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# Empowering computing students with proficiency in robotics via situated learning

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## Abstract

With the increasing employment of robots in multiple areas such as smart manufacturing and intelligent transportation, both undergraduate and graduate students from computing related majors (e.g., computer science and information technology) demonstrated strong interests in learning robotics technology to broaden their career opportunities. However, instilling computing students with robotics knowledge remains a challenge since most of them have limited pre-training in engineering subjects such as electronics and mechatronics. Therefore, robotics education for computing students demands an immersive real-world learning environment by considering both theories and intensive hands-on projects. Different from traditional textbook-directed robotics learning, in this study, a situated learning-based robotics education pedagogy is proposed for computing students to equip them with robotics expertise and foster their problem-solving skills in real-world human–robot interaction contexts. To create a realistic human–robot collaboration situation, a multi-modal collaborative robot is employed in the classroom-based learning community for the whole semester. Mini-project-based homework and team projects are designed for students to practice their critical thinking and hands-on experiences. The bidirectional-evaluation approach is utilized by the instructor and students to assess the quality of the proposed pedagogy. Practice results and student evaluations suggested that the proposed situated learning-based pedagogy and robotics curriculum provided computing students to learn robotics in an effective way, which was well recognized and accepted by students even most of them were beginners. Future work of this study is also discussed.

**Keywords:** Situated learning, Computer science, Collaborative learning, Hands-on experience, Human–robot interaction, Teamwork

## Introduction

Robotics technology plays a significant role in the fourth industrial revolution (Bahrin et al., 2016) with prominent characteristics, such as integrating artificial intelligence (AI) approaches, improving smart manufacturing processes, protecting humans from hazardous task environments, and reducing humans' efforts in complex tasks (Wang et al., 2018). Collaborative robot, which is one of the fast-developing robots in the robotics community, is increasingly attracting the attention of industries and researchers worldwide (Djuric et al., 2016). Different from traditional industrial robots, the collaborative robots are not fenced off from humans in the workplace and have the power to

democratize application areas moving toward fulfilling dynamic customer demands with high variability. Human–robot collaboration is a significant component within the contexts of smart manufacturing, intelligent transportation, advanced education, and daily assistance. In human–robot collaboration, the robot is occupied in some trained repetitive subtasks while its human counterpart works on the flexible subtasks that the robot is not capable of doing (Wang et al., 2019). Therefore, the human–robot team has the ability to respond rapidly to customized and dynamic task requirements and increasing innovation in diverse fields.

With the increasing application of robots to multiple areas, both undergraduate and graduate students from computing related majors (e.g., computer science and information technology) demonstrated strong interests in learning robotics technology to broaden their career opportunities (Davcev et al., 2019; Kumar et al., 2008; Paramasivam et al., 2017). In addition, learning and being versed in robotics can also make the student a well AI-ready worker, which is increasingly required by modern markets. A renaissance computing workforce demands proficiency in both conventional computer science theory as well as a hands-on engineering skillset to implement the subsequent complicated jobs. Consequently, training computing students with robotics to have them possess well both science and engineering problem-solving skills is a significant work in computing education.

Education 4.0 emphasizes the learning process on students instead of instructors to achieve a steadily increasing demand for adaptive and personalized education (Hussin, 2018; Puncreobutr, 2016). To address this challenge, a sustainable and effective robotics pedagogy based on situated learning is proposed and implemented with promising results in the Department of Computer Science at Montclair State University. In what follows, several related studies of robotics education for students and situated learning-based education are reviewed in Section “[Related work](#)”. The overall pedagogical framework is shown and discussed in Section “[Pedagogical framework](#)”. Section “[Instructional approach](#)” expounds the instructional approach development. The design of mini-project-based homework assignments and hands-on projects are detailed in Sections “[Mini-project-based homework assignments](#)” and “[Final projects](#)”, respectively. Implementation results and pedagogy evaluations are analyzed in Section “[Results and evaluations](#)”. Finally, the conclusions of research findings and future directions are presented in Section “[Conclusion and future work](#)”. The contributions of this paper can be summarized as:

1. A situated learning-based robotics education pedagogy is proposed to empower computing students with proficiency in robotics and a comprehensive pedagogical framework is constructed for the robotics curriculum development. The employed robot provides students with multiple flexible interactions in real-world application contexts to promote their deep learning during the whole learning process.
2. Mini-project-based homework assignments and hands-on projects are designed for students to increase their engagement and foster their problem-solving thinking in real-world human–robot interaction situations.
3. The proposed methodology is practically implemented for computing students in the classroom-based learning community. Results and evaluations suggest that the pro-

posed pedagogy provides an effective teaching practice for computing students to be equipped with robotics knowledge, and is highly recognized and accepted by them.

### **Related work**

In recent years, robotics education has been seeing a distinct rising trend in a variety of school communities from K-12 to graduate students (Mataric, 2004). Many robotics curriculums have been developed to cultivate students with robotics knowledge. In order to increase students' interests in robotics, a course entitled Fun With Robots was offered by Shamlan et al. for learners who were from a wide variety of disciplines and education levels (Shamlan et al., 2006). Nourbakhsh et al. designed a seven-week robotic autonomy course for high school students to explore robot basics such as robot mechanism, electronics, and remote teleoperation (Nourbakhsh et al., 2005). Jung et al. presented an undergraduate-level robotics course for engineering students to integrate what they learned by making a robotic system (Jung, 2012). Additionally, several online training approaches were also carried out to support and motivate robotics education. In (Corke et al., 2016), the educators discussed their teaching experience in the massive open online course (MOOC) Introduction to Robotics, which ran for six weeks with all teaching activities conducted online. Almeida et al. introduced a remote robotics laboratory to help students from geographically distant locations to learn robot programming and conduct robotics experiments online (Almeida et al., 2017).

However, instilling computing students with comprehensive robotics expertise to broaden their career opportunities remains a challenge given most of computing students have limited pre-training in engineering subjects such as electronics and mechatronics. In addition, although learning robotics online is an economic way, it cannot provide learners such as computing students with tangible and firsthand experience to get intuitive and deep understandings of robotics technology. Therefore, different from above robotics curriculums that were designed for high school basic training or college engineering students, robotics education for computing students requires to create a unique and real-world learning environment by considering both basic theories and intensive hands-on projects.

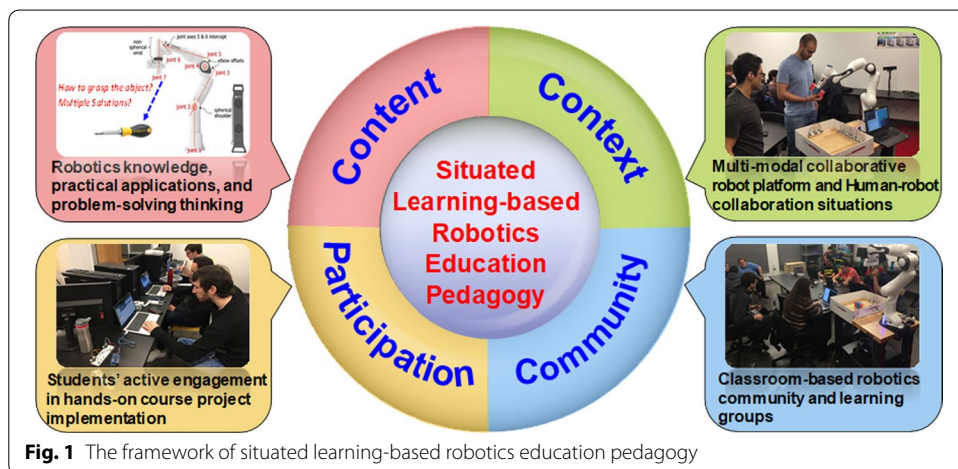
Different from the traditional teacher-directed and textbook-oriented pedagogies, situated learning is a theory that focuses on having students participate in realistic settings during their learning processes to acquire professional skills (Lave & Wenger, 1991). It has been utilized for professional education in multiple areas including language education (Miner, 2018), earth sciences education (Fortner et al., 2020), physical education (Kirk & Macdonald, 1998), and health professions education (O'Brien & Battista, 2020). Through situated learning, the classroom culture will be converted from more of knowledge supplying to an interactive and dynamic learning community, where group of students could collaborate and exploit their problem-solving skills. Robotics is a cross-disciplinary subject which encompasses software development and hardware integration. Teaching students in realistic robotics environments could evaluate their performance in different tasks and focus on the learning process and product. Therefore, developing robotics education for computing students by leveraging situated learning is believed as an effective solution to well equip them with professional skills in robotics.

To this end, a situated learning-based robotics education pedagogy is proposed for computing students to learn robotics knowledge from real-world human–robot interaction contexts. A multi-modal collaborative robot is employed in the classroom-based learning community. The development of the instructional approach is presented. A bidirectional-evaluation approach—instructor-evaluating-student and student-evaluating-instructor—is adopted to assess the quality of the proposed pedagogy. Practice results and student evaluations indicate that this situated learning-based robotics education pedagogy is ideal to be used for students to achieve robotics competency.

**Pedagogical framework**

The overall framework of the proposed situated learning-based robotics education pedagogy is presented in Fig. 1. The framework consists of four elements including content, context, community, and participation (Stein, 1998), which are seamlessly integrated in the whole process of robotics curriculum development and implementation. The overarching vision of the proposed pedagogy is to provide an effective solution to empower computing students with proficiency in robotics via students’ engagement in human–robot interaction situations. Some scholars stated that the project-based learning (PBL) is a form of situated learning (Greeno & Engeström, 2006; Krajcik & Blumenfeld, 2006). In PBL, under the support of the instructor, students are given a problem and the tools necessary to solve the problem with independence (Thomas, 2000). In this study, different from traditional project-based learning, the proposed situated learning-based robotics education pedagogy employs a multi-modal collaborative robot to accompany and work with students during the whole learning process. The robot provides students with multiple flexible interactions in real-world application contexts to promote their deep learning.

In this situated learning-based robotics course, all contents are derived from daily life robot applications, such as human–robot object hand-over in collaborative tasks. Instead of rote learning, this course focuses on fostering students’ reflective and higher-level thinking through intensive engagement in real-word problems, in which the collaborative robot plays an important role to provide students with practical learning contents, explicit learning motivations, and tangible hands-on projects. That is,



**Fig. 1** The framework of situated learning-based robotics education pedagogy

the proposed pedagogy will deal with how students obtain, create, and interpret their knowledge over the process of activities supported by the collaborative robot.

For the context construction, the collaborative robot is employed during the students' learning for the whole semester. This robot is able to work with students safely for shared tasks in human–robot collaboration situations. Based on this collaborative robot platform, mini-project-based homework assignments and hands-on projects are designed for students to assess their learning experience and outcomes. Therefore, the collaborative robot plays a significant role in the context creation of the proposed situated learning-based pedagogy.

The learning community can help students to create, interpret, reflect, and form meanings of what they learned. In this study, under the support of the multi-modal collaborative robot platform, a classroom-based learning community is constructed for students to build the bridge between classroom situations and outside-classroom applications. This learning community, employing robotics-related homework assignments and course projects, can effectively provide tangible opportunities for students to interact with each other and share learning experience. Therefore, students could focus on building personalized knowledge to solve problems that they are interested in.

Participation is necessary and significant for every student in this situated learning-based robotics education pedagogy. The robot-supported teamwork, which greatly enables all students' participation in all learning activities, is also one of the features of this pedagogy. Working with the collaborative robot, students will accomplish the designed final projects of the robotics course through small teams and each team contains several members. In the participation process, students can exchange their ideas with teammates and engage in hands-on projects with effective and optimized solutions.

The following sections (Sections “[Instructional approach](#)”, “[Mini-project-based homework assignments](#)”, “[Final projects](#)”, and “[Results and evaluations](#)”) elaborate the development and implementation of the proposed situated learning-based robotics education pedagogy.

## **Instructional approach**

### **Course description**

The situated learning-based robotics education for computing students in the Department of Computer Science at Montclair State University started from Fall 2019. The department offers this robotics class as a 3-credit course for undergraduate and graduate students from majors of computer science and information technology. The robotics course totally runs for 15 weeks. This robotics course introduces the fundamental technology and advanced algorithms of robotics, including overview of robotics development, robot kinematics, sensors and actuators, vision system, signal processing, system controls, motion planning, machine learning, human–robot collaboration, and state-of-the-art robot programming approaches. The most featured parts of this course are mini-project-based homework assignments (see Section “[Mini-project-based homework assignments](#)” for details) and hands-on projects (see Section “[Final projects](#)” for details), which are designed for students to apply their learned knowledge to robotics in real-world human–robot collaboration situations.

### Intended learning outcomes

The main intended learning outcomes (LO) of this robotics education pedagogy can be summarized as follows:

LO1. Understand the fundamental knowledge of robotics such as sensing technologies, control technologies, and motion planning technologies, and can apply them to robotics.

LO2. Be familiar with basic knowledge on machine learning technologies and can apply them to robotics.

LO3. Be familiar with the state-of-the-art robot programming technologies and can apply them to robots in human–robot collaboration tasks in practical situations.

LO4. Integrate different technologies to achieve various robotics functions and obtain professional hands-on experience and teamwork experience through course projects.

### Who is permitted?

Although this robotics course is developed for a broader audience from computer science and information technology, some prerequisites are required to meet by the undergraduate students. In addition to 100-level and 200-level courses required by the department, the undergraduate students should have completed at least one 300-level course, such as Computer Networks or Database Systems, when taking the robotics course. For graduate students, since they have been trained by undergraduate computing courses, the robotics course is open to all graduate students from computer science and information technology. In Fall 2019, most students in the robotics class had never been exposed to robotics knowledge before.

### Curriculum modules and schedule

Since robotics is a rapidly evolving subject, there was no required textbook for the course. All reference materials and reference sources in the class are collected from up-to-date robotics scientific papers and related technologies. As shown in Table 1,

**Table 1** Course modules and schedule

Module	Weeks	Topics
Module 1: Robot basics	2	Introduction to robotics development Robot kinematics
Module 2: Robot electronics and integration	5	Sensors and actuators for robotics Signal processing for robotics Computer vision for robotics System controls for robotics Mid-term exam
Module 3: Robot advanced applications	3	Robot motion planning Robot operating system Robot programming Machine learning technologies and applications in robotics
Module 4: Hands-on projects	5	Project 1: Robot simulation system Project 2: Object location system for robot grasping

the overall course was broadly split into 4 modules with a stair-stepping structure including robotics basics, robot electronics and integration, robotics advanced applications, and hands-on projects. Operationally, each module is equipped with several topics that are designed for the students to study and work with the robot.

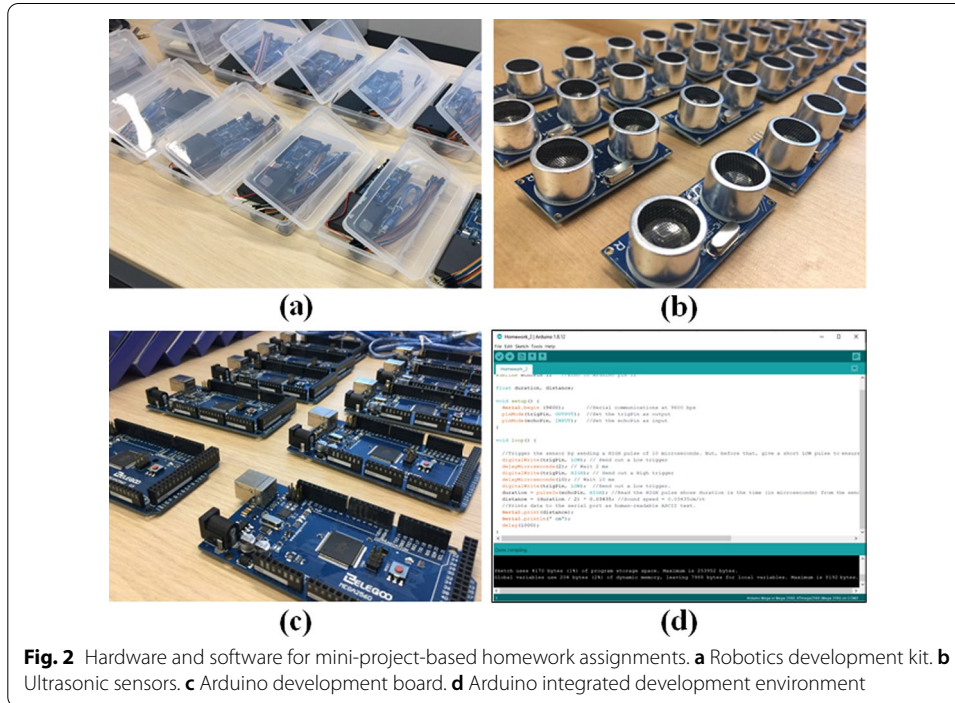
The first two weeks of the class cover the module 1, which is dedicated to fundamental robotics concepts and theories, addressing the following topics: Introduction to robotics development and Robot kinematics. Along with the Introduction to robotics development, our collaborative robot is showed to students in the class. Students are able to touch, manipulate, and interact with the robot in real-world contexts, which will largely enhance the students' interests in learning robotics. For example, students can manipulate the robot directly via dragging the end effector of the robot. The robot will interact with the students compliantly by sensing the students' maneuver intentions and moving its arm through the force torque sensors and motors. In the robotics kinematics class, the robotics morphology and terminology such as degrees of freedom, architecture, reachability, precision, repeatability, forward kinematics, inverse kinematics, and D-H parameters are delivered to students via the operation demonstrations of the collaborative robot. Through such real-world robot-student interactions in this smart learning environment, students will get a direct and deeper understanding of the latest robot construction and applications.

The second module focuses on robot electronics and integration technology including Sensors and actuators, Signal processing, Computer vision, and System controls for robotics. In addition, the Mid-term exam is also conducted in this module. The robot could interact with students in some mini-project-based homework assignments. For example, after learning the sensors and actuators, each student will complete a homework assignment in which they are required to develop a measurement system using ultrasonic sensors to measure the distance from the robot to the object. The robot will present the detected distance to each student through an intuitive interface in its control system. By such tangible robot-student interactive activities, students will be highly encouraged improve problem-solving thinking and exploit hands-on skills by themselves. Several topics on robot advanced applications such as Robot motion planning, Robot operating system (ROS) (Quigley et al., 2009), Robot programming, and Machine learning technologies and applications in robotics are discussed in module 3. In particular, the state-of-the-art robot programming technologies ROS and MoveIt (Chitta et al., 2012) are studied and explored in student-robot interaction situations.

In the remaining weeks, a more situation-based hands-on module is designed. Working with the robot and under the guidance of the instructor, students are grouped by 6 teams and each team spends 1.5 weeks developing a full-dimensional robot simulation system using the robot programming approaches and algorithms. After that, in realistic human-robot collaboration situations, students spend 3.5 weeks developing an object location system for robot grasping using the learned knowledge of robotics electronics and advanced applications. At the end of the semester, the course has an open competition, in which each team shows off their hands-on project achievements to the University community by on-site demonstrations with the robot.

**Table 2** Course grading policy

Assignments/Activities	Homework Assignments	Mid-term Exam	Hands-on Projects
Percentage of Final Grade	30%	20%	50%



### Assessment strategy

Assessment approach is also one of the critical sections in situated learning. In this study, the assessment strategy is proposed to not only focus on students' performance in each learning module, but also evaluate the whole learning process and outcomes. The grading policy for each assessment element is presented in Table 2. Three homework assignments contribute 30% (10% for each homework) towards the final course grade. The mid-term exam takes 20% of the final grade. The remaining 50% is assigned to hands-on projects for assessing students' project code, project on-site demonstration, presentation, and technical report.

### Mini-project-based homework assignments

In this situated learning-based robotics course, every computing student is allocated a robotics development kit, as shown in Fig. 2a. The kits, containing several ultrasonic sensors, an Arduino board, and other robotics electronic accessories, are used by students for mini-project-based homework assignments. Three homework assignments were spread over the first three modules to have students integrate their learned with practical applications through mini-projects.



The ultrasonic sensor utilized in this work is HC-SR04 with detection range 0.02 m to 4 m (Freaks, 2018), as shown in Fig. 2b. It utilizes the reflective properties of ultrasonic waves to evaluate the distance from obstacles to the source through its transmitter and receiver. For example, if the sensor is used in air, the distance can be computed by

$$distance = (343 \text{ m/s} * T)/2 \quad (1)$$

where 343 m/s is the speed and  $T$  is the flight time of sound, respectively.

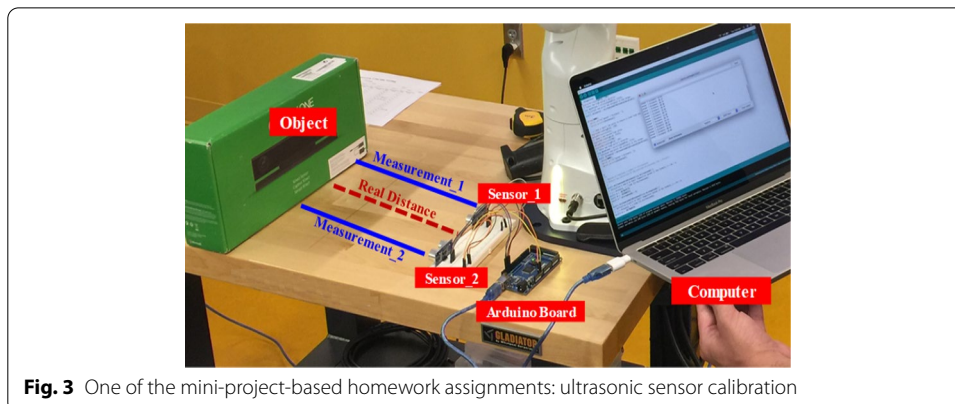
As presented in Fig. 2c, the Arduino board selected in this course is MEGA 2560 (Kusriyanto and Putra 2016), which is a microcontroller board based on the ATmega2560 and has 54 digital inputs/outputs and 16 analog inputs. This board can be used to collect and process sensor data for robotics electronics integration in students' homework assignments and final hands-on projects. Additionally, as shown in Fig. 2d, the Arduino integrated development environment (IDE) is employed for students to program Arduino and ultrasonic sensors.

Figure 3 shows an example of the mini-project-based homework assignments: ultrasonic sensor calibration. In this homework, students are required to calibrate two ultrasonic sensors to have measured values be same as the real distance from sensors to the object. On the due day, all students are required to showcase their calibration results via on-site demonstrations in the classroom-based learning community. The student's homework is graded by the instructor according to the accuracy of calibration results.

## Final projects

### Background of the final projects

In situated learning, the learner's knowledge is obtained through practical thought and activities that are grounded in concrete scenarios. Problems are usually solved in situated contexts provided by anchored instructions, which highlight the environments of the situated learning. In the classroom-based learning community of the proposed situated learning-based robotics education pedagogy, two hands-on projects are designed to motivate computer students' intellectual and psychomotor skills via real-life human-robot interactive contexts that are different from traditional classroom activities.



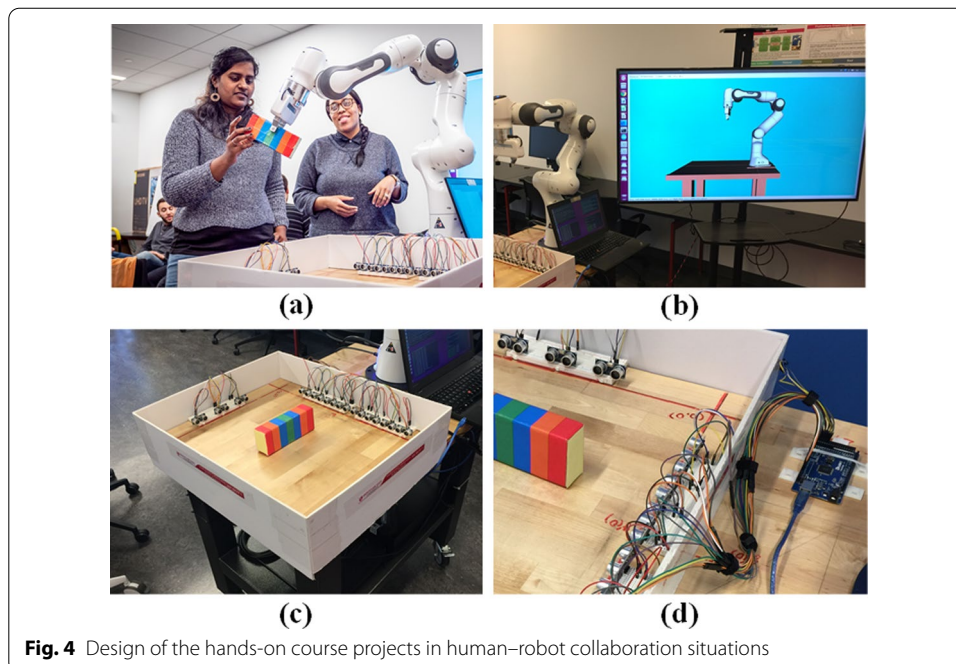
**Fig. 3** One of the mini-project-based homework assignments: ultrasonic sensor calibration

Generally, locating target objects accurately for robots to grasp is a challengeable work in the robotics community. Existing approaches such as vision-based systems for object location are usually too expensive and complex. To explore this challengeable problem, students utilize their learned from the first three modules to develop a full-dimensional robot simulation platform and a cost-competitive object location system for the robot to grasp objects and work with its human partners, as shown in Fig. 4a.

### Project design

In project 1, students employ the state-of-the-art robot programming approaches (ROS and MoveIt) to build a robot simulation system, as presented in Fig. 4b. The robot in the classroom-based learning community can be driven by the simulation system to perform picking and delivery tasks. Based on project 1, as shown in Fig. 4c, students build an object location system for the robot to correctly grasp objects from the workspace and deliver it to its human partner in realistic human–robot collaboration situations. Ultrasonic sensor arrays and Arduino platform are used to collect environmental signals and process the data for robot motion planning, respectively. As presented in Fig. 4d, when the object is placed in the workspace, the ultrasonic sensor arrays are able to detect the object position and send it to the Arduino board. The Arduino can further process the sensor data and calculate the exact object position via object location algorithms developed by students.

The robot used in this course is Franka Emika Panda. Panda robot is a 7-DoF collaborative robot comprising a sensitive robotic arm, a two-finger parallel gripper, a pilot user interface, and a local controller (Gaz et al., 2019). Since the torque sensors in all seven axes enable Panda to manipulate objects in a skillful and sensitive way, the robot can work with humans safely and intuitively like human–human collaboration in shared tasks. ROS is employed for students in the robot simulation system development. ROS



**Fig. 4** Design of the hands-on course projects in human–robot collaboration situations

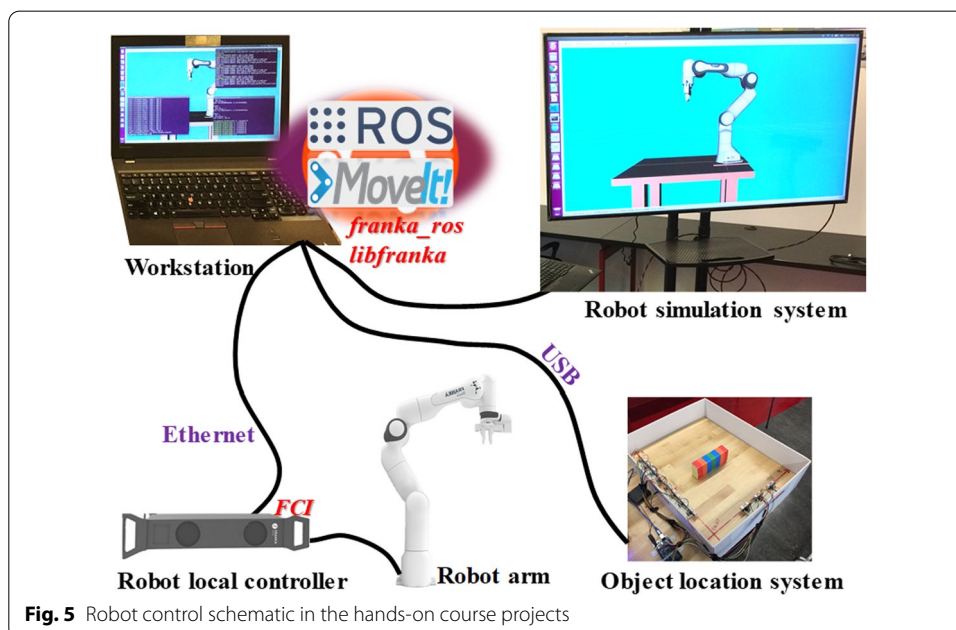
is an open-source middleware framework for large-scale cross-platform communication and control. Because of its multi-functional and real-time performance, ROS rapidly became one of the de-facto standard development platforms in the robotics community. In addition, another package MoveIt that runs in the ROS framework is also used. ROS and MoveIt are able to simplify programming work by permitting coding one task in multiple languages, such as Python, C++, and Matlab, which can enable beginner students to engage rapidly.

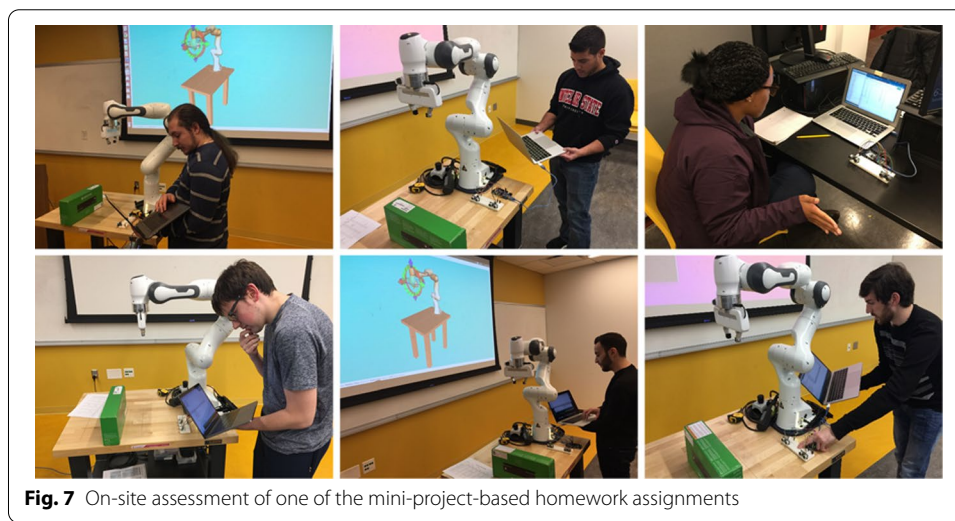
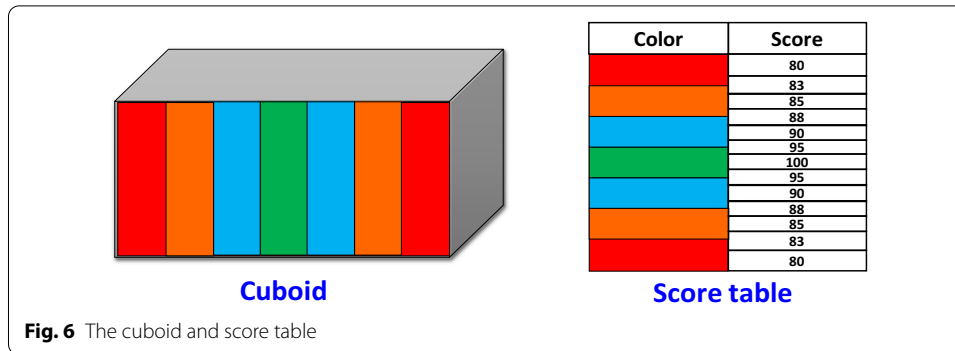
Figure 5 shows the robot control schematic in hands-on course projects. The distributed control technology is employed to monitor and control the robot in the object location and human–robot collaboration process. A workstation is deployed for students to program the Arduino and Panda robot. After being calculated by the Arduino from the location system, the object position is sent to the workstation to control the robot to grasp the object and deliver it to students in collaborative situations. Moreover, the sensor integration, signal processing, and robot programming are done on Ubuntu operating system.

### Grading rubrics

Computing students from different teams develop their own robot simulation systems and object location algorithms, then program the robot to grasp the target object. Grading rules for hands-on projects are described below:

1. The instructor puts a cuboid into the robot workspace randomly with unpredefined locations.
2. Each team locates the object with their developed systems, then sends the object position for the robot to grasp. Each team has three trials. If the robot receives a valid object position information, the robot will interact with the team by saying “Oh, there is an object”, then grasp the object using the received position.





- Each trial's on-site testing score is determined by the robot's grasping accuracy. As shown in Fig. 6, the cuboid is painted with different colors from the center to both ends. A score table is designed for each color area when the robot grasps the cuboid. The more middle of the cuboid is grasped by the robot, the more grasping accuracy is judged and the higher score is got by the corresponding team. Therefore, the robot can tell each team the detection accuracy of their algorithms by graphing different color areas of the cuboid.
- The final grade of hands-on course projects of each team is determined by the project implementation results, including on-site testing score (60%), code quality (20%), presentation (10%), and technical report (10%).

## Results and evaluations

### Homework accomplishment and assessment

The mini-project-based homework assignments are graded according to on-site demonstrations of each student in the classroom-based learning community. As presented in Fig. 7, some students were showing their results of the homework ultrasonic sensor calibration on the due day. In the on-site assessment, a box was placed in front of two

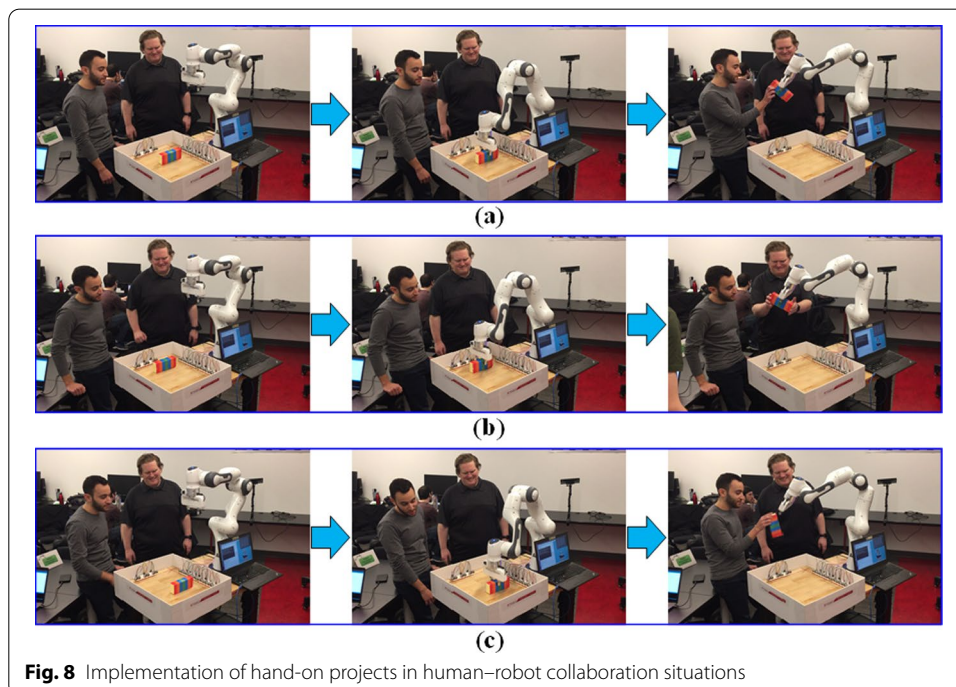
ultrasonic sensors with a given distance. Each student downloaded their own sensor calibration code to the Arduino. Then the Arduino presented the measured distance readings on the computer using the calibration code. The student's grade was calculated by

$$\frac{((1 - |real - measurement_1|/real) * 100 + (1 - |real - measurement_2|/real) * 100)/2}{(2)}$$

In this homework, two students' sensor calibration accuracy reached 99% and the remaining students' results all exceeded 98%. The average calibration accuracy was 98.88%. It can be seen that the students did a good job on the mini-project-based homework assignments in this situated learning-based robotics course although some of them were beginner in robotics.

### Final project implementation

Figure 8 presents the hands-on project implementation results of one of the teams in the robotics class. For the first trial, as shown in Fig. 8a, a student randomly putted the cuboid into the robot's workspace. The ultrasonic sensors detected the cuboid's position in the x axis and y axis and sent the raw data to Arduino for future processing. Since the robot grasped the same object in different trials, the object's position in the z axis was set as a fixed value. After receiving the raw sensor data, the Arduino evaluated the cuboid exact position in the robot coordinate system via the team's object location algorithms, then sent the position to the workstation. As presented in the second picture of Fig. 8a, the workstation gave the position commands to the robot controller to have the robot grasp the cuboid in the workspace. It can be observed that the robot grasped the green area of the cuboid, which meant that the team could get 100 points in this



**Fig. 8** Implementation of hand-on projects in human-robot collaboration situations

trial. As shown in the third picture of Fig. 8a, the robot handed-over the cuboid to its human partner after got it. Figure 8b, c presented the team's second trial and third trial in different locations, respectively. It can be seen that the robot grasped the cuboid and delivered to the students with high points. The on-site demonstrations of culminated course projects indicated that the proposed situated learning-based pedagogy worked well on robotics education for computing students. One of the project demos is available at: <https://www.youtube.com/watch?v=p9Bj11PLtms>.

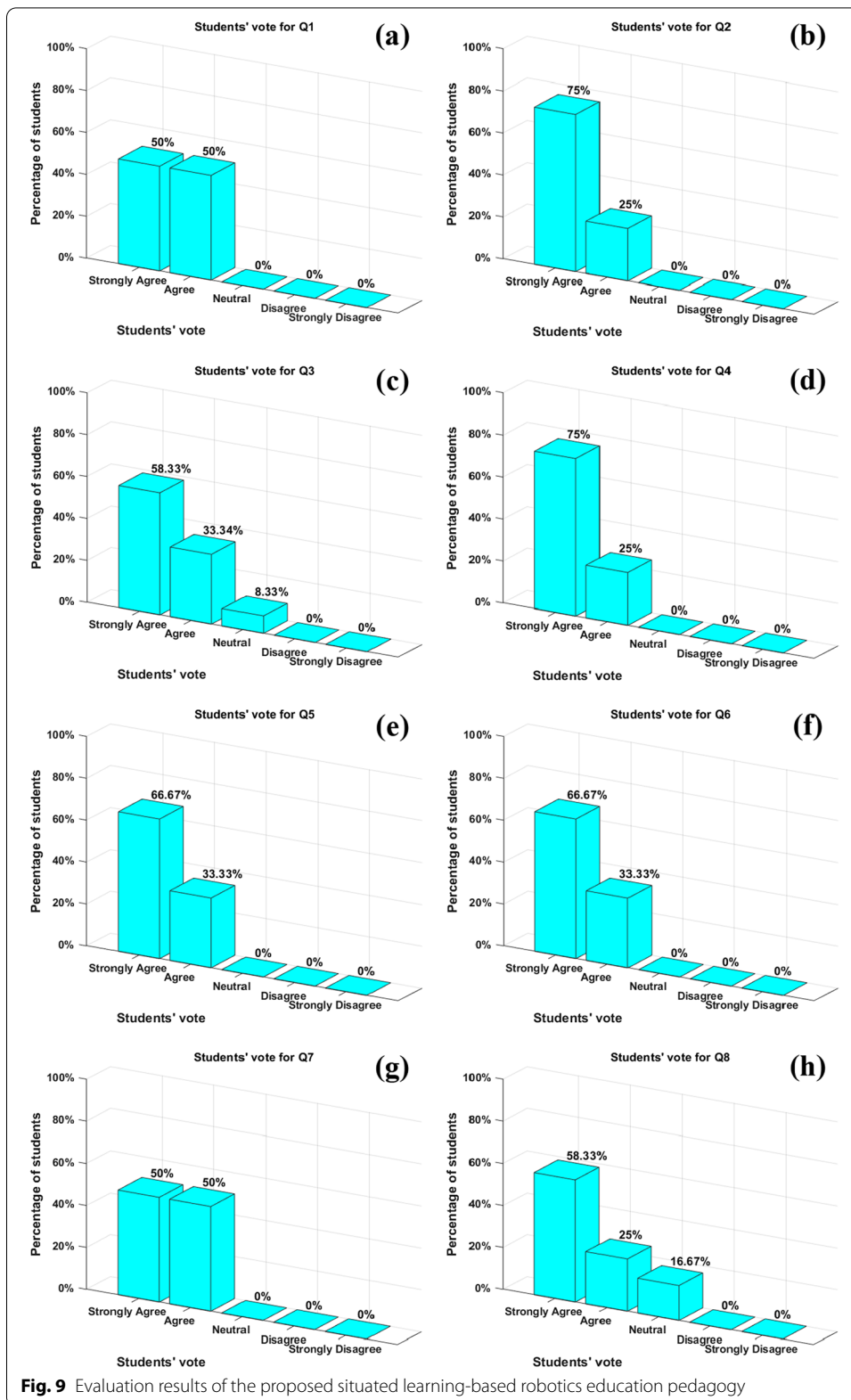
### Course evaluation from students

The feedback from students is helpful for the instructor to identify their satisfaction about the course and to improve the course quality. Subsequently, a voluntary survey with anonymity was conducted at the end of the semester to evaluate students' experience and expectations of this robotics education pedagogy. As shown in Table 3, the survey included 8 questions, which were responded as a scale from 1 to 5 level: 1-Strongly agree, 2-Agree, 3-Neutral, 4-Disagree, 5-Strongly disagree. Afterwards, students were asked to provide his/her recommendations and comments by one or two sentences.

Figure 9 summarizes the evaluation results of each question received from students. It can be observed from Fig. 9a that 50% of students strongly agreed and 50% of students agreed that the course had clearly defined concepts and skills in their learning processes, respectively. As shown in Fig. 9b, 75% of students were strongly satisfied with the course preparation and organization in each class. When the participants were asked to rate if the proposed pedagogy framework was interesting and meaningful, as presented in Fig. 9c, 58.33% of them were strongly satisfied with this point, 33.34% of them agreed it, and 8.33% of them held neutralizing attitude, separately. It indicates that some more measures should be taken to make the robotics education pedagogy more interesting and meaningful. As shown in Fig. 9d, all the participants considered that this course was approachable and had a positive attitude toward progress. Of the respondents, 75% of students strongly agreed and 25% of students agreed this point. Figure 9e indicates that all the participants agreed that the proposed pedagogy framework provided a learning experience in their studies, of which 66.67% were strongly satisfied. When asked if the course was taught in an effective manner, as shown in Fig. 9f, 66.67% of students strongly agreed and 33.33% of students agreed. It means that all computing students in this class

**Table 3** Questions of evaluating for the proposed situated learning-based robotics education pedagogy

No	Do you think that
Q1	This course has clearly defined the concepts and skills to be obtained?
Q2	This course is well prepared and organized in each class?
Q3	The proposed pedagogy framework is interesting and meaningful?
Q4	This course is approachable and has a positive attitude toward progress?
Q5	The proposed pedagogy framework provides a learning experience?
Q6	This course is taught in an effective manner?
Q7	The pace of this course is appropriate for students?
Q8	This course encourages student participation?



could effectively learn the robotics knowledge through the proposed situated learning-based robotics education pedagogy.

Since most of computing students were beginners in the robotics class, the pace of teaching was also considered as one of the significant elements when the course is developed. It is pleased to see that, as presented in Fig. 9g, half students strongly agreed and half students agreed that the pace of this course was appropriate for them. When asked if this course encouraged student participation, as shown in Fig. 9h, the vote results of strongly agree, agree, and neutral of the student were 58.33%, 25%, and 16.67%, respectively. It implies that most of the students were satisfied with the participations in this class, while some students considered that the course participations could be better.

The collected recommendations and comments from students can be grouped by three aspects. First, 40% of students strongly agreed that learning robotics knowledge in real-world human–robot interaction situations of this course was more interesting and more effective than learning from just slides. In addition, 40% of students made comments that the instructor had a passion for teaching, the knowledge was delivered clearly, and the workload for students was reasonable. The rest of students recommended that the course would be better if more hands-on projects were introduced for students.

Based on the evaluation results, most students agreed that the proposed situated learning-based robotics education pedagogy was effective for even novices to learn robotics knowledge. Additionally, hands-on projects are more attractive for students comparing to slide-based lectures. It is also an aspect that will be strengthened (e.g., designing more hands-on projects for students) in the instructional approach development.

### Enrollment trend

In order to evaluate the computing students' recognition and acceptance of the proposed robotics education pedagogy from another perspective, a comparison of robotics course enrollment counts between Fall 2019 and Spring 2020 is conducted. When the situated learning-based robotics course was first launched in Fall 2019 semester, the majority of computing students in the department were equipped with little robotics knowledge and they were afraid of not being able to take this course well. Therefore, it was supposed that, after being enjoyed by the first group of enrolled students in Fall 2019, this robotics course would attract more computing students. As presented in Table 4, comparing to Fall 2019, in Spring 2020 the enrollment growth rate of undergraduate computing student is 250% and the enrollment growth rate of graduate computing student is 50%, respectively. The overall growth rate is 83.33%. The comparison results indicate that the proposed pedagogy is more recognized and more popular with computing students at both undergraduate and graduate levels.

**Table 4** Comparison of robotics course enrollment counts of fall 2019 and spring 2020

Semester	Undergraduate	Graduate
Fall 2019	2	10
Spring 2020	7	15
Growth rate	250%	50%
Overall growth rate	83.33%	



## Conclusion and future work

A situated learning-based robotics education pedagogy have been proposed for computing students to learning robotics knowledge in real-world human–robot interaction contexts. Instead of textbook-directed lectures, a hands-on-project-oriented robotics curriculum has been developed based on the situated learning methodology for undergraduate and graduate computing students. In order to create a realistic human–robot collaboration situation, a multi-modal collaborative robot has been adopted in the classroom-based learning community. Through the situated learning, the robotics course projects have been successfully implemented. A bidirectional-evaluation approach has been utilized by the instructor and students to assess the proposed pedagogy. Practice results and evaluations suggested that the proposed situated learning-based robotics education pedagogy was well recognized and accepted by students even most of them were beginners.

In order to make this course more popular with students, several constructive measures will be taken such as designing new hands-on projects for students based on some emergent social applications which can help improve people's lives. Second, some new teaching strategies, such as group discussions or brainstorm to increase the engagement level of students, will be introduced. Third, a comprehensive evaluation system with more questions, such as how each performance is when integrating the robot into the four components of situated learning, in smart learning environments will be developed and more data of students' feedback and recommendations will be collected to evaluate and improve the proposed robotics education pedagogy and enrich course modules. Fourth, to promote the students' deep learning in robotics, we will design some new sections in our robotics course to have the robot more actively provide each student with progressive personalized feedback and suggestions based on their learning behaviors.

### Abbreviations

MOOC: Massive open online course; LO: Learning outcomes; ROS: Robot operating system; IDE: Integrated development environment.

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## Declarations

### Competing interests

The authors declare that they have no competing interests.

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## References

Almeida, T. O., Netto, J. F. d. M., & Rios, M. L. Remote robotics laboratory as support to teaching programming. In *2017 IEEE frontiers in education conference (FIE), 2017* (pp. 1–6). IEEE.

- Bahrin, M. A. K., Othman, M. F., Azli, N. H. N., & Talib, M. F. (2016). Industry 4.0: A review on industrial automation and robotic. *Jurnal Teknologi*, 78, 6–13.
- Chitta, S., Sukan, I., & Cousins, S. (2012). Moveit! *IEEE Robotics & Automation Magazine*, 19(1), 18–19.
- Corke, P., Greener, E., & Philip, R. (2016). An innovative educational change: Massive open online courses in robotics and robotic vision. *IEEE Robotics & Automation Magazine*, 23(2), 81–89.
- Davcev, K., Koceska, N., & Koceski, S. (2019). Teaching basics of serial Robot Chains's kinematics to computer science students.
- Djuric, A. M., Urbanic, R., & Rickli, J. (2016). A framework for collaborative robot (CoBot) integration in advanced manufacturing systems. *SAE International Journal of Materials and Manufacturing*, 9(2), 457–464.
- Fortner, S. K., Scherer, H. H., & Ritter, J. B. (2020). Community engagement in the earth sciences: A situated learning model at Wittenberg University. In *Preparing students for community-engaged scholarship in higher education* (pp. 361–378). IGI Global.
- Freaks, E. (2018). Ultrasonic ranging module HC-SR04 datasheet. Accessed.
- Gaz, C., Cognetti, M., Oliva, A., Giordano, P. R., & De Luca, A. (2019). Dynamic identification of the franka emika panda robot with retrieval of feasible parameters using penalty-based optimization. *IEEE Robotics and Automation Letters*, 4(4), 4147–4154.
- Greeno, J. G., & Engeström, Y. (2006). Learning in activity. In *The Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 79–96). Cambridge, England: Cambridge University Press.
- Hussin, A. A. (2018). Education 4.0 made simple: Ideas for teaching. *International Journal of Education and Literacy Studies*, 6(3), 92–98.
- Jung, S. (2012). Experiences in developing an experimental robotics course program for undergraduate education. *IEEE Transactions on Education*, 56(1), 129–136.
- Kirk, D., & Macdonald, D. (1998). Situated learning in physical education. *Journal of Teaching in Physical Education*, 17(3), 376–387.
- Krajcik, J. S., & Blumenfeld, P. C. (2006). Project-based learning. In *The Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 317–334). Cambridge, England: Cambridge University Press.
- Kumar, D., Blank, D. S., Balch, T. R., O'Hara, K. J., Guzdial, M., & Tansley, S. Engaging computing students with AI and robotics. In *AAAI spring symposium: Using AI to motivate greater participation in computer science, 2008* (pp. 55–60).
- Kusriyanto, M., & Putra, B. D. (2016). Smart home using local area network (LAN) based arduino mega 2560. In *2016 2nd international conference on wireless and telematics (ICWT), 2016* (pp. 127–131). IEEE.
- Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.
- Mataric, M. J. (2004). Robotics education for all ages. In *Proceedings of AAAI spring symposium on accessible, hands-on AI and robotics education*.
- Miner, A. (2018). *The use and perceived effectiveness of situated learning in American Sign Language-English interpreter education*. Gallaudet University.
- Nourbakhsh, I. R., Crowley, K., Bhav, A., Hamner, E., Hsiu, T., Perez-Bergquist, A., et al. (2005). The robotic autonomy mobile robotics course: Robot design, curriculum design and educational assessment. *Autonomous Robots*, 18(1), 103–127.
- O'Brien, B. C., & Battista, A. (2020). Situated learning theory in health professions education research: a scoping review. *Advances in Health Sciences Education*, 25(2), 483–509.
- Paramasivam, V., Huang, J., Elliott, S., & Cakmak, M. Computer science outreach with end-user robot-programming tools. In *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education, 2017* (pp. 447–452)
- Puncreobutr, V. (2016). Education 4.0: New challenge of learning. *St. Theresa Journal of Humanities and Social Sciences*, 2(2), 92–97.
- Quigley, M., Conley, K., Gerkey, B., Faust, J., Foote, T., Leibs, J., et al. ROS: an open-source Robot Operating System. In *ICRA workshop on open source software, 2009* (Vol. 3, pp. 5, Vol. 3.2): Kobe, Japan
- Shamlian, S. V., Killfoile, K., Kellogg, R., & Duvallet, F. Fun with robots: A student-taught undergraduate robotics course. In *Proceedings 2006 IEEE international conference on robotics and automation, 2006. ICRA 2006, 2006* (pp. 369–374): IEEE
- Stein, D. (1998). *Situated learning in adult education*: ERIC Clearinghouse on Adult, Career, and Vocational Education.
- Thomas, J. W. (2000). A review of research on project-based learning. California.
- Wang, W., Li, R., Chen, Y., Diekel, Z. M., & Jia, Y. (2018). Facilitating human–robot collaborative tasks by teaching-learning–collaboration from human demonstrations. *IEEE Transactions on Automation Science and Engineering*, 16(2), 640–653.
- Wang, W., Li, R., Diekel, Z. M., Chen, Y., Zhang, Z., & Jia, Y. (2019). Controlling object hand-over in human-robot collaboration via natural wearable sensing. *IEEE Transactions on Human-Machine Systems*, 49(1), 59–71.

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