these concepts, students are actively able to problem solve, collaborate, be creative, and build resiliency. All of which are important skills in any environment and tie into today's 21st century skills.

> "Knowledge has become vital in the 21st-century and people need to acquire such skills to enter the workforce called 21st-century skills. In general, 21st-century skills include collaboration, communication, digital literacy, citizenship, problem solving, critical thinking, creativity and productivity. These skills are labelled 21st-century skills to indicate that they are more related to the current economic and social developments than with those of the past century characterized as an industrial mode of production"[21].

The purpose of this paper is to present the advantages of the VEX V5 Workcell in an educational setting to introduce industrial robotics. In doing so, this paper shows that the VEX V5 Workcell provides an all-encompassing solution to introduce students to industrial robotics in an educational setting that is cost-effective, lowers the programming barrier of entry, and focuses on big ideas that help students develop important skills. In current initiatives, high school teacher trainings are being conducted to explain and promote the objectives of this new system for teaching industrial robotics and automation as well as manufacturing. Additional hardware development efforts have also been carried out by the academic collaborator and his team. These new components and their configurations will also be complemented by relevant software development work by the company.

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