Robotics Education Online

Flipping a Traditional Mobile Robotics Classroom

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***Abstract*— The goal of this paper is to describe the motivation, process and results of converting a traditional mobile robotics classroom into a flipped one. Mobile robotics has been taught at this university for 10 years and the course has proven to be very successful. The challenge with this success is that there is only one instructor, one section, once per year with an enrollment cap of 24 students. These constraints are due to faculty workload, classroom size as well as available robots. Although more robots can be purchased, it is not possible to add more faculty to teach the course or change the classroom. The other challenges are the need to elevate the laboratory assignments to focus on high level technical aspects of mobile robotics control and provide more student assistance. In order to resolve this dilemma, the author feels that there must be more time in class to focus on the laboratory recitation and assignments while emphasizing background theory both online and in class. Therefore, in winter quarter 2016 the mobile robotics course was flipped to resolve some of these challenges. The lectures were moved online and the classroom time was spent on lab recitation, implementation, and demonstration. This paper will summarize the process of designing the flipped mobile robotics course as well as a presentation of the preliminary results of the first offering as compared to the traditional course.**

Keywords*— *robotics education; online education; robot programming; robot control

I. Introduction

Mobile robotics has been taught in a traditional classroom at this university for the past 10 years. The course has proven to be very popular among multiple disciplines and for the last couple of years there has actually been a waiting list. Part of the popularity is due to the fact that this course is not only required for the multidisciplinary minor in robotics but it is also a very popular elective for computer science, mechanical, electrical, software and computer engineering students. Although the course has been shown to be very successful, there are some challenges related to the popularity and learning objectives. The first challenge is that there is only one instructor, limited robot hardware, appropriate classroom space, and a high demand for the course. The second challenge is that some students view the robot as a toy and take the course to play with a robot. Although this is encouraging as a motivation, the author wishes to impress upon the students that this course is also about learning robotics history, theory, and control. By flipping the course, it will be possible to offer the course to more students because the lectures will be online which will reduce the faculty classroom contact hours. In addition, the course content can be elevated by devoting more in class time to laboratory recitations with connections to lecture theory and also provide more personal instruction to help students implement the control theory on the robot. Since this course is typically taken by students in their last year of study and this university does not have many graduate students, it is not possible to get a teaching assistant to help with classroom lab time.

The objectives of this 4-credit course are to teach students about the history, theory, and application of mobile robots. The topics include robot components, effectors, actuators, locomotion, sensors, feedback control, control architectures, representation, localization, and navigation. With such an extensive and ambitious introduction to mobile robotics in one 10-week quarter, it is vital to have an integral hands-on project-based component. However, once there is an introduction of hardware into a course, students deal with electrical and mechanical issues such as bandwidth limitations, memory constraints, sensor, odometry and modeling errors. These issues require the students to spend more time in class working on the hardware. This is not possible in a traditional classroom since the class only meets 6 hours per week and 50% of that time is lecture. This dilemma is not the same in a class that uses simulated robots because if a student creates the perfect program, the robot in theory will work as expected unless there is some modeling of hardware errors. In addition, the requirement for students to have prerequisite knowledge in programming, controls, sensors, and mechanics affords multidisciplinary teams which may have members with diverse skill sets. When part of the class time includes the lectures, it is sometimes difficult to give the lab assignments the adequate treatment and motivation to elevate the richness of the robot challenges. This is not ideal because it is very important that the students appreciate the theory and application of robotics versus simply taking the course in order to play with a robot. Some of the robot labs and projects are based upon remote control, obstacle avoidance, wall following, light behaviors, behavior-based control, reactive control, hybrid control, deliberative control, path planning, mapping, and localization. Although flipping the classroom will require students to learn more independently and spend more time working outside of the classroom, it will more adequately prepare them for each class meeting, it will also allow the class time to be spent building complete systematic flowcharts, pseudocode, state diagrams, programs, and robot control architectures versus ad hoc software to meet the challenge. In the prior offerings of the course, these

978-1-5090-5920-1/17/$31.00 ©2017 IEEE

artifacts were typically completed haphazardly with no clear connection between how they framed the lab implementation. Since this course is taught at a primarily undergraduate engineering teaching institution, the quality of the education and interpersonal interaction cannot be compromised because some course content is moved online. Therefore it cannot follow the model offered by a traditional MOOC. There must be individual student attention and the hands-on lab component must have the same rigor and meet the same learning objectives as the traditional classroom. This paper will present the process used to convert from the traditional to the flipped classroom while not compromising on the learning objectives. It will also present the results of the first offering of the converted classroom.

II. Literature Review

In order to convert the traditional mobile robotics course to a flipped one, a literature review was performed to determine how other institutions address some of these challenges. The questions to be answered were, what were the learning objectives and how were they addressed in an online platform. The search revealed that there are many courses that use some online component or simulation in order to teach robotics but not many that followed the flipped model presented in this paper. Avanzanto at Pennsylvania State University describes using virtual world simulation for mobile robot simulation to enable rapid prototyping, low cost development and delivery, interaction and cooperation with an online international community [1]. He states that virtual worlds will be integral in the area of robotics education and research, in particular human-robot interaction. Bicci, Caiti, Pallottino, and Tonietti at the University of Pisa created a virtual laboratory with experiments accessible by students to allow for application of theory and greater availability [2]. The robotics experiments involved path planning with multiple robots through programming, debugging, simulation, and interpretation. These experiments are part of a web-based course on elementary robotics and mechatronics. The key difference between the Avanzanto and Bicci implementations is simulation versus actual hardware manipulation viewable via a webcam. Conversely, Chiou et al. provided simulation in 3D and hardware internet-based robotics and mechatronics experiments [3-5]. The laboratory experiments involved PLCs, robot programming, and sensors and were part of a classroom lecture component along with the associated online laboratory component. Eslami et al., Candelas-Herías et al., Jara et al., McKee, and Marin et al. implemented similar remote-access and virtual robotics laboratories, typically with industrial robots for their distance learning courses [6-10].

Although there was a plethora of literature on robotics courses taught with online or virtual laboratories, it was not possible to find any courses with a flipped robotics classroom with any similarity to the one described in this document. There was also one paper on flipping a robotics classroom for a massive open online classroom at Georgia Tech but this was also not a similar model to the one described here [11-12]. The Georgia Tech MOOC had video lectures and lab recitations, a simulated robotics laboratory in MATLAB, and an optional hardware lab where the students built a robot from scratch and programmed it in Python. The author actually completed this MOOC in preparation for flipping the introduction to mobile robotics course.

Finally, Gallagher and Drushel compared the distance learning and traditional offering of an autonomous robotics course [13]. The online course involved a web-connected mobile robot with 24/7 access and an open-sourced Java-based robot simulation environment. The hardware lab at Case Western Reserve University and Wright State University were implemented by using LEGOs. The authors examined the effect of the 2 different offerings of the course based upon factors such as gender, classification and student grade performance. The authors used ANOVA methods to identify any differences in the key independent variables. The first discovery was that in the traditional course, there was no significant difference in the graded performance between the graduate and undergraduate students. Although there was only 15% females in the course, they significantly outperformed males in the design book entries, mechanical design, neatness and course grade. The online course did not have a mechanical design component so the authors compensated by requiring more complex design problems and expressive programming languages. Since the authors have only offered the online course once with a low enrollment, they provided more anecdotal observations than statistical analysis. Results indicated that it appeared that the electronic design notebooks were typically inferior to the handwritten and electronic for the traditional course. In conclusion, the authors have not provided any initial comparison of the data only a preliminary set of criteria due to the small sample size of 5 students for the online course.

III. Method

The Introduction to Mobile Robotics course has been taught since 2007 at Rose-Hulman and has undergone several updates [14-15]. The course is a required elective in the multidisciplinary minor in robotics and is typically taken by students in computer science, computer, electrical, mechanical and software engineering. It is also an optional elective in electrical and computer engineering. The course is a senior-level course although juniors are allowed to take it if they meet the prerequisites of control systems and programming proficiency. It was initially offered during the spring quarter and in 2011 it was changed to winter quarter to accommodate more schedules. The traditional 4-credit hour course met for 6 hours per week with approximately 3 hours of lecture and 3 hours of lab. As previously stated, it was discovered that this model did not always provide enough time for students to be able to implement the open-ended complex labs and final projects. Although there was an expectation that student teams work on the assignments outside of the class period, they sometimes needed more individualized attention to achieve the lab requirements.

This is a unique model for teaching mobile robotics because it is a project-oriented course and the students have hands-on experience on a real mobile robot to complete the laboratory assignments and final design project. The final design project has changed over the years but typically involves some type of navigation including path planning, localization, search and/or mapping. A summary of the graded components is provided in Table 1. Note that there are no exams or homework because creating a complete robot control architecture in software from scratch is very time and brain intensive. Some of the most significant course changes were in the robot hardware, sensors, peripherals and laboratory assignments (see Table 2 and Table 3). The motivation for the changes was typically to make the objectives of the course more achievable. Since various robot platforms and controllers have different capabilities it was desirable to identify features that work the best with the students' skillsets.

Some of the key changes in the assignments and graded components was adding a required weekly literature review as part of the weekly readings. The quizzes were changed to twice per week with one on the lecture and one on the literature review. The quizzes were also moved online to Moodle with random questions and a 45 minute time limit. The laboratory assignments had three graded components including a demonstration, technical memo, and code submission. The labs were completed in teams of two and the demonstration, memo, and properly documented code were due once per week. The final project was completed the last 3 weeks of the quarter with multiple demonstrations, and a properly commented code and technical report submission. Many quarters the class culminated with a final competition for bragging rights and extra credit.

TABLE I. GRADED COMPONENTS

Component	Percentage
Participation	10
Quizzes	30
Laboratory assignments	30
Final project	30

TABLE II. ROBOT HARDWARE AND PERIPHERALS

Year	Hardware	Sensor/Peripherals
2007-2008	Traxster I with Microchip PIC 18 microcontroller	Infrared, Sonar Light (photoresistor) Temperature (thermopile array) Wireless transceiver IR receiver and remote Bluetooth Pushbutton Buzzer, LED, LCD Display, Compass, Line Following Sensor
2009-2010	Traxster II with Robotics Connection Serializer	
2011-2014	CEENBoT with Atmel microcontroller	
2015	Arduino Robot	
2016	CEENBoT with Arduino MEGA 2560	

TABLE III. LABORATORY AND FINAL PROJECT ASSIGNMENTS

Wireless Communication IR Remote and Receiver, PlayStation Controller with Bluetooth Wireless Transceiver with Keyboard Control
Locomotion and Odometry
Random Wander, Obstacle Avoidance, Go to Goal
Wall Following (PD or PI Control)
Line Following (PI Control)
Reactive Control – Light or Temperature Sensing
Hybrid Control – Homing and Docking wall following path planning light or temperature sensing
Topological Path Planning
Metric Path Planning – Wavefront Propagation, Grassfire Expansion
Mapping
Localization

A. *Flipping The Course*

In 2016, the decision was made to flip the course and return to the CEENBot with a more user-friendly controller, the Arduino Mega. As previously mentioned, the motivation for flipping the class was to provide more in class time in order to elevate the technical aspects and achievement on the lab assignments. It was desired to flip the course versus making it blended learning because the online learning was required to be completed before coming to class. The online content was explored in more depth through the in-class laboratory assignments as opposed to being a simple complement for each other. The reason for the change in the hardware was to finally converge on a platform with all of the required capabilities for the labs but also a programming interface that was achievable for all students considering their varied prerequisite skills. Since Arduino is a hobbyist platform with a plethora of online material there are many resources at the students' fingertips to help with design and troubleshooting. Unfortunately, although the original CEENBot chassis was ideal for our needs, the programming IDE was not user friendly and did not afford easy debugging. There was also one additional literature review quiz added so that there was a total of 7 literature and 8 lecture quizzes versus the original 6 literature and 9 lecture. The number of quizzes and topics addressed were changed to balance out the topics but none of the key content was removed.

As part of the re-design, the course was separated into modules and concept maps that linked all the materials together for the global and sequential learner. The active and reflective learner needs could also be addressed through the reading, video lectures, and laboratory component. Each module had learning objectives, quizzes, readings, lab assignments, and video lectures [16]. The class meeting times were reduced from 6 hours to 4 hours since the lectures were completed online and the instructor was able to offer 2 sections of the course instead of the typical one. The students were required to work for at least 10 hours per week outside of the class meeting period to complete the readings, videos, quizzes and some part of the pre-lab and lab assignments. The class time was dedicated to the lab recitations, lab work, demonstrations and assistance [17]. In order to allow the students to reflect more on their design and be more intentional about the lab assignments, a prelab was added to each lab that required the students to create the architecture in advance by using either flow charts, state diagrams, pseudocode, or subsumption architecture. Module 0 was required to be completed before the first day of class and it required exploring the online Moodle course site, viewing the welcome video and taking a quiz on the syllabus, schedule, and concept map. Table 4 provides a summary of the modules for the flipped course.

TABLE IV. FLIPPED COURSE MODULES

Module #	Weeks	Topic
0	0	Welcome to Robotics
1	1	Robotics Overview and History
2	2	Robot Control Overview, Sensors and Perception
3	3	Schema Theory, Potential Fields, Feedback Control
4	4	Behavior-Based, Hierarchical Control Architecture
5	5	Hybrid Paradigm, Navigation
6	6	Path Planning
7	7-10	Mapping and Localization, Final Project

IV. RESULTS

In order to evaluate the effectiveness of the first offering of the flipped course, qualitative and quantitative data including course evaluations and course grades was examined. In order to reduce confounding variables, only the courses that used the CEENBot robot were examined which were 2011-2014 and 2016. In addition, since all of these courses were taught during the winter quarter by the same instructor, there should not be any influence based upon those factors. Some anecdotal evidence that the author has already observed was that it appeared to take some lab teams longer to complete the assignments than in prior quarters. One conjecture is that this may be due to the elevated requirements to be more systematic and intentional about the implementation of the assignment.

There were 64 students who took the traditional course with the CEENBot including 56 male (87.5%) and 8 female (12.5%). There were 42 students who took the flipped course including 31 male (78%) and 11 female (26%). The flipped course had 4 graduate and exchange students while the original course had 6. Figure 1 provide the course demographics for the populations that were used in the analysis.

A. *Quantitative*

The quantitative analysis examined the averages for quizzes, a select lab, final project and the overall final grade to identify if there was any difference in performance for the two versions of the course. The lab assignments selected were wall following, path planning, localization, and mapping because these were consistent over all the course offerings and the most difficult. Figure 2 shows a summary of the results for the lecture and literature review quizzes based upon the course format. The results indicate that the quiz average dropped by approximately one letter grade for the flipped course. This was surprising for the literature review quiz because there was no change in the delivery of the content. However, for the lecture quizzes this may indicate that students are not mastering the material as well in the video format or that they are not doing the readings or watching the videos at all. Figure 3 presents a comparison of the wall following lab based upon the course format. There is no significant difference in the student team's performance on the demo, code and memo of the wall following lab. Figure 4 compares the student performance on the navigation competencies (path planning, localization, and mapping) for the two course formats. There is also no significant difference in performance on the final project based upon the course format. The overall grade for the students for the traditional and flipped course formats was 91% and 88%, respectively. It can be deduced that there was no significant difference in overall course performance either.

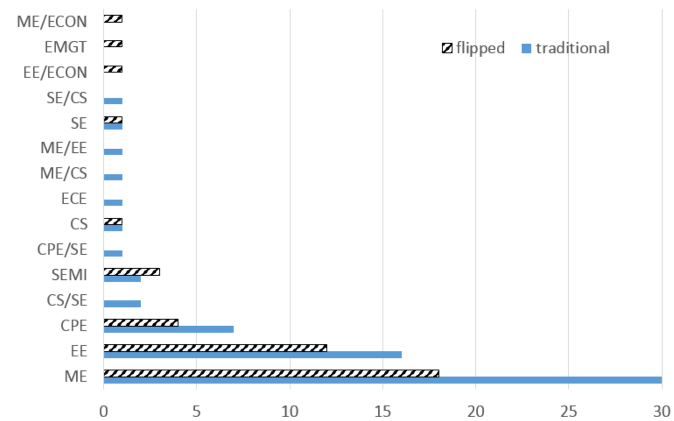

Fig. 1. Course Major Demographics

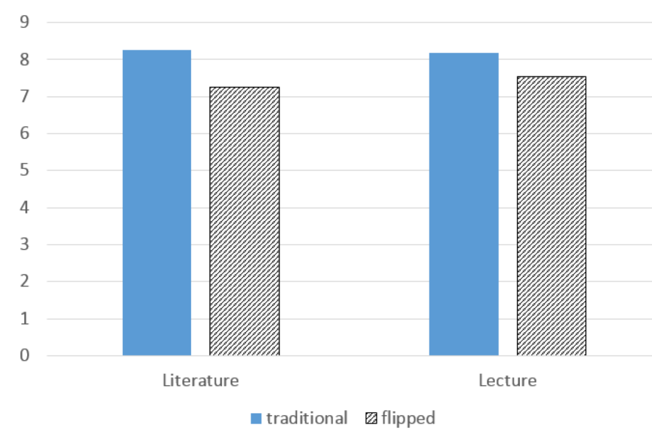

Fig. 2. Quiz Performance

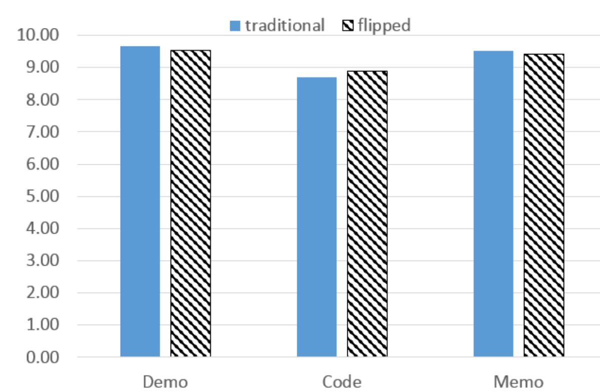

Fig. 3. Wall Following Lab

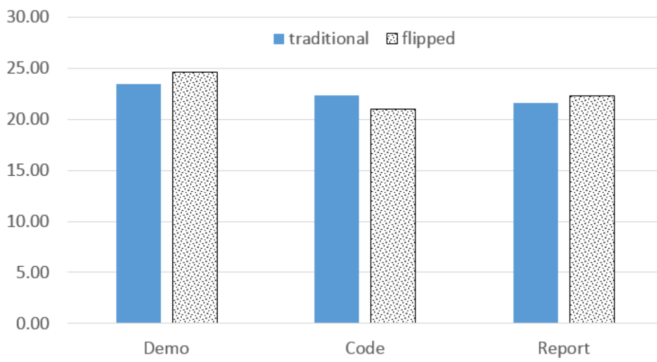

Fig. 4. Navigation Competencies Final Project

B. *Qualitative*

The qualitative analysis examined the course evaluation averages and responses. The categories were learning, course, and instruction. The learning and course questions were examined for differences based upon the course format. The summary of the data is provided in Table 5. The rating was a Likert scale from 1 to 5. The mean for both formats was very similar and the one promising effect is that the workload in the flipped class was reduced a little although still rather high.

The qualitative feedback indicated that some students felt that the videos and readings correlated well with the labs to understand how the theory applied. However, there was also another subset of students who felt that there was not a direct correlation between the lectures and the labs. Part of these concerns were based upon the fact that the lecture was sometimes a week or two ahead of the lab based upon the time it took to complete the lab. Although the videos were always available some students did not return to watch them again. One student also stated that the inverted classroom style of teaching was effective because it allowed for more time to work on the labs and get help in class. Some students liked the ability to re-watch and review material outside of class and learn at their own pace. One student stated that he liked the flipped classroom and it being project-based because they learn more in this more immersive environment. Some students felt that the videos were informative in order to learn about the history of mobile robotics and important research that has been done in the field. However, there were also some who do not like flipped classes based upon previous exposure and these feelings carried over and continued with the mobile robotics course. Several students felt that the quizzes were too difficult and although this was consistent feedback for the course before it was flipped, it is an area that may need to be examined in more detail. The quiz questions were not changed although the lectures were moved online so the quizzes may simply just be too difficult and need to be modified even though a 70% mean is average and acceptable.

TABLE V. COURSE EVALUATION RESPONSES

Questions	Traditional	Flipped
Please rate the quality of your learning in this course. Excellent (5) – Poor (1)	3.787	3.840
The laboratory assignments and course material reinforced one another. Strongly Agree (5) - Strongly Disagree (1)	4.330	4.120
The work load for this course in relation to other courses of equal credit was Much Ligher(5) – Much Heavier (1)	2.170	2.475
Overall how would you rate this course? Excellent (5) – Poor (1)	3.833	3.840

V. CONCLUSIONS

In conclusion, this paper has presented a summary of converting a traditional mobile robotics course to a flipped one. It involved building a Moodle course site with weekly modules, video lectures, resources, and assignments. The motivation for the change to the course was to provide more in-class time on lab assignments, give a more thorough treatment of the technical foundations and to offer more sections of the course. This work is innovative because typically robotics online and face to face is taught in simulation or with elementary-level hardware such as LEGO robots. Courses that do have an online component typically use simulation or online labs with a webcam.

The course was offered for the first time in winter quarter 2016 with promising results. For most evaluation categories there were no significant differences in performance based upon course format. Two components that may require some modification based upon the quantitative and qualitative results are the quizzes and lectures. One recommendation may be to include simple mastery quizzes integrated with the video lecture completion and track student usage. Also it may be necessary to greatly simply the weekly reading and lecture quizzes to only hit upon the most important points with fewer questions. Some changes to the lab recitations will be to include more instruction on how to create the program structure and relate it to the pseudocode, flowchart, state diagrams or subsumption architecture. Ideally, the course has finally converged on the appropriate robot platform and controller. However, there will be the addition of more peripherals such as Pixy cameras and encoders to update some of the lab assignments and final project.

Although there was no significant difference in student performance or course feedback, all of this work to flip the classroom was definitely worth it. The reasons it was worth it are:

- It is now possible to offer more sections of a course that has proven to be very popular in the past.
- There is now a more depth versus breadth exposure and treatment of the mobile robotics topics.
- Students receive more in class instruction and help on completing the labs.
- Students have a documented plan of attack to complete the lab assignments through the prelab requirement to create pseudocode, state diagrams, subsumption architecture, and flowcharts.
- Labs can be updated to include more theoretical application and hardware since the students have more resources available to help with implementation.

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