Multi-Lab-Driven Learning Method Used for Robotics ROS System Development

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Multi-Lab-Driven Learning Method Used for Robotics ROS Study

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Abstract

The Robot Operating System (ROS), a collection of tools, libraries, and conventions, is a powerful framework for programming robot software, and ROS-based mobile robot systems are becoming increasingly significant in human life. ROS has therefore been extensively taught in robotics program in electrical engineering programs. However, although it is a low-cost solution to allowing students to perform a variety of simulations and validating new algorithms before implementing them on an actual mobile robot, teaching ROS so that students can use it efficiently and effectively is a challenging task. Regular electrical engineering courses on ROS may focus on theories but neglect hands-on experiences. Traditional lab-driven pedagogy may provide hands-on opportunities on ROS itself but may still not bring students close enough to the actual applications of ROS to their major robot projects in their electrical engineering education. In this paper, a technological content knowledge (TCK) based method is utilized to create learning opportunities that allow students to construct their knowledge of the technology/tool (the T) in close relation to the content/robot programming (the C). The multi-lab-driven method (MLDM) was employed to construct the TCK of ROS of students in the context of designing an autonomous mobile robot system. A sequence of multiple labs were assigned to students to cover various topics in the ROS. A variety of labs that reflect the ROS experiments and assist students in better understanding robotics programming were elaborately managed. Based on students' performance on various lab assignments, lab reports, presentations, the final robot project, students' input to the official course evaluation administered by the university, and a comparison to the instructor's previous years of teaching experience, we propose that the MLDM is effective in helping students to learn ROS efficiently and meaningfully in the real world of engineering projects. Preliminary assessment of this multi-lab-driven learning method for providing robotics education supports its effectiveness.

1. Introduction

With the continued advances in autonomous robotics over the several decades, it is becoming increasingly vital that the development of a new curriculum on Robot Operating System (ROS) in a university be well aligned to technology advancements and applications [1,2,15]. The ROS has drawn attention from the field of robotics over the last several years [15]. The primary objective of ROS is to provide an open source, configurable, and unified programming framework utilized for controlling robots in a variety of simulated environments, and even in the real world. The ROS, now equipped with a collection of tools, libraries, and conventions, is a powerful framework for programming robot software. ROS-based mobile robot systems are increasingly significant in various aspects of human life. The ROS not only simplifies missions of creating complex and robust robot behavior across a broad variety of robotic platforms but also provides a low cost solution for students to situations where a variety of simulations need be performed to complete the project at an expedited pace.

ROS has been extensively taught in robotics program in the Electrical Engineering but it is a challenging mission to teach and learn well. Regular electrical engineering courses usually focus on theories of ROS and the students may not have hands-on opportunities to learn the ROS advanced software development [15]. Lab-driven learning has been considered to be the most effective pedagogy for teaching and learning in electrical engineering [17]. However, if the lab activities are not authentic, too large to handle, or not well-aligned to what we expect our students to learn about ROS, students will still not be able to master ROS meaningfully. The meaningful mastery of a technology is beyond learning about the technology's functions represented in the tool bars or menus, or even beyond doing a few random exercises through trial and error. To make meaningful mastery happen, we call for the adaptation of TPACK, a theoretical framework regarding teachers' development of Technological, Pedagogical, and Content Knowledge (TPACK) [3]. Our prospective engineers do not need to know about pedagogies, but the other letters in the acronym, TCK, *i.e.* Technological Content Knowledge, definitely grasps what expect our engineering students to develop.

The ROS embedded in our ELEE4010 Senior Design course, therefore, are associated with a series of lab assignments that engage students in various topics in the context of ROS, from robot path planning, to navigation, and mapping applications. Such teaching and learning strategies based on multi-lab methodology and authentic tasks are in alignment with ABET learning outcomes related to student research and development capability [4]. In the next section we will report the above conceptual framework in more details against its literature background.

2. The Multiple-Lab-Driven Pedagogy with TCK Integrated

There have been plenty of studies performed on lab-based curriculum. For instance, Abbas and Leseman [5] developed a laboratory-based curriculum on the theory, fabrication, and characterization of microelectromechanical systems, in which course assessment data is input by students from three semesters, based on which the effectiveness of the laboratory project is evaluated. Alexander and Smelser [6] proposed a distance laboratory teaching method that combined multi-media computer experiments, portable hands-on exercises, and place-bound laboratory experiments. Zhang *et al.* [7] utilized graphical development tools to better teach engineering technology laboratories, in which they revamped the previous Engineering Technology undergraduate lab courses with LabVIEW and implemented their lab-driven pedagogy in their ELET 3451 Robotics Lab. Whitmal [8] reported implementation and assessment of a lab-based course in real time digital signal processing. With regard to ROS courses, it seems that the lab-driven pedagogy is also a well-considered option with some variations. Huletski and Kartashov [9] employed a prediction-correction method to estimate current robot pose and map that resolve the SLAM (simultaneous localization and mapping) issue on ROS platform. Yousuf, *et al.* [10] adopted project-based pedagogy to teach Electrical Engineering Technology students ROS and kinematics of robotics. Some labs have been developed to introduce Kinematics using ROS, in which students learned to utilize accelerometers, and gyros to track actual robots on ROS. Recently, Sprague [11] developed a teaching and learning method for teaching robotics using ROS. Some components in robotics such as localization, navigation, mapping, and image processing were taught by using the ROS platform. In order to assist students in understanding how the ROS system works, Yousuf, *et al.* [12] developed pedagogy to teach students robot arms through projects and hands-on experience. The Department of Electrical and Computer Engineering at the University of Detroit Mercy offers track concentration on the Robotics and Mechatronics. The Robotics and Mechatronics degree in undergraduate and graduate program integrates three traditional engineering disciplines - electronics, mechatronics, and software. ROS has therefore been extensively taught in robotics program in the electrical engineering programs. Due to the complexity of ROS, however, it needs to upgrade the lab-driven pedagogy to its multi-lab version, and meanwhile to integrate with it the rationale of TCK.

A course following the multi-lab driven pedagogy with TCK integrated does not just mean the provision of multiple lab opportunities. Unlike the traditional multi-lab course design, our multi-lab driven methodology emphasizes the inter-connectedness between labs. For instance, Lab 5 is ready to be adjusted based on the student performance of Lab 4, representing a pursuit of data-driven lab teaching decision making. It implies an on-going series of labs that have synergistic connections. Unlike other lab courses, the multiple labs generated are both independent and tightly inter-related with the primary goal to achieve the final project. Each previous lab lays the foundation for a subsequent towards the final design project. While students operate in ROS to achieve the final goal of controlling a mobile robot, each ROS function or tool they are learning to use has taken on a meaning (the C in TCK) for the final purpose instead of for learning's sake or for technology's sake (the T in TCK). In this multi-lab course, it is vital to integrate student team activities, lab assignment tracking, and faculty involvement for the on-going labs to maximize the teaching and learning effectiveness for ROS-driven project [15].

3. The ROS Labs

3.1 The TCK Integrated Multi-Lab Methodology Concretized

The primary objective of the multi-stage labs is to teach students ROS through hands-on experiments with hardware and software on the ROS platform. Multiple on-going labs are assigned to students for developing a sequence of ROS algorithms until it is integrated into one final project for navigation, SLAM, path planning and mapping of an autonomous robot. The lab course consists of seven on-going labs targeted at the major functions of ROS [15]. Every lab assignment is assigned to students one or two weeks after the corresponding tutorial materials are covered in the classroom. The ***inter-correlated*** labs and their descriptions are summarized in Table 1.

Table 1 The lab assignments and their descriptions

Lab	Description
L_1: Installation of ROS and Ubuntu	This lab guides students in installing and configuring the ROS Environment. The objective of this lab is to teach students to install ROS and Ubuntu planforms. It includes, for example, the following topics: navigating the ROS filesystem; creating and building ROS Package; understanding ROS nodes and topics, services and parameters; creating a ROS package manually; and running ROS across multiple machines, etc.
L_2: ROS simulation on turtlesim	Performing simulation of ROS on turtlesim, this lab allows students to learn and practice ROS topics and utilize the *rostopic* and *rqt_plot* command line tools.
L_3: ROS simulation on Stage	The objective of this lab is to perform simulation of ROS on Stage simulator. This lab enables students to learn and practice ROS topics and utilize some command line tools. Students are supposed to use the Stage simulator to simulate a single, Erratic-like robot, roaming an environment similar as the Willow Garage building.
L_4: Sensor configuration with ROS	A variety of sensors are configured on ROS to fulfill the mission of navigation, SLAM, and mapping of a mobile robot.
L_5: ROS configuration of the navigation and SLAM stack	In this Lab, students are taught to explore surrounding areas and make a map, as well as navigate a robot with a known map, through Gmapping process.
L_6: PRM navigation and mapping configured on ROS	In this Lab, students are taught to program a path planner of an intelligent mobile robot with given maps by Probabilistic Roadmap (PRM) path planner on ROS. Students are required to create assigned maps and run the PRM path planner and navigation and tune parameters on ROS.
L_7: ROS simulated on robot *Clearpath* Husky	In this lab, students learn how to run the Husky robot and get familiar with the Husky hardware system and sensor configuration on ROS.
Culminating ROS design project	In this phase, students are able to integrate previous labs into one design project to test its applicability and effectiveness for a real-time intelligent mobile robot navigation and motion planning system. It consists of final presentation, documentation and demonstration.

Of the seven small lab assignments, Lab 1 is relatively independent in the sense that it contains more tutorial content regarding the basics of ROS. In addition, Lab 1 is also the session to present to students the whole scenario of the project from the small lab projects to the culminating product.

3.2 Tracking Learning through Multiple Lab Student Performance Evaluations

Students are assessed for their performance at the end of each lab session to monitor the evolution of learning. Table 2 presents the specific tasks to be completed for each lab assignment session and students' performance evaluation in the form of average percentage. Figure 1 illustrates the performance evaluation data in a way reflecting the actual learning curve. An ideal curve should demonstrate a continual progress. However, students in this ROS course went through a high-low-high process. Indeed, the performance of Lab 1 is excellent as the difficulty level is low while the performance in Lab 5 is poor owing to its high difficulty level (shown in Figure 1). In Lab 5, students need to understand and carry out the SLAM, navigation and mapping simulation completely and operate their algorithms on an actual robot as well to prepare for the final project implantation. Overall, the performance with the progress of the lab assignments has been improved given the effort of careful preparation for the lab assignments and final project. The simulation result of navigation on ROS in the lab is shown in Figure 2.

Table 2 The lab assignments, progress and performance evaluation in progress report mode

Lab Sequence	Lab Tasks	Performance Evaluation (%)
L_1	Students should complete the following tasks: navigating the ROS filesystem; creating and building ROS Package; understanding ROS nodes and topics, services and parameters; creating a ROS package by hand; and running ROS across multiple machines, etc. Additionally, they should install packages with SVN, Git, and Mercurial.	95
L_2	A mobile robot should be navigated in turtlesim simulation environment. Students will understand stacks, packages, nodes, messages, services, etc.	87
L_3	Students need to simulate two mobile robots in the Stage simulator. It includes navigation, mapping and SLAM, in which two robots roam an environment.	92
L_4	Students will learn how to utilize a low-cost Kinect sensor that is widely used in robotics, and understand how the Kinect sends data from the sensors and tracks the data. Install the Kinect ROS drivers. This Kinect has the following three sensors that we can use for vision and robotics tasks: A color VGA video camera to see the world in color; the depth sensor, which is an infrared projector; and a monochrome CMOS sensor working together, to see objects in 3D A multi-array	85

	microphone that is used to isolate the voices of the players from the noise in the room.	
L_5	A SLAM-capable robot can build a map of an unknown environment while simultaneously locating itself in that map. Implementation of SLAM (Simultaneous Localization and Mapping), which is associated with ROS package of *gmapping*. It wraps the open source *gmapping* implementation.	65
L_6	A map in ROS is simply a bitmap image representing an occupancy grid where white pixels indicate free space; black pixels represent obstacles, and grey pixels. The robot equipped with a laser scanner and depth camera, will create its own map as it moves around the target area.	89
L_7	Student will have hands-on experience to get familiar with the Husky hardware system and sensor configuration on ROS.	91
Final Presentation and Demo	Presentation, Documentation, and Demonstration	93

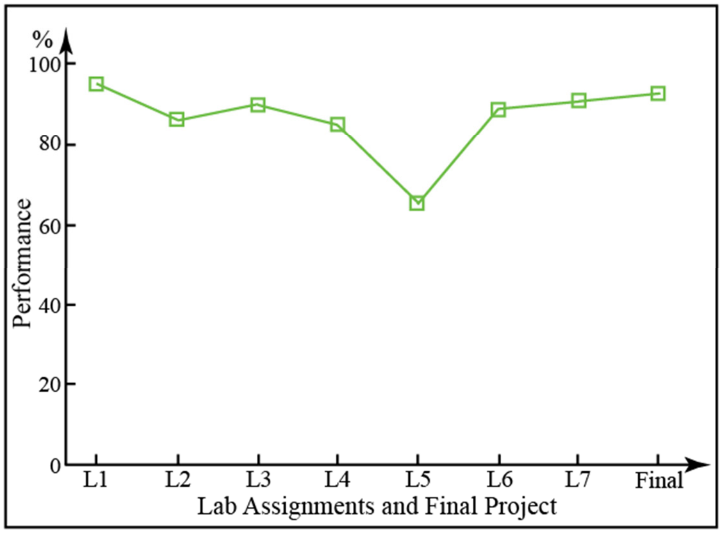

Figure 1 Performance with regard to lab assignments and final project

4. Discussion: Final Self-Assessment, and Rudimental Evaluation of the Multi-Lab Method

Students in ELEE4010 provided quantitative feedbacks through the self-assessment questionnaire required by the Department of Electrical and Computer Engineering. However, the instructor administers the survey and may modify the questions to reflect the curriculum. Such self-assessments in alignment with ABET outcomes may suggest the strengths and weaknesses of the teaching and learning cycles. Therefore, students' feedback about the multiple lab assignments as phases towards the completion of the entire design project through ROS may assist us in conducting a rudimentary evaluation of the TCK integrated multi-lab method. The questionnaire covers the seven questions below. The outcomes specified in the parentheses are in accordance with the ABET standards.

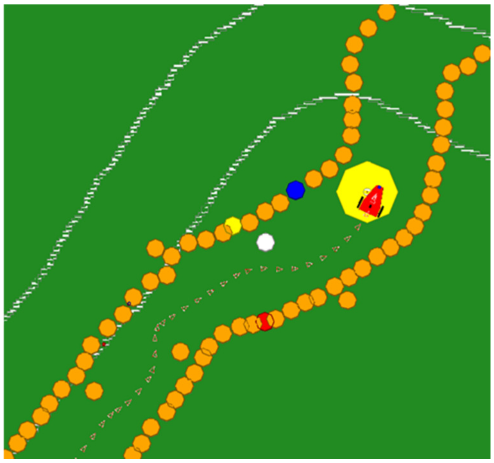

Figure 2 Generated ROS navigation environment

- Question 1 - "I can apply formal engineering design methodology to carry out the design, experiments and construction of labs and project based on ROS data and interpretation." (Outcome b: An ability to design and conduct experiments, as well as to analyze and interpret data relating to electrical systems.)
- Question 2 - "I understand the fundamental algorithms on ROS and software/hardware co-design in the labs and can utilize them to complete the project" (Outcome c: An ability to design electrical systems, systems containing hardware & software components, or processes to meet desired needs.)
- Question 3 - "I can understand how I plan, analyze and start a lab based on what I learned in the class on ROS." (Outcome e: An ability to identify, formulate, and solve electrical engineering problems.)
- Question 4 - "I can understand, analyze and design my portion/sub-system assigned in labs and project to me to solve some ROS problems in the robotics labs and project." (Outcome e: An ability to identify, formulate, and solve electrical engineering problems.)
- Question 5 - "I can use ROS skills and MATLAB/C module-based programming techniques to evaluate and validate ROS design concepts and systems in the labs and project". (Outcome k: An ability to use the techniques, skills, and modern engineering tools necessary for electrical engineering practice.)
- Question 6 - "I have effective communication skills in the context of a collaborative, multi-disciplinary design activity in the labs and project". (Outcome g: An ability to communicate effectively.)
- Question 7 - "I can create professional documentation in connection with the lab assignments and design project". (Outcome g: An ability to communicate effectively.)

The results of the self-assessment questionnaire are summarized in Table 3 and represented in Figure 3. As the data demonstrate, most students 'strongly agree' or 'agree' with the statements regarding ABET outcomes (b) (c), (e), (k) and (g). Students' responses to Questions 1 and 5 are most encouraging because these two questions address learning outcomes more related to the hands-on abilities and application of knowledge and skills to problem solving in the actual project. These results may lift our confidence that the TCK integrated multi-lab methodology has brought about desired learning outcomes and should be continued in future teaching. In contrast to students' responses to Questions 1 and 5, their responses to Questions 3 and 4 are less encouraging although they are still fairly good. These two questions are both related to certain systematic understanding rather than actual operation. In particular, when examining students' responses to Question 2 (25% for 'strongly agree' and 75% for 'agree'), we further have to admit that we need make effort to improve students' abstract, system-level understanding of ROS and its' application to project design. The positive side, however, is that students' experiential knowledge acquired through doing may lay a good foundation for future development of system-level understanding [13]. And it may be just an issue of time. Quite often learning is a restructuring and adaptive process responding to multiple, radically changing situational demands [14].

Table 3 The questionnaire of students for assessment of education quality

Question and Outcome	Survey			
	Strongly agree	Agree	Disagree	Strongly disagree
Q1-b	75%	25%	0%	0%
Q2-c	25%	75%	0%	0%
Q3-e	50%	50%	0%	0%
Q4-e	50%	50%	0%	0%
Q5-k	75%	25%	0%	0%
Q6-g	75%	25%	0%	0%
Q7-g	50%	50%	0%	0%

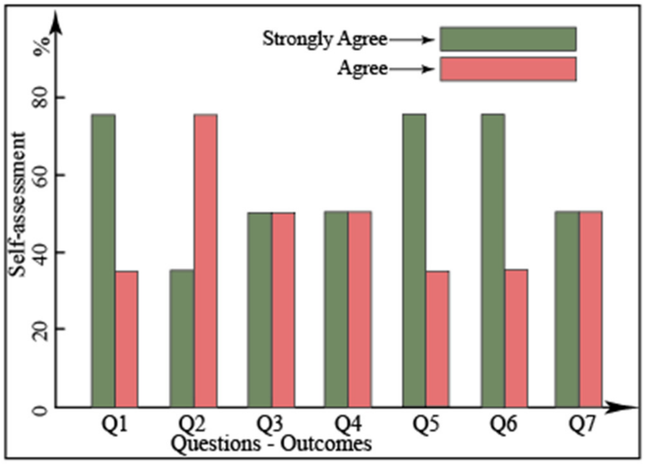

Figure 3 Self-assessment with regard to the learning quality

A comparison of student ABET outcome assessment in this study with that in [16] (Table 4 in [16]) indicates an overall advantage of this methodology in student learning. For example, on ABET Outcome *c*, we have 25% and 75% for 'strong agreement' and 'agreement,' respectively in this study, corresponding to 50% and 0% in the previous study. Although the percentage for 'strong agreement' is not so high, the percentage for disagreement is 0%, compared to the previous 33.3%. The comparisons on other ABET outcomes also demonstrate better statistics of agreement versus disagreement [16]. The overall higher percentages of agreement and strong agreement, especially the zero percentage of disagreement, are supportive of our hypothesis that the TCK-integrated MLDM may better help most or all students to master concepts or skills in authentic situations. Therefore, we believe the methodology in this study, after fine-tuning, should be continued to be applied in future teaching.

5. Conclusion

In this study we reported the rationale, implementation, and tentative assessment findings of our ROS lab course design. Data related to the evaluation of students' actual performances throughout the series of inter-related lab tasks leading to the final project helped us visualize students' learning process. Data from students' self-assessment questionnaire provided further evidence that the TCK integrated multi-lab-driven pedagogy is effective in achieving the learning outcomes designed for this ROS lab course. Students have reached 93% in the final project by using our metrics.

Among the encouraging results we have also identified limitations. For example, although students seem to have learned to use ROS and demonstrated basic skills and understanding of ROS, they seem less confident in a comprehensive, system-level understanding of ROS. Although we believe all learning is a process that may not happen in a short time or within one course, we believe it necessary to fill this hole either in another course in the engineering curriculum or still in this course by polishing the current methodology. A possible direction would be integrate the requirements of self-reflection at the end of each small lab project. Perhaps this new component will be able to call up students' metacognitive ability and find it easier to form higher-level and conceptual understandings based on their actual experiences using ROS for robotics design.

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