Empowering Students with Self-Regulation in a Project-Based Embedded Systems Course

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1. Introduction

In most educational settings, including higher education, all our effort is centered on educating or training our students to be ready for their selected professions, which are concretized as various learning outcomes in our curriculum. To achieve these learning outcomes in engineering education (*i.e.* ABET), various pedagogical considerations have been experimented and implemented.

Project-based teaching and learning has been a major line of research and practice in engineering education due to engineering profession's particular need to connect classroom or lab learning to the actual ability needed in the professional world. In Marlor's [1] project-based course in a mechanics & statics curriculum, attention was paid to the necessity of hands-on and intuitive design experiences in the early phase of students' learning development [7]. In Ulseth *et al.*'s [2] engineering design course, emphasis was given to the creation of student experiences aiming at the development of skills for effective teamwork. Thomas *et al.* [3] developed a project-based undergraduate Computer Engineering curriculum, with an embedded systems concentration. There are other innovations along the line of research on project-based teaching and learning in engineering education, *e.g.* in Parten's research [4].

This study follows this line of research and intends to fine-tune the project-based methodology (PBM) in a lab course design under the theoretical framework of self-regulation. We believe the PBM enhanced with some features of self-regulation will not only achieve PBM's original purpose of immersive experience but also empower the students in the sense of becoming active agents seeking to achieve goals through self-reflection and self-adjustment [8].

Under the framework of social cognitive theory of learning mainly driven by Albert Bandura [5, 6], people, and not environmental forces, are the predominant causes of their own behavior [9]. This personal agency, the potential to control our own behavior, grows out of our skills of self-control and self-regulation [10]. While self-control is the ability to control one's actions in the absence of external reinforcement or punishment, self-regulation involves the consistent and appropriate application of self-control skills to new situations. As self-regulation is considered to be a critically important capacity to develop in face of more and more complex projects from schools to society, a world with rapid pace of change, scholars have researched and recommended various models of self-regulation.

One model, proposed by Barry Zimmerman [11, 12], consists of three phases in a cyclical manner. The forethought phase is the phase of task analysis and strategic planning; the performance phase is the phase of performing the task under self-control and self-observation; and the self-reflection phase is the phase of self-evaluation and self-reaction to think about what to improve. The self-reflection phase both concludes a cycle of self-regulation and ushers in a new cycle by influencing a new phase of forethought.

We have a strong interest in empowering students by providing them with the opportunities to practice their personal agency. Following the model of self-regulation, therefore, we need pay special attention to two of the three phases: forethought, and self-reflection. In other words, there is the need to design experiences to foster students' ability of task analysis and their goal orientation, and also the need to engage students in experiences such as self-reflection, which will feed into their own forethought, starting the next cycle of self-regulation.

To make space for self-regulation, which is normally a process of multiple cycles, another consideration of lab course design must be directed to dividing a normally big project into sub-projects or sub-tasks. Otherwise students will not have the sufficient opportunity to reflect and apply their results of self-reflection to the next step towards the completion of the whole project. This study focuses on the aspects of the course design following the above principles, and our reflection on its implementation and students' learning outcomes based on students' artifacts of self-reflection, project products, and course evaluation.

2. Description of the Course Design

ELEE4790/5790 Embedded Systems, one 3-hour lab session per week, is the second microcontroller course in our microcontroller course sequence after the ELEE3860/3870 Introduction to Microcontrollers at the University of Detroit Mercy. While ELEE3860/3870 covers assembly language programming and basic microcontroller interfacing, the emphasis of ELEE4790/5790 is for students to learn to apply a system design methodology based on top-down principles to advanced interfacing and development of embedded systems. The C language for project-based embedded system development is introduced in order to provide the student with a strong development tool compatible with more complex processors. A range of peripheral systems are utilized to implement a hardware/software design project undertaken in coordination with the lecture course ELEE4780/5770. While most programming is performed with C, assembly language is utilized to facilitate efficient Interrupt service routine coding. Module-based programming techniques are taught to allow students think in modules instead of in a single C language statement.

A project-based methodology is utilized in the sense that students' all learning activities from embedded system design, construction, implementation, to testing are anchored in one semester-long design project. Specifically, each group of students are assigned an embedded system design project. The students are required to develop a *complete* system that meets the stated project objectives and specifications. The whole process is necessarily an on-going, multistage process requiring sophisticated programming and careful circuit design and construction. In addition, the project's objectives and specifications start from students themselves. That is, students themselves initiate the process of context analysis, exploring design constraints, and developing requirement definitions that clarify precise project specifications. Students are then required to present their complete system design using block diagrams and schematics. Finally students must construct and demonstrate the project. This whole project is carried out in conjunction with the lecture course ELEE4780/5770. The design assignments in both classes are complementary to each other, but the hardware construction, programming, and testing take place in the laboratory. Grades are assigned for each major deliverable. Milestone-based written progress reports and interviews are conducted throughout the semester to ascertain the diligence and relative contributions of each design group member.

3. The Project Description

In this project, a control and wireless communication system is designed and built to remotely control a mobile robot, iRobot. The sensor information gathered from the onboard sensors of the robot is displayed on the terminal computer. A mini 5-way digital onboard joystick is employed to drive the iRobot. The iRobot equipped with sensors and wireless communication components is illustrated in Figure1.

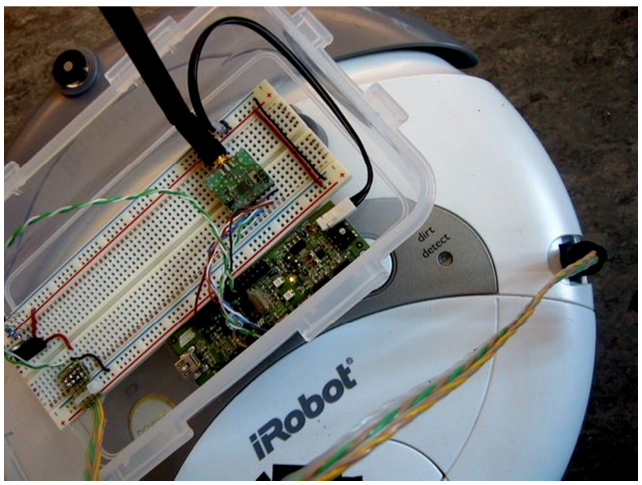


Figure 1 The iRobot equipped with sensors and wireless communication components

3.1 System Design

The embedded system consists of an iRobot (Roomba), a low power microcontroller (AT90USB1287), a single chip 2.4GHz transceiver (nRF24L01), a breakout board (FT232R), and a UART-USB component (configured as UART, Universal Asynchronous Receiver/Transmitter). The system design is illustrated in Figure 2 below.

The AT90USB1287 board, as the microcontroller, carries out the primary mission of coordinating with such other components as its onboard mini joystick, nRF24L01, and TF232R to meet the timing deadline of required tasks. The missions of this AT90USB1287 (defined as the Client hereafter) include the capturing of user input and translating the user input into packets so that the radio chip is capable of sending the message to the remote station that consists of a radio chip controlled by another AT90USB1287 (Host), which will then take the command received via the radio and push it using UART interface into Roomba's SCI (Serial Communication Interface).

Upon receiving the command triggered by the user input (joystick movement) on the other end (Client), the Roomba sends its sensor data back as an acknowledgment of the command and then starts executing it. In turn, we can print the sensor data to the terminal program running on the PC that is connected through the UART-to-USB chip. The features of the nRF24L01 and TF232R make it easy to achieve our goal. It relieves the burden of the microcontroller, shown in Figure 3. The AT90USB1287 USB keys are used throughout this project. Its mini 5-way digital onboard joystick provides a simple way to drive the Roomba. For the purpose of wireless communication, the nRF24L01 breakout is controlled via SPI (Serial Peripheral Interface) for transmitting/receiving data.

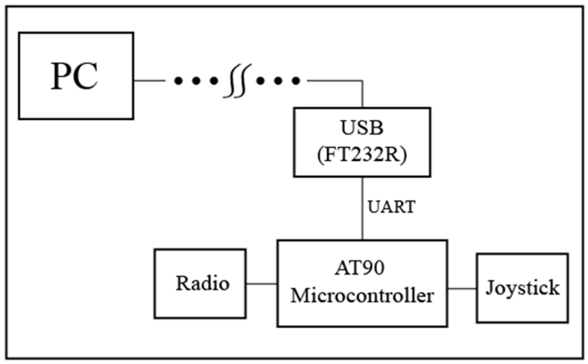
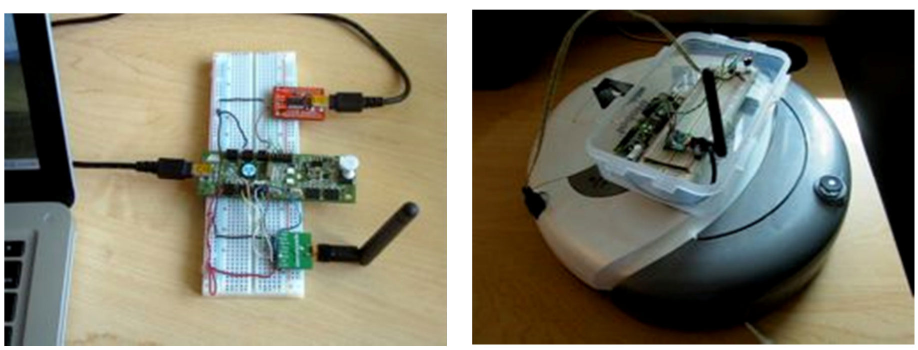


Figure 2 The system design



(a) (b)

Figure 3 The system design: (a) the host; (b) the client

3.2 Hardware Configuration

The hardware configuration contains an iRobot (Roomba), a low power microcontroller (AT90USB1287), a single chip 2.4GHz transceiver (nRF24L01), a breakout board (FT232R), and a UART-USB component. The hardware configuration is introduced as follows.

- AT90USB1287: As is illustrated in Figure 4, this high-performance, low-power Atmel 8-bit AVR RISC-based microcontroller combines a 128KB ISP flash memory with read-while-write capabilities, 4KB EEPROM, 8KB SRAM, 48 general purpose I/O lines, 32 general purpose working registers, real time counter, four flexible timer/counters with compare modes and PWM, USART, byte oriented 2-wire serial interface, USB 2.0 low-speed and full-speed On-The-Go (OTG) host/device, an 8-channel 10-bit A/D converter with optional differential input stage with programmable gain, a programmable watchdog timer with internal oscillator, SPI serial port, JTAG (IEEE 1149.1 compliant) interface for on-chip debugging, and six software selectable power saving modes.

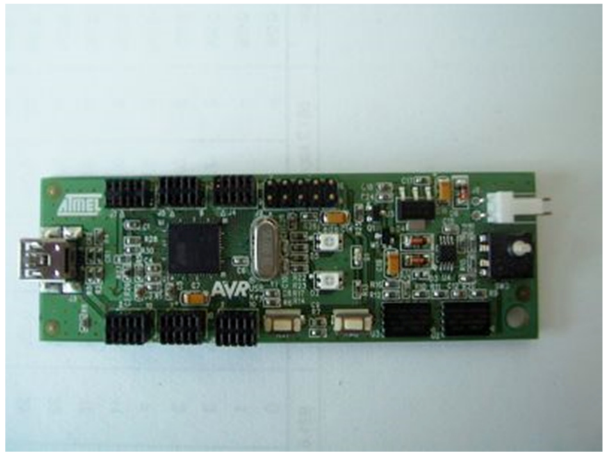


Figure 4 The AT90USB1287, a low-power Atmel AVR RISC-based microcontroller

- nRF24L01: As is illustrated in Figure 5, the nRF24L01 is a highly integrated, ultra-low power (ULP) 2Mbps RF transceiver IC for the 2.4GHz ISM (Industrial, Scientific and Medical) band. It integrates a complete 2.4GHz RF transceiver, an RF synthesizer, and a baseband logic that includes the Enhanced ShockBurst™ hardware protocol accelerator supporting a high-speed SPI interface for the application controller.

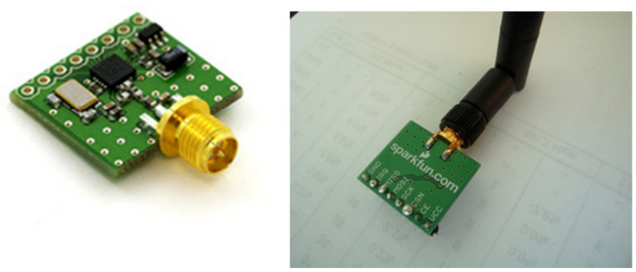


Figure 5 The nRF24L01, a highly integrated, ultra-low power RF transceiver

- The FT232R (Figure 6) is the latest device to be added to FTDI’s range of USB UART interfacing with Integrated Circuit Devices. The FT232R is a USB to serial UART interface with optional clock generator output, and the new FTDIChip-ID™ security dongle feature. In addition, asynchronous and synchronous bit bang interface modes are available. USB to serial designs using the FT232R have been further simplified by fully integrating the external EEPROM, clock circuit and USB resistors onto the device.

- The hardware configuration with FT232R, nRF24L01 and AT90USB1287 is illustrated in Figure 7.

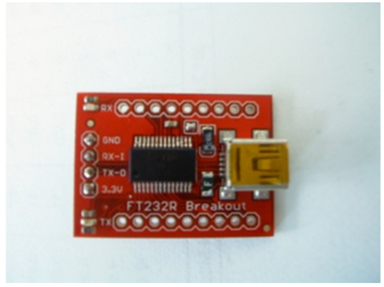


Figure 6 The FT232R, a USB to serial UART interface

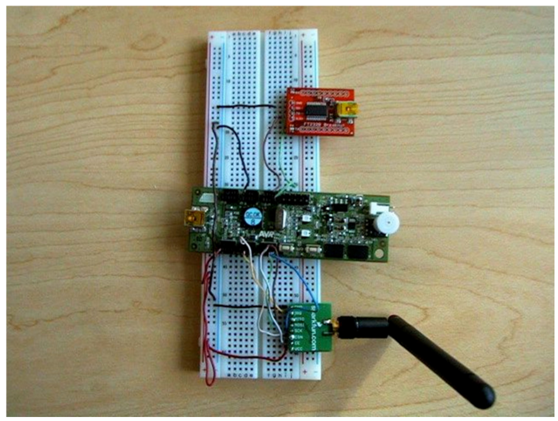


Figure 7 The hardware configuration with the wireless communication device

3.3 Software Architecture

The AVRStudio, WinAVR, and FLIP are the software development tools provided by ATMEL. We use AVRStudio 4, which is a fairly decent IDE for writing AVR applications in Windows environment. It includes an assembler and a simulator. We employ FLIP, which stands for "FLexible In-system Programmer," to upload the compiled source file via USB to AT90USB1287's program memory. We start by creating the project in AVRStudio, and then select AT90USB1287 as our target hardware. After writing our applications, we build the project, and a .hex file is generated. We can then use FLIP to get connected to AT90USB1287 and upload the .hex file. For the AT90USB to be detected by the Windows, it has to be in the bootloader, which is equipped with a simple USB driver that allows us to upload the program file.

4. The Project-based Pedagogy Infused with Self-Regulation Opportunities

As is previously introduced, the ultimate big project is divided into a series of small sub-projects to create rhythm and allow space for self-regulation to happen. The sub-projects, briefly described in Table 1 below, have synergistic inter-connections. The session of Sub-Project 1 is also an orientation session informing students that each sub-project is a stepping stone for the next in the whole series that culminate in the final big project. The instructor makes special effort making students know their responsibilities but at the same time reducing their anxiety level. If a student is at risk failing a sub-project, the instructor or the teaching assistant will provide timely feedback and facilitation to avoid accumulated failure in the end. If one student fails to fulfill a certain sub-project, he or she receives low grade. However, the instructor and the TA will help the student analyze the reasons of failure and provide constructive feedbacks so that this current sub-project will succeed and the successful experiences may transfer to the next sub-project. The teaching assistant is available to facilitate both the regular labs and students' voluntary after-hour lab efforts.

Table 1 The descriptions of the sub-projects

Sub-Projects (SP)	Description	Average Performance (%)
SP_1: System design and project plan	The project plan is made. The overall design should be fulfilled. Students are initially requested to develop a requirements definition, undertake a context analysis, and explore design constraints. Students are required to present their complete system design using block diagrams and schematics.	85
SP_2: Device component ordering	Students need to place the order for the device components such as iRobot, microcontroller, transceiver (nRF24L01), breakout board (FT232R), and UART-USB component.	95
SP_3: Three hardware component test and debugging	Students should test and debug the following three components: AT90USB1287 microcontroller board, nRF24L01 transceiver, and TF232R, to meet the timing deadline of required tasks.	89
SP_4: Hardware configuration	All the hardware device components should be connected and configured to meet the stated project objectives and specifications with regard to the hardware configuration.	90
SP_5: Wireless communication test and measurement	Students carry out the wireless communication test and measurement to implement the communication between the host and client.	86
SP_6: Software test and debugging	Students learn to program the AVRStudio, WinAVR, and FLIP software development tools to test the software architecture.	83
SP_7: Hardware and software co-test, and debugging	Students test and debug both hardware, software and communication pieces to ensure the embedded system design function well.	90
SP_8: System test, measurement and debugging	The design products from the previous sub-projects are integrated into an embedded system. The hardware construction, programming, circuit design and testing take	92

	place in this stage.	
Final: project demo, report, and presentation	Students integrate all previous products into one design project to test its applicability and effectiveness for the mobile robot project. Students should construct and demonstrate the project.	93

Students are evaluated on each sub-project (the results of which are also added in Table 1 as 'Performance') based on the actual product/output, a written sub-project report and a sub-project interview with the instructor in light of the written report that the student brings to the interview. This evaluation constitutes 70% of the final grade. Here-in-mentioned written reports and the interviews are the opportunities intended for students to do self-reflection and consider any adjustments needed for the next step. For illustration purpose, here are a few sample prompt questions that we use to guide students' written report:

- *Please list any hardware components you have configured in your project.*
- *Please draw your hardware block diagram that you have improved over the previous one.*
- *Please list any software modules you have completed in your project.*
- *Please list any software modules you plan to add in your project.*
- *Please list any problems you have encountered in your project so far.*
- *Please list any work that is still pending in your project.*
- *Please describe your plan of the next stage in your project.*

When students come to the interview with a written report addressing such questions as the above, they should have gone through a cycle of *self-reflection* and *fore-thought*. In the interview, the instructor interacts with the student in a Socratic style to engage the students in a second round of self-reflection, thought clarification, and adjustment planning. For example, becoming aware of any existing problems or deficiency is a necessary part of self-reflection pointing towards possible progress. Some themes of issues that emerged in the interviews in this study, which may benefit both the students and the instructor (to better help the current students and to improve teaching for prospective students), include *a learning curve with new devices, difficulty in debugging and test, problem-solving skills, team communication, lack of programming experience, etc*. In this study we do not have direct evidence for the effect of such opportunities for self-regulation. However, we may get a glimpse of it when we read students' qualitative comments in institutional course evaluation forms that contain such statements as '(the instructor) *would not simply answer our questions but would rather point us in the right direction so we could find the solution on our own,'* and '(the instructor) *usually made me thinking and made me a good understanding of this tough course. He always can discover our learning problem and solve these problems.*'

5. The Self-Assessments as One Way to Gauge Learning Outcomes

Aligned to ABET outcomes, the self-assessments are required by the Department of Electrical and Electronic Engineering, but can be modified by the instructors to reflect the actual content instructed. These self-assessments take place at the end of the semester and may form the basis for instructors to improve the teaching and the course design. Students in this course respond to the following five questions. In the parentheses are the corresponding ABET outcomes.

- Question 1 - “I can apply formal engineering design methodology to perform the design, experiments and construction of the embedded system project based on experimental test 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 can understand, write and execute C and Assembly programs using modern compilers, linkers, and debuggers as appropriate for the Freescale HS12 microcontroller to interface with LED/LCD, keypad, switch, SPI, SCI, Timer, and PWM to complete the project.” (Outcome c: An ability to design electrical systems, components, or processes to meet desired needs).
- Question 3 - “I can understand, write and execute C programs (module-based programming technique) for the Freescale HS12 microcontroller to solve specific engineering problems.” (Outcome e: An ability to identify, formulate, and solve electrical engineering problems.)
- Question 4 - “I have effective communication skills in the context of a collaborative, multi-disciplinary design activity in the project”. (Outcome g: An ability to communicate effectively.)
- Question 5 - “I can create professional documentation in connection with the assignments and design project”. (Outcome g: An ability to communicate effectively.)

The self-assessment questionnaire results are summarized in Table 2 and Figure 8. As are demonstrated, all students ‘strongly agree’ or ‘agree’ with the statements aligned to the ABET outcomes (b) (c), (e) and (g). In the instructor’s experience of teaching multiple courses, the percentages for ‘strongly agree’ are higher in this course, pointing to a possible effect of the pedagogies we applied. In particular, students’ percentages of ‘strongly agree’ on Questions 3 and 4 are much higher at 85% than usual. Question 3 is tied to an ability to identify, formulate, and solve problems, and Question 4 is related to an ability to communicate in a collaborative context. In addition, in comparison with the instructor’s previous experience teaching this course with a traditional project-based method (*i.e.* no sub-projects, and no interview sessions for reflection and adjustments), the percentages for ‘strongly agree’ and ‘agree’ in the current course are also much higher. We infer that the modified version of the project-based pedagogy in this study is more effective and that the processes of writing reflection reports and communicating with the instructor about the projects should all have played a role in empowering the students in the sense that they have taken ownership of the self-regulation cycles around problem solving – forethought, performance, and reflection.

Table 2 The questionnaire of students for assessment of education quality

Questions and Outcome	Survey			
	Strongly agree	Agree	Disagree	Strongly disagree
Q1-b	70%	30%	0%	0%
Q2-c	70%	30%	0%	0%

Q3-e	85%	15%	0%	0%
Q4-g	85%	15%	0%	0%
Q5-g	70%	30%	0%	0%

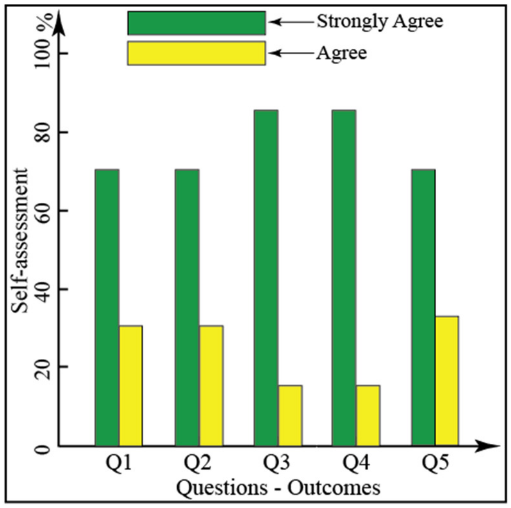


Figure 8 The illustration of the self-assessment results

6. Conclusion

We have reported our effort in approaching the instruction of an embedded system course with a modified version of the project-based methodology. With an interest to empower the students in the sense of playing out personal agency, the whole project is divided into small projects, and each small project is followed by students' written reports and interviews based on those reports, which might be a unique feature of the pedagogy in this study compared to other studies of project-based teaching and learning. We have shared some of the questions guiding students' reports and the style of the interview. From the nature of those questions and some anecdotal evidences in students' comments in the course evaluation, particularly in relation to the semester-end self-assessments in alignment to the ABET leaning outcomes, we tend to suggest that the students in this course have had high-quality learning experience and that this high-quality learning experience may be related to those self-regulation opportunities that have, consciously or unconsciously, fostered their personal agency and therefore facilitated their ownership of learning.

We are aware of some limitations in this research report, however. For example, as a course in engineering education, we were eager to implement innovative pedagogies to instruction but did not start well in advance to think about collecting direct evidences, such as recordings of the interviews, for the purpose of gaining insight into what happened and identifying causal relationship between the reports, the interviews, and the learning outcomes. The current indirect evidences and the positive learning outcomes seem to encourage us to take this next step along this line of research.

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