ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37734

Work in Progress: Accessible Engineering Education for Workforce 4.0

Rui Li

Dr. Li earned his master's degree in Chemical Engineering from the Imperial College of London, 2009 and his Ph.D in Robotics from the University of Georgia, 2020. His current research interests are student motivation, inclusive learning and educational robotics.

Jack Bringardner

Jack Bringardner is the Assistant Dean for Academic and Curricular Affairs at NYU Tandon School of Engineering. He is an Industry Associate Professor and Director of the General Engineering Program. He teaches the first-year engineering course Introduction to Engineering and Design. He is also the Director of the Vertically Integrated Projects Program at NYU. His Vertically Integrated Projects course is on the future of engineering education. His primary focus is developing curriculum, mentoring students, and engineering education research, particularly for project-based curriculum, first-year engineering, and student success. He is active in the American Society for Engineering Education and is the NYU ASEE Campus Representative. He serves on the First-Year Programs Division Executive Board as well as the Webmaster for the ASEE First-Year Programs Division and the First-Year Engineering Experience Conference.

Victoria Bill (MakerSpace Director)

Victoria Bill is the Managing Director of the MakerSpace Lab & Experiential Learning Center at NYU Tandon School of Engineering. She is also an adjunct professor in the first-year engineering and VIP programs, as well as a PhD student in Engineering Education at The Ohio State University. Her research interests include asset-based professional and technical skill development of engineers through extracurricular and co-curricular activities.

Vikram Kapila (Professor)

Vikram Kapila is a Professor of Mechanical and Aerospace Engineering. He directs a Mechatronics, Controls, and Robotics Laboratory and has held visiting positions with the Air Force Research Laboratories in Dayton, OH. His current research is focused at the convergence of frontier technologies (e.g., robotics, artificial intelligence, augmented/virtual reality, and blockchain) with applications to natural and intuitive human-robot interaction, digital health, and STEM education. Under the Research Experience for Teachers Site, GK-12 Fellows, DR K-12, and ITEST projects, all funded by NSF, and the Central Brooklyn STEM Initiative, funded by six philanthropic foundations, he has conducted significant K-12 education, training, mentoring, and outreach activities to integrate engineering concepts in science classrooms and labs of dozens of New York City public schools. His STEM education research, conducted as a collaborative partnership involving engineering and education faculty, postgraduate and graduate researchers, and K-12 educators, has: (1) created, implemented, and examined over 100 standards-aligned robotics-based science and math lessons and (2) developed, practiced, and examined research-guided pedagogical approaches for science and math learning using robotics. He received NYU Tandon's 2002, 2008, 2011, and 2014 Jacobs Excellence in Education Award, 2002 Jacobs Innovation Grant, 2003 Distinguished Teacher Award, and 2012 Inaugural Distinguished Award for Excellence in the category Inspiration through Leadership. Moreover, he is a recipient of 2014-2015 University Distinguished Teaching Award at NYU. His scholarly activities have included 3 edited books, 10 chapters in edited books, 1 book review, 67 journal articles, and 171 conference papers. He has mentored 6 research associates; 1 B.S., 45 M.S., and 10 Ph.D. students; 66 undergraduate research students and 11 undergraduate senior design project teams; over 500 K-12 teachers and 130 high school student researchers; and 18 undergraduate GK-12 Fellows and 59 graduate GK-12 Fellows.

Work in Progress: Accessible Engineering Education for Workforce 4.0

1. Introduction

The recent emergence of *Industry 4.0* [1] — a new industrial revolution that focuses on interconnectivity, automation, artificial intelligence, and big data analysis — demands a new education paradigm, namely *Education 4.0* [2]. Several recent studies [3,4] have projected that up to 375 million workers worldwide will experience changes in their occupational categories by 2030. Creating and implementing effective education and training programs for preparing the future workforce for *Industry 4.0*, namely *Workforce 4.0*, remains a challenging task. *Workforce 4.0* [5] is expected to have a multidimensional preparation with the knowledge of information technology, data analytics, cyber security, as well as skills in computer programming and the ability to interact with modern interfaces, among others. Recent research [6,7] has suggested that effective integration of contemporary technology can enhance classroom teaching and learning. In this spirit, an AI-enabled robotic manipulator is proposed as a technology-integrated teaching and learning platform for testing a variety of educational research paradigms such as situated cognition, collaborative learning, and project-based learning.

2. Background

First, situated learning theory is considered to be the theoretical framework for this study. Second, several prior implementations of educational robots are briefly reviewed.

2.1. Situated Learning

Situated learning theory (SLT), as described by Lave and Wenger [8], suggests that socially situated practice is important in the process of learning new knowledge. Accordingly, SLT suggests that for effective delivery of content knowledge to students, one begin by creating a situational context for learning with direct relevance and resemblance to *real-life* applications that are personally meaningful for students. As observed by Das et al. [2], project-based learning constitutes a key feature of Education 4.0, and it offers a compelling framework to operationalize SLT. In fact, Das et al. [2] propose that learners should be able to apply their skills in a variety of situations. Moreover, Wang et al. [9] recommend transforming the conventional culture of the classroom, typified as the unidirectional transmission of knowledge, into a highly interactive and dynamic learning environment. With the increasing diversity in the student population, it becomes paramount to adopt more inclusive teaching practices in the classroom under the umbrella of SLT. As first-generation students enter undergraduate engineering programs, it may be an effective strategy to incorporate their interests and motivations by embedding real-life scenarios in classroom teaching and learning. SLT also advocates for improving contextual settings by integrating technology into the classroom pedagogy [10-13]. Finally, engaging in a situated learning environment with experts can facilitate learning opportunities under the framework of cognitive apprenticeship that can transfer students from novice to expert learners [14-16].

2.2. Implementation of Educational Robotics

Papert [17], regarded as one of the early developers of the LOGO programming language, is also considered a proponent of situated constructivism [18]. Since his foundational work, numerous studies have examined the use of educational robots in teaching STEM concepts [19,20]. Moreover, educational robots such as LEGO Mindstorms have been considered for teacher professional development [13]. Robotics can naturally integrate varied STEM disciplines [20-22], including mechanical engineering, electrical engineering, and computer science. A large number of prior studies have investigated the use of educational robots in developing STEM-related concepts and skills among students. For example, educational robotics has been shown to help students cultivate essential engineering skillsets such as critical thinking and problem-solving [23-25]. Studies have shown that educational robotics can also increase students' STEM motivation and STEM skills [26,27], e.g., in proportional reasoning [28]. The use of robotics is known to bring innovative engagement in STEM classrooms and foster problem-solving and teamwork skills [29]. Furthermore, some studies have described how robots can nurture students' skills in team collaboration and technical communication [30-32]. In summary, the number of robotics-related educational research studies has experienced a steady increase [33-35]. Nonetheless, thus far, only a few studies have focused on developing and integrating real-world case scenarios when applying educational robotics in classrooms. This paper will specifically address how robotics laboratories and projects can be used in first-year engineering education to help students develop teamwork skills. The outcome of the study can provide answers to the research question: *How to create practical and accessible engineering education for the Industry 4.0 workforce?*

This study aims to conceptualize and develop a robotics laboratory for students to answer a series of questions: how does a robot recognize an object and place it at the desired location; to what extent can robotics help with real-world problems; and what kind of skillsets do we need for Workforce 4.0? Throughout this study, we will employ a desktop-size educational robot platform that can be endowed with wireless communication and computer vision capabilities.

3. Methods

3.1. Context

This study is currently in the plan and design stage and represents a work in progress at a large private university located in the Northeastern region of the United States. Approximately 300 first-year students take an introductory engineering course each semester. The course includes seven laboratory exercises. A new laboratory with two different work scenarios is planned for the Fall 2022 semester. The first scenario entails creating a robotic solution that can serve as a *third* *hand* to assist a surgeon by delivering objects (e.g., surgical tools, band-aid roll, cotton swab, etc.) to a location that is easily accessible to the surgeon performing a procedure in the operating room. The second scenario is a robotic system to support construction workers by lifting and stacking objects for them. The laboratory performance metrics will be accuracy, precision, alignment, and time of task completion. A student survey will be sent out at the end of the semester to anonymously collect information about student satisfaction with and learning experience from the laboratory. Moreover, team assignments, including lab reports and presentations, will be used to assess several learning outcomes and improve the instruction and learning design. The learning outcomes will be cross-referenced with student demographics, i.e., their racial, cultural, and gender backgrounds, to improve the design for inclusion and accessibility.

This research is to be conducted in "settings that include common educational practices that are not likely to negatively impact students' learning […] or instructor's assessment." Such a study is deemed exempt from the review by the Institutional Review Board. Nonetheless, a formal request for the exempt status of this study will be submitted prior to its launch in Fall 2022.

3.2. Theoretical Framework

The framework for developing situated learning-based robotic education pedagogy is shown in Figure 1. There are four basic elements: content, context, community, and participation [8]. Participant A, an instructor, will provide the context and content of real-world problems to participants B and C, the learners, in the learning community space, i.e., the laboratory room. The interaction between the instructor and learners will facilitate the transition of students from novice learners to experts. The interaction between participants B and C will enable collaborative teamwork. The outer circle represents the learning context, which consists of a low-cost, portable, programmable, and smartphone-controlled robotic arm.

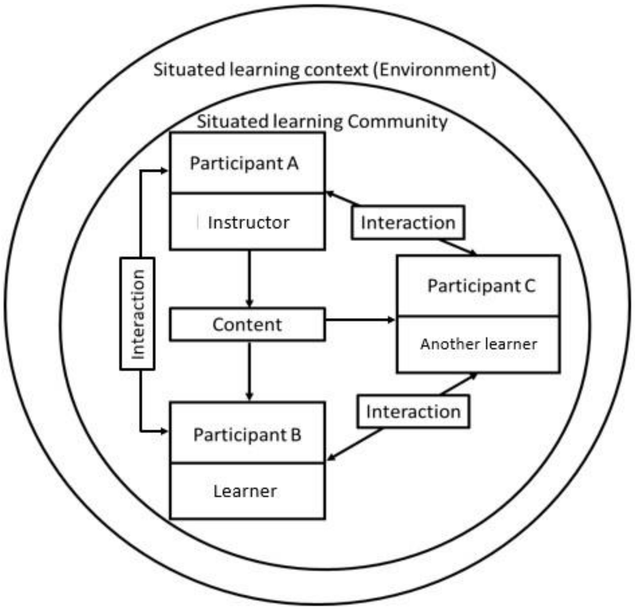


Figure 1: Ecological analysis of situated learning in engineering schools

3.2.1. Content: For the content, this laboratory emphasizes using real-world scenarios to help students gain a solid understanding of the working principles and applications of robotics. In this laboratory, students will learn the technical knowledge and professional skills shown in Table 1. Two thematic applications of robotics, namely a healthcare environment and a construction site, will be developed to promote knowledge and skill acquisition among students. Each theme will identify a central problem for students to solve by working in a three-person team. Student teams will have the freedom to select their desired theme for participation. The healthcare theme will challenge the students to solve a problem that allows a surgical technician to teleoperate the robotic arm and deliver surgical tools and materials to a site proximal to the surgeon performing the operation. Here, the focus is on positional accuracy, precision, and time. The construction theme will challenge the students to solve the problem of using the robotic arm in helping construction workers to stack bricks in a short amount of time. Here, the focus is on alignment and time. The students will collaborate and compete in a mock-up arena to demonstrate their solutions. The winning teams will receive extra credit for their first-year engineering introductory course. See Table 2 for connections between the laboratory modules, skills, and ABET criteria.

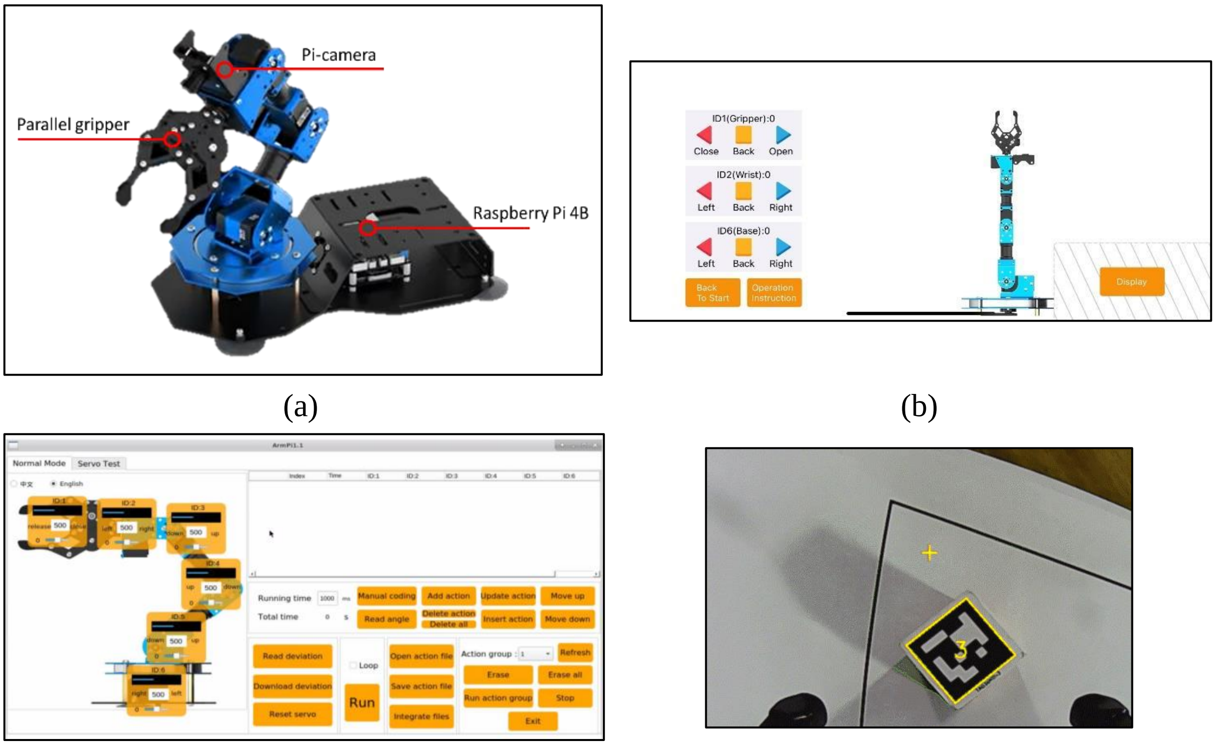
Table 1: Knowledge and skillset development in the robotic laboratory

Technical knowledge	**Professional skills**
Kinematic analysis	Team communication
Programming, including computer vision	Report writing
Human-robot interaction	Presentation
Internet of things	

3.2.2. Context: For the robot assembly, programming, and operation, a collaborative robot is to be used to promote student learning. The robot platform has been intentionally selected to be of low cost, easy to assemble and provide operational access through a smartphone application. The robot platform has three modes of operation, allowing students to safely perform activities in the manual, partially automated, and fully automated modes. The specific robot to be used is a 6-DOF robotic arm (Figure 2 (a)) interfaced with a Raspberry Pi for programming and control operations. Hands-on projects and team-based assignments such as laboratory reports and oral presentations are designed for students. For example, students will begin with the development and testing of the robot in a simulation environment that is created using the Robot Operation System (ROS). ROS is a middle framework which is ideal for robotic control and communication. Because of its versatility, ROS has quickly become a common and standard development platform in the robotics community. Another package called MoveIt will also be used. ROS and MoveIt simplify the process of programming robotics operations by permitting code writing tasks in popular programming environments such as Python and C++. Briefly, the three operational modes for the robot are as follows. First, in Mode I, i.e., the manual mode, students can operate the robot arm via the smartphone application (Figure 2 (b)). Next, in Mode II, i.e., partially automated mode, students can operate the robot arm using a desktop interface by setting up action groups

Table 2: Laboratory modules, skill development, and covered ABET criteria

Lab content	Workforce 4.0 skill development [36]	ABET criteria [37]
Guided questions included in the lab manual	Critical thinking	"An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics" "An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments."
Team task assignment	Team communication	"An ability to function effectively on a team whose members together provide leadership"
Establish wireless communication	Technical: Wireless communication	"An ability to develop and conduct appropriate experimentation"
Select ROS, MoveIt, and RViz to operate the robot and carry out motion planning for grabbing the objects	Technical: Python programming and use of Linux commands	"An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions"
Operate the robot from the manual to fully-automated modes	Technical: Robotic Operation System (ROS) programming	"An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions"
Record the position and temporal data, participate in the competition, and write a team lab report	Technical: Excel and Google Doc Professional: report writing and team communication	"An ability to function effectively on a team whose members together provide leadership"
Team presentation	Technical: Microsoft PowerPoint Professional: oral presentation and team communication	"An ability to communicate effectively with a range of audiences"



(a)

(b)

(c)

(d)

Figure 2: Laboratory set up: (a) robotic arm overview; (b) Mode I: human-in-the-loop; (c) Mode II: partially automated operation using pre-defined action groups; and (d) Model III: fully automated operation using computer vision

(Figure 2 (c)). Specifically, for each desired waypoint for the robot, students determine the corresponding motor commands for each joint to produce the required action group. Finally, in Mode III, i.e., fully automated mode, students can use a Pi camera, which can recognize the specific QR code on the tools (Figure 2 (d)). For this method, students will need to determine and code the various program elements for acquiring, processing, and using the data from the Pi camera. While a pre-made Python program skeleton will be provided to students, they will need to fill in certain essential aspects of the program to create a complete solution for the problem. Being endowed with the Pi camera and programmed to recognize specific placement locations or objects in its operational environment, the robot is rendered as an AI-enabled manipulator. The level of automation increases from Mode I to Mode III.

3.2.3. Community and participation: A careful consideration and incorporation of the elements of community and participation can create an interactive learning environment for students. The laboratory is additionally envisioned to provide an inclusive learning experience for students. They will work in a collaborative setting of clearly defined individual roles that may entail hardware development, path planning, robot kinematics, software development, and external liaison, among others. The student assigned to the external liaison role will need to reach out to a local hospital or a construction company to talk to a medical technician or a construction supervisor, respectively, to gain an understanding of their work scenario and potential for deploying robotics in a meaningful manner for real-world applications. Alternatively, they may obtain the relevant information through online videos and trade publications.

3.3. Assessment Strategy

The student laboratory performance will be assessed through the following aspects: accuracy, precision, alignment, and task completion time. The accuracy refers to the ability of the robot arm to deliver the items to accurate positions. The precision refers to the ability of the robot arm to repeat the same tasks without human intervention. The alignment refers to the minimal deviation between stacked blocks. The task completion time refers to the duration for the robotic arm to complete all tasks from beginning to end.

3.4. Participants

Participants of this study will be 300 first-year engineering students enrolled in the Fall 2022 semester. The student will be randomly divided into groups of three. The process of randomization will include consideration of random selection by gender, cultural, and the racial group. At the end of the semester, students will be asked to anonymously share their opinions on the new laboratory.

3.5. Learning Outcomes

According to the revised Bloom's taxonomy by Anderson and Krathwohl [38], the cognitive domain is the intersection of the cognitive process dimension (CPD) and the knowledge dimension (KD). By the end of this laboratory, the CPD will be at the level of "understand" and "apply" while the KD will be the conceptual knowledge about robotic operation. The intended learning outcomes will be:

I. Understand the fundamental knowledge of robotic operations, such as sensing, control, and motion planning.
II. Remember the fundamental concepts of computer vision.
III. Apply robotic operation and computer vision in practical scenarios.
IV. Understand the importance of teamwork in solving real-world problems.
V. Understand the benefits of human-robot interactions.

3.6. Data Collection

Student feedback is critical to determine their level of satisfaction with the laboratory and can be used to improve its quality. A preliminary survey has been created that will allow the assessment of students' experiences and expectations from this laboratory. The survey includes 22 Likert-scale questions based on the Intrinsic Motivation Inventory (IMI), a widely studied and validated survey tool that seeks to assess participants' positive and negative experiences regarding laboratory activities. The survey also includes two qualitative questions to identify the potential benefits and drawbacks of the laboratory based on student perspectives. Qualtrics XM platform will be used to develop and implement the survey.

4. Current Progress

This section explains the ongoing progress in developing and testing the laboratory elements. As mentioned above, there are two major themes involved in this laboratory: the surgical environment and the construction site. For the surgical environment, students will program the robot to deliver wood blocks, as stand-ins for some surgical tools or materials, to a specific bullseye target position that is considered to be proximal to the surgeon performing the operation (Figure 3 (a)). For the construction site, students will stack two or more wood blocks on top of each other (Figure 3 (b)).

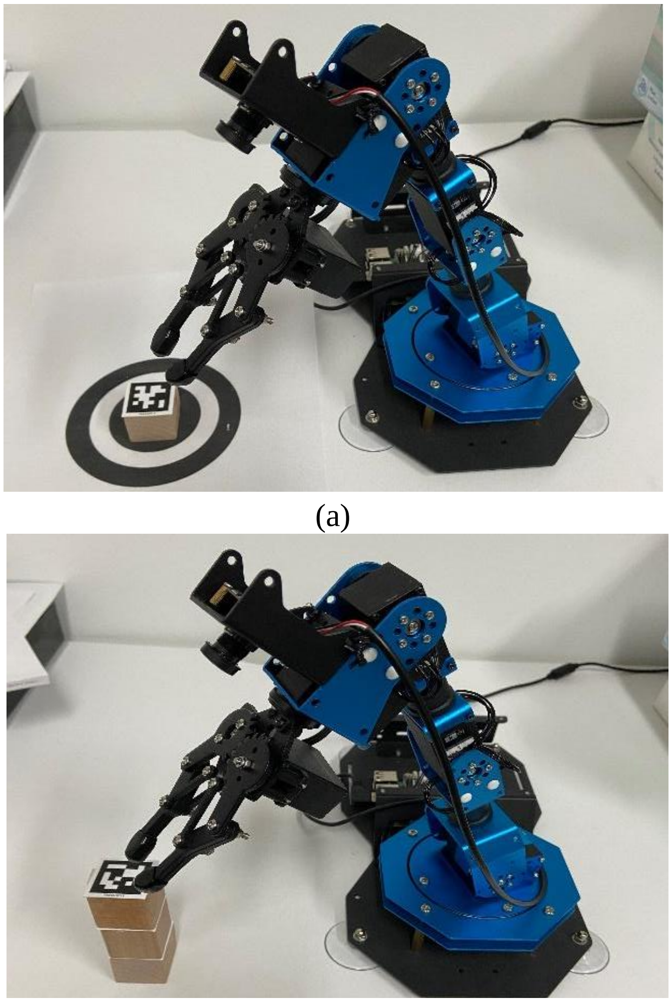

(a)

Figure 3: Two different laboratory setups: (a) shows the healthcare theme with a bullseye target and (b) shows the construction theme with stacked objects.

4.1. Healthcare Environment Theme

This laboratory theme mainly focuses on object pick-and-place. The students will work in groups of three to solve this problem. The initial test runs show that the instructor can finish the laboratory within 90 minutes, and thus it is estimated that students of varying ability levels can finish the exercise in the usual three-hour laboratory schedule. Below is the list of tasks that students need to work on in this laboratory.

1. Assign roles to each laboratory member, e.g., programming, robot assembly and positioning, and motion planning, among others.
2. Establish wireless communication with the robotic arm using NoMachine.
3. The students have the option to use ROS, MoveIt, and RViz to simulate and control the robotic arm. The motion planning can be done in RViz.
4. Operate the robot with the use of Mode I to Mode III.
5. Place the block in the designated area and measure the accuracy of placement.
6. Record the operation time.
7. Repeat the process three times and measure the precision of placement.

4.2. Construction Environment Theme

This laboratory theme mainly focuses on object stacking. The students will work in groups of three to solve this problem. As with the healthcare theme, the instructor can finish the laboratory within 90 minutes, and thus students can finish the exercise in the usual three-hour laboratory schedule. Pre-made Python scripts and ROS commands will be used in this part of the laboratory. Below is the list of tasks that students need to work on in this laboratory.

1. Access the ROS interface to wirelessly communicate with the robot.
2. Input the Linux command to turn on the Pi camera.
3. Input the Linux command to initialize the Pi camera to detect the QR code.
4. Fill in lines of codes for a robot in Python scripts to stack the bricks on top of each other.
5. Record the time taken to complete the operation.
6. Compute the accuracy by measuring the alignment of the final stacking.

4.3. Study Survey Development

The study survey will be used to assess individual student satisfaction. The survey has four subscales: interest/enjoyment, perceived choice, perceived competence, and pressure/tension. For the questions labeled for reverse score (R), the student responses will be recorded by subtracting them from 8. The subscale scores can be calculated by averaging the items belonging to each subscale. Table 3 shows all the questions adopted for the survey from [39]. As noted in [39], several survey items within each subscale have some overlap. Nonetheless, [39] suggests organizing the survey items in random order instead of by subscales to minimize the effect of overlapping items on the survey respondents.

Table 3: Task evaluation survey developed by the Intrinsic Motivation Inventory

Likert Prompt: Strongly agree (7) Agree (6) Somewhat agree (5) Neutral (4) Somewhat disagree (3) Disagree (2) Strongly disagree (1)

Questions adapted from the IMI survey [39]	Sub-scales	Aims
While I was working on the task, I was thinking about how much I enjoyed it.	Interest/enjoyment	Evaluate if students enjoy the content of the laboratory
I found the task very interesting.		
Doing the task was fun.		
I enjoyed doing the task very much.		
I thought the task was very boring. (R)		
I thought the task was very interesting.		
I would describe the task as very enjoyable.		
I think I am pretty good at this task.	Perceived competence	Evaluate if students are comfortable operating the robot (in the context of the laboratory)
I think I did pretty well at this activity compared to other students.		
I am satisfied with my performance on this task.		
I felt pretty skilled at this task.		
After working on this task for a while, I felt pretty competent.		
I felt that it was my choice to do the task.	Perceived choice	Assess the level of participation or engagement of students.
I didn’t really have a choice about doing the task. (R)		
I felt like I was doing what I wanted to do while I was working on the task.		
I felt like I had to do the task. (R)		
I did the task because I had no choice. (R)		
I did not feel at all nervous about doing the task. (R)	Pressure/tension	Evaluate students’ perception of the community, i.e., the team working environment.
I felt tense while doing the task.		
I felt relaxed while doing the task. (Reverse score)		
I was anxious while doing the task.		
I felt pressured while doing the task.		

4.4 Summative Learning Assessment

Students’ learning outcomes I — V mentioned in Section 3.5 will be assessed via their written laboratory reports and team presentations. The students will collaboratively prepare their laboratory reports using Google Docs by following a structured format consisting of elements such as abstract, introduction, procedure, results, conclusion, and contribution statement. The abstract will briefly summarize the laboratory exercises and competition outcome. The introduction will describe fundamental concepts, such as computer vision, robotic sensing, control, and motion planning. Moreover, the competition rules and definition of the Laboratory Performance Index (LPI) will also be outlined. The procedure will cover the content of sections 4.1 and 4.2. In the results, the performance metrics of accuracy, precision, alignment, and task completion time will be presented using tables and figures. The entire laboratory setup will be documented using images and line drawings. The benefits and risks of human-robot interaction will be discussed. The conclusion will summarize all the findings of the laboratory activity and provide suggestions for potential improvements. The contribution statement will describe the individual role and importance of individual contribution. Finally, the team presentation will help assess learning outcome IV through collaborative preparation of a professional slide deck and a timed presentation (5 minutes).

5. Discussion and Conclusion

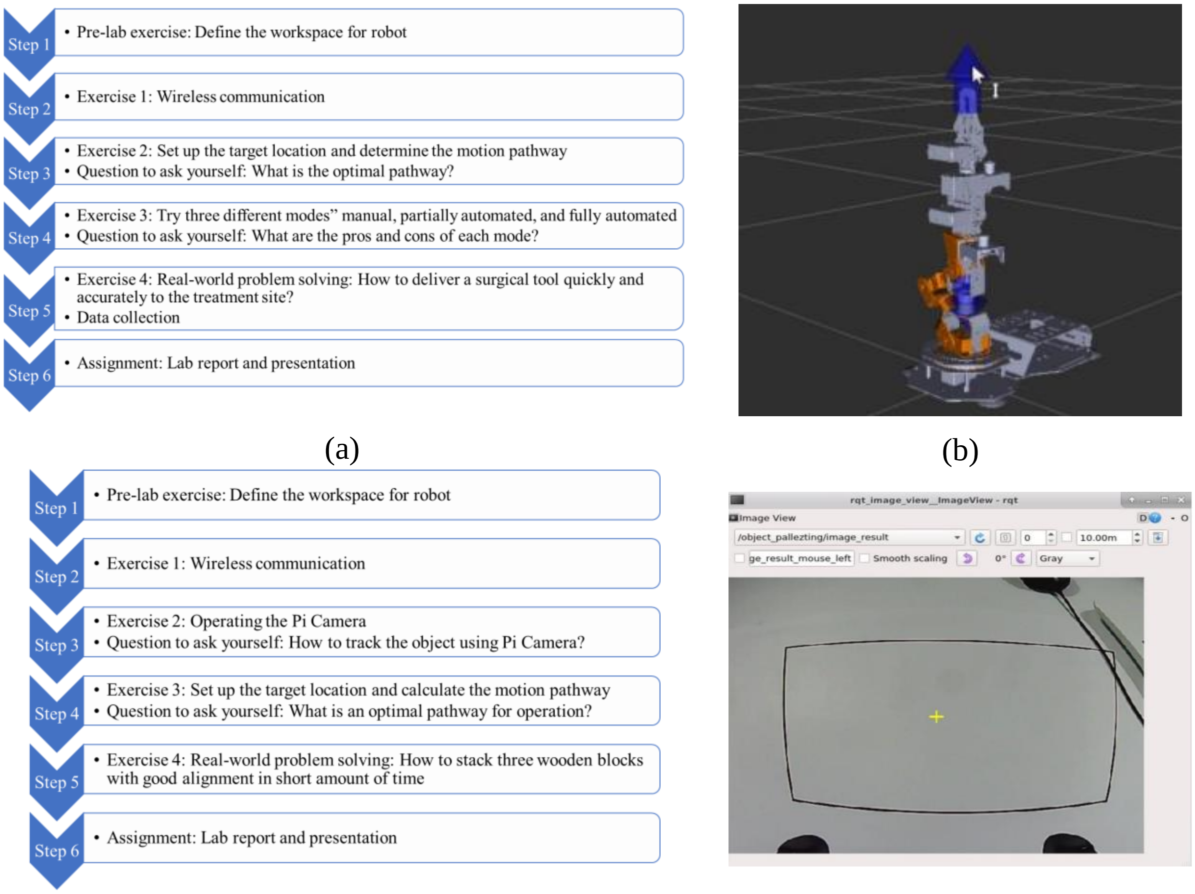
5.1. Laboratory Objectives

Conducting this project can help students achieve several laboratory objectives. The laboratory covers all four elements of situated learning, namely content, context, community, and participation, while allowing students to have an interactive robotic learning experience. The primary laboratory objective is to allow students to solve a real-world problem in a team setting. The students will be assigned individual tasks and find out an optimal solution through discussions and guided questions listed in Figure 4. In doing so, they will learn the skills of communication, collaboration, and perspective-taking, among others, all of which are critical for successful teamwork. The second laboratory objective is to ensure that the students become familiar with the emerging technologies of Industry 4.0, such as automation, robotics, and the Internet of things. There are different work scenarios that may require robotic assistance. For example, some tasks can be done by robots to reduce operational costs; some tasks can be completed by robots with better outcomes, and some other tasks may require a human operator in the loop for safety reasons. It is essential for students to understand the benefits and potential risks of human-robot interaction. With such an experiential journey, they can equip themselves to participate in the fourth industrial revolution and fit into the roles required by Workforce 4.0.

5.2. Laboratory Assessment

5.2.1. Healthcare theme: There are three major metrics to be assessed in the healthcare theme: accuracy, precision, and time efficiency. The overall score will be calculated based on the LPI, as shown in Eq. (1).

$$\mathrm{LPI}_{\mathrm{Healthcare}} = \frac{\text{Accuracy Score}+\text{Precision Score}}{\text{Time Taken for Task Completion}} \quad (1)$$



Step 1
- Pre-lab exercise: Define the workspace for robot

Step 2
- Exercise 1: Wireless communication

Step 3
- Exercise 2: Set up the target location and determine the motion pathway
- Question to ask yourself: What is the optimal pathway?

Step 4
- Exercise 3: Try three different modes" manual, partially automated, and fully automated
- Question to ask yourself: What are the pros and cons of each mode?

Step 5
- Exercise 4: Real-world problem solving: How to deliver a surgical tool quickly and accurately to the treatment site?
- Data collection

Step 6
- Assignment: Lab report and presentation

(a)

(b)

Step 1
- Pre-lab exercise: Define the workspace for robot

Step 2
- Exercise 1: Wireless communication

Step 3
- Exercise 2: Operating the Pi Camera
- Question to ask yourself: How to track the object using Pi Camera?

Step 4
- Exercise 3: Set up the target location and calculate the motion pathway
- Question to ask yourself: What is an optimal pathway for operation?

Step 5
- Exercise 4: Real-world problem solving: How to stack three wooden blocks with good alignment in short amount of time

Step 6
- Assignment: Lab report and presentation

(c)

(d)

Figure 4: Guiding students through the laboratory for (a) workflow of healthcare theme; (b) simulated arm; (c) workflow of construction theme; and (d) activated Pi camera

The accuracy is to be measured by the position that is determined based on the distance of the wooden block drop-off location from the target (Figure 5(a)). The precision is to be measured by the average separation between repeated placements of the wooden block (Figure 5(b)). The mean separation can be calculated using Eq. (2) below. Finally, the efficiency is to be measured by the time taken to complete the task. The accuracy, precision, and efficiency scores will be given based on Table 4. Then the overall team ranking can be calculated based on LPI as shown in Eq. (1).

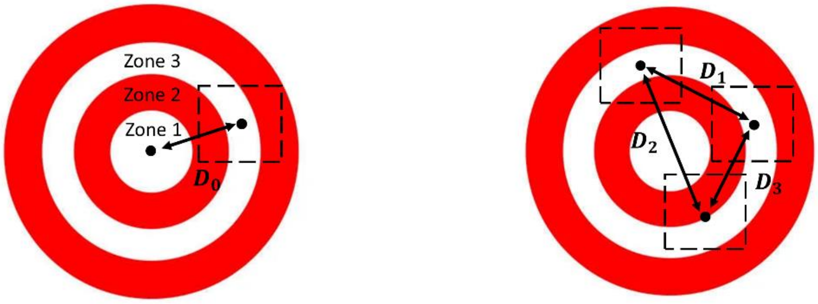
$$\text{Mean separaion} = \frac{D_1 + D_2 + D_3}{3} \qquad (2)$$

5.2.1. Construction theme: In this theme, the laboratory performance will be assessed mainly in two components: the alignment of stacking and time taken for stacking. The overall score will be calculated using Eq. (3). The LPI, indicating the students' performance, is proportional to the stacking quality (alignment score) and inversely proportional to the task completion time. The score will be given based on Table 5. Then the overall team ranking can be calculated based on the accuracy and time taken for task completion.

$$\text{LPI}_{\text{Construction}} = \frac{\text{Alignment score}}{\text{Time Taken for Task Completion}} \qquad (3)$$

Table 4: Accuracy, precision, and time score

Accuracy (deviation from the target location)	Score
Zone 1 (0 cm $\leq D_0 <$ 3 cm)	5
Zone 2 (3 cm $\leq D_0 <$ 6 cm)	4
Zone 3 (6 cm $\leq D_0 <$ 9 cm)	3
Precision (mean separation from each trial position)	Score
±5 mm	5
±8 mm	4
±10 mm	3
Time taken for the robot to complete the task	Score
Within 1 minute	1
Within 2 minutes	2
Within 5 minutes	3



(a) (b)

Figure 5: Laboratory assessment: (a) accuracy measurement from the desired target position and (b) mean separation between three different placements; the average value can be calculated from D_1, D_2, and D_3

Table 5: Alignment and time score

Alignment (average deviation from the bottom block)	Score
± 5 mm	10
± 8 mm	8
± 10 mm	6
Time taken for the robot to complete the task	Score
Within 1 minute	1
Within 2 minutes	2
Within 5 minutes	3

5.3. Answers to the Research Question

The students will need to collaborate to complete the laboratory objectives. There will be three students per laboratory team who will be assigned one or more roles, e.g., robot hardware, path planning, robot kinematics, and robot programming, among others. They will communicate, exchange ideas, and aim to answer the guided questions as shown in Figure 4 (a) and (c). The laboratory assignments will include group presentations and collaborative report writing. The students will realize the importance of time management, respectfulness, accountability, decision-making, and creativity, all of which are key elements for developing teamwork skills [40].

To address the practical aspect of educating Workforce 4.0, the robotic laboratory includes two scenarios. Each scenario addresses a real-world engineering problem. In the healthcare industry, surgeons in need of assistance in the operating room can rely on the robot arm that has the ability to perform with accuracy, precision, and efficiency while offering flexibility and accessibility. Moreover, when robots are used for minimally invasive surgery, surgeons can deliver lifesaving treatments with few complications and faster postoperative recovery. In the construction industry, the workers can receive assistance from the robotic arm as it increases alignment accuracy and efficiency. Such an approach can reduce worker injuries and provides a safer work environment.

To address the accessible aspect of educating Workforce 4.0, the robot arm can be operated with various computing platforms, e.g., using a smartphone application or desktop software. The unit cost of the robot hardware is under $400, which is affordable for use at school or home. Moreover, the laboratory does not require the purchase of any textbooks or additional hardware. The online laboratory manual can allow beginners to follow step-by-step guidance and achieve the laboratory objectives. The footprint of the robotic arm has the size of a normal laptop, and it can be placed on any level surface. No special setup is required for running the laboratory.

This work has the potential to draw interest from K-12 and university educators as the proposed robotic platform is versatile, robust, and will allow students to visualize the impact of automation in our society. The outcome of this study will reveal how to effectively deliver challenging and engaging technical content at an early stage of college learning. This study will increase STEM career awareness among students by showing them the relevance of these disciplines in their everyday lives. One of the potential directions is to add more design elements such as soft robotic grippers into the arm design. This can spur students' interest in fabricating soft materials using 3D printers. Another direction is to incorporate augmented reality (AR) and virtual reality (VR) technologies into robotic control. Moreover, a new theme of smart warehouses as the logistic sector is one of the most important industries in the near future.

References

1. Culot, G., *et al.*, Behind the definition of Industry 4.0: Analysis and open questions. *International Journal of Production Economics*, 2020. 226: p. 107617.
2. Das, S., Kleinke, D.K., and Pistrui, D. Reimagining engineering education: Does Industry 4.0 need Education 4.0? in *Proceedings of ASEE Virtual Annual Conference* 2020.
3. Illanes, P., *et al.*, Retraining and reskilling workers in the age of automation. *McKinsey Global Institute*, 2018.
4. Manyika, J., *et al.*, What the future of work will mean for jobs, skills, and wages. *McKinsey Global Institute*, 2017.
5. Gehrke, L., *et al.*, A discussion of qualifications and skills in the factory of the future: A German and American perspective. *VDI/ASME Industry*, 2015. 4: p. 1-28.
6. Huda, M., *et al.*, Understanding modern learning environment (MLE) in big data era. *International Journal of Emerging Technologies in Learning*, 2018. 13(5).
7. You, H.S., Chacko, S.M., and Kapila, V., Examining the effectiveness of a professional development program: integration of educational robotics into science and mathematics curricula. *Journal of Science Education and Technology*, 2021. 30(4): p. 567-581.
8. Lave, J. and Wenger, E., *Situated Learning: Legitimate Peripheral Participation*. 1991: Cambridge University Press.
9. Wang, W., Coutras, C., and Zhu, M., Empowering computing students with proficiency in robotics via situated learning. *Smart Learning Environments*, 2021. 8(1): p. 24.
10. Herrington, J. and Oliver, R. Critical characteristics of situated learning: Implications for the instructional design of multimedia. in *Proceedings of ASCILITE*. 1995. Melbourne, Australia. p. 253-262.
11. Oliver, R. and Herrington, J., Using situated learning as a design strategy for web-based learning, in *Instructional and Cognitive Impacts of Web-based Education*. 2000, IGI Global. p. 178-191.
12. Bell, R.L., Maeng, J.L., and Binns, I.C., Learning in context: Technology integration in a teacher preparation program informed by situated learning theory. *Journal of Research in Science Teaching*, 2013. 50(3): p. 348-379.
13. Moorhead, M., *et al.* Professional development through situated learning techniques adapted with design-based research. in *Proceedings of ASEE Annual Conference & Exposition*. 2016.
14. Orsmond, P., Merry, S., and Callaghan, A., Communities of practice and ways to learning: Charting the progress of biology undergraduates. *Studies in Higher Education*, 2013. 38(6): p. 890-906.
15. Cope, P., Cuthbertson, P., and Stoddart, B., Situated learning in the practice placement. *Journal of Advanced Nursing*, 2000. 31(4): p. 850-856.
16. Rahman, S.M. and Kapila, V. A systems approach to analyzing design-based research in robotics-focused middle school STEM lessons through cognitive apprenticeship. in *Proceedings of ASEE Annual Conference & Exposition*. 2017.
17. Papert, S., *Mindstorms: Children, Computers, and Powerful Ideas*. 1980: Harvester Press (U.K.)
18. Papert, S. and Harel, I., Situating constructionism. *Constructionism*, 1991. 36(2): p. 1-11.
19. Touretzky, D.S., *et al.* Accelerating K-12 computational thinking using scaffolding, staging, and abstraction. in *Proceedings of ACM Technical Symposium on Computer Science Education*. 2013. p. 609-614.
20. Khanlari, A. and Mansourkiaie, F. Using robotics for STEM education in primary/elementary schools: Teachers' perceptions. in *Proceedings of International Conference on Computer Science & Education (ICCSE)*. 2015. Cambridge, UK: IEEE. p. 3-7.

21. Grubbs, M., Robotics intrigue middle school students and build STEM skills. *Technology and Engineering Teacher*, 2013. 72(6): p. 12.

22. Kopcha, T., *et al.*, Developing an integrative STEM curriculum for robotics education through educational design research. *Journal of Formative Design in Learning*, 2017. 1(1): p. 31-44.

23. Okita, S.Y., The relative merits of transparency: Investigating situations that support the use of robotics in developing student learning adaptability across virtual and physical computing platforms. *British Journal of Educational Technology*, 2014. 45(5): p. 844-862.

24. Stork, M.G., Supporting twenty-first century competencies using robots and digital storytelling. *Journal of Formative Design in Learning*, 2020. 4(1): p. 43-50.

25. Durak, H.Y., Yilmaz, F.G.K., and Yilmaz, R., Computational thinking, programming self-efficacy, problem solving and experiences in the programming process conducted with robotic activities. *Contemporary Educational Technology*, 2019. 10(2): p. 173-197.

26. Kim, C., *et al.*, Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching. *Computers & Education*, 2015. 91: p. 14-31.

27. Mohr-Schroeder, M.J., *et al.*, Developing middle school students' interests in STEM via summer learning experiences: See blue STEM camp. *School Science and Mathematics*, 2014. 114(6): p. 291-301.

28. Alfieri, L., *et al.*, Case studies of a robot-based game to shape interests and hone proportional reasoning skills. *International Journal of STEM Education*, 2015. 2(1): p. 1-13.

29. Merdan, M., *et al.*, *Robotics in Education: Research and Practices for Robotics in STEM Education*. Vol. 457. 2016: Springer.

30. Alimisis, D. and Kynigos, C., Constructionism and robotics in education. *Teacher Education on Robotic-enhanced Constructivist Pedagogical Methods*, 2009: p. 11-26.

31. Atmatzidou, S., Markelis, I., and Demetriadis, S. The use of LEGO Mindstorms in elementary and secondary education: game as a way of triggering learning. in *Proceedings of International Conference of Simulation, Modeling and Programming for Autonomous Robots (SIMPAR), Venice, Italy*. 2008. p. 22-30.

32. Carbonaro, M., Rex, M., and Chambers, J., Using LEGO robotics in a project-based learning environment. *The Interactive Multimedia Electronic Journal of Computer-Enhanced Learning*, 2004. 6(1): p. 55-70.

33. Alimisis, D., Educational robotics: Open questions and new challenges. *Themes in Science and Technology Education*, 2013. 6(1): p. 63-71.

34. Witherspoon, E.B., *et al.*, Gender, interest, and prior experience shape opportunities to learn programming in robotics competitions. *International Journal of STEM Education*, 2016. 3(1): p. 1-12.

35. Eguchi, A. Robotics as a learning tool for educational transformation. in *Proceedings of International Workshop Teaching Robotics, Teaching with Robotics & International Conference Robotics in Education* 2014. Padova, Italy. p. 27-34.

36. Maisiri, W., Darwish, H., and Van Dyk, L., An investigation of Industry 4.0 skills requirements. *South African Journal of Industrial Engineering*, 2019. 30(3): p. 90-105.

37. Engineering Accreditation Commission, *Criteria for Accrediting Engineering Programs*. 2022 [cited 2022 May 10]; Available from: https://www.abet.org/wp-content/uploads/2022/01/2022-23-EAC-Criteria.pdf.

38. Wilson, L.O., Anderson and Krathwohl–Bloom's taxonomy revised. *Understanding the New Version of Bloom's Taxonomy*, 2016.

39. Center for Self-determination Theory, *Intrinsic Motivation Inventory (IMI)*. 2022 [cited 2022 Feb 10]; Available from: https://selfdeterminationtheory.org/intrinsic-motivation-inventory/.

40. Acendre, *7 Elements for a Successful Team*. 2022 [cited 2022 Feb 10]; Available from: https://acendre.com/blog/posts/7-elements-for-a-successful-team/.