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Flipping the Microprocessors Classroom: A Comparative Assessment

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Flipping the Microprocessors Classroom: A comparative assessment

Abstract

At East Carolina University (ECU), undergraduate students in an electrical engineering concentration within a general engineering program are required to complete a microprocessors course. This course has been taught for three years. During the first two years, the course was offered in a traditional format with three weekly lectures and one weekly hands-on lab. It was discovered that the weekly lab time was insufficient to complete several longer lab assignments and many students had to complete their lab assignments outside of the allotted lab period. It was also discovered that many students had misconceptions about course material and often attended office hours to get help understanding the material. During the third year, the instructor flipped the classroom by recording the lectures and posting them for students to watch before coming to class. While the contact time between the students and instructor remained the same throughout the week, the lecture periods were changed to include hands-on activities such as completing worksheets to assess lecture content knowledge, practice writing subroutines that could be used as part of the weekly lab assignment, or building circuits to interface external devices with a microcontroller. Each of the in-class activities was designed to measure student understanding of course topics and to offload some of the laboratory work done during previous semesters to the lecture period.

This paper assesses the differences in student outcomes between the traditional and flipped format of the course. Common final exam question responses from the traditional and flipped offering are compared to showcase the differences in student comprehension of course topics. Student survey results are also assessed to determine the benefits and limitations of the flipped classroom approach versus the traditional classroom format. The shortcomings of the current format are addressed and suggestions for improvement based upon one semester of using a flipped classroom approach are discussed.

Introduction

A core component of most electrical and computer engineering curriculums is a microprocessors or microcontrollers programming course. While these courses have shifted over the last few decades from being steeped in studying long datasheets, wiring large circuits, and writing some code to more comprehensive embedded systems courses (Wolf, 2001), the microprocessors curriculum at most universities continue to require extensive study and understanding of computer architecture, coding, timing, and hardware requirements. These courses typically blend lecture material with hands-on programming exercises. As technology has evolved, the need to modify and expand the content included in a microprocessors course has also expanded in order to provide students with relevant knowledge and skills to be able to contribute to microprocessor-based projects upon graduation. As more microprocessor-based systems are embedded into a variety of consumer devices, wearable electronics, and transportation systems, embedded systems has emerged as a stand-alone course at many universities. Over the last two decades, educators have observed a need to revise their electrical and computer engineering curricula in order to accommodate more emphasis on microprocessor-based applications and to ensure a proper blend between instruction on computer architecture, digital logic, programming, interfacing with external devices, design considerations, and technology selection along with hands-on exercises to allow students to gain meaningful experience working with emerging technologies. While such courses have evolved, there has been discussion about the appropriate level of abstraction of code that should be presented to students (Jones, 2014). Some instructors emphasize deep understanding of datasheets and register level programming in assembly, while other instructors emphasize the tools of modern industry and high-level programming languages. As microcontroller-based technology has become pervasive, some universities have even expanding the offering of microcontroller courses to majors outside of electrical and computer engineering (He, 2015).

Design of a Microprocessors Course Within a General Engineering Curriculum

At ECU, students do not pursue a traditional BS in Electrical Engineering or BS in Computer Engineering, but rather pursue a broad BS in Engineering and gain depth in their studies by selecting a track from one of six engineering concentration areas. The electrical engineering concentration curriculum includes six required electrical engineering courses and one technical elective. Microprocessors is a 4-semester-hour course and is required for all students pursuing the electrical engineering concentration. A course in digital electronics is a prerequisite for the microprocessors class, so all students who take the course in microprocessors have been exposed to number systems, combinational and sequential logic, and the concept of registers.

When the course was first implemented in the Fall 2013 semester, it was designed with three weekly 50-minute lectures and a weekly 2-hour laboratory session. The lectures were designed to introduce the theory that the students would practice in the lab each week. The QL200 trainer kit (QL200, 2016) was selected as the platform for laboratory exercises and featured a PIC microcontroller. Depicted in Figure 1, this trainer kit features a 40-pin PIC microcontroller, an LCD panel, a 4x4 keypad, 7-segment displays, pushbutton switches, potentiometers for analog voltage input, a speaker, an SD card reader, and serial ports for communication. The trainer board is packaged in a small, closeable case with a breadboard and hookup wire as depicted in Figure 2. These trainer kits allowed for easy storage in the lab and portability so students could take their trainer kits home to complete assignments or gain more practice.

The benefit of using a PIC microcontroller is the reduced instruction set requiring a small learning curve when compared with more advanced microcontrollers. The instructor wanted students to understand the logic in the detailed operation of the microcontroller, so the first third of the course involved students learning assembly programming and when students were ready for more advanced exercises, they were taught to program the PIC microcontroller in C.

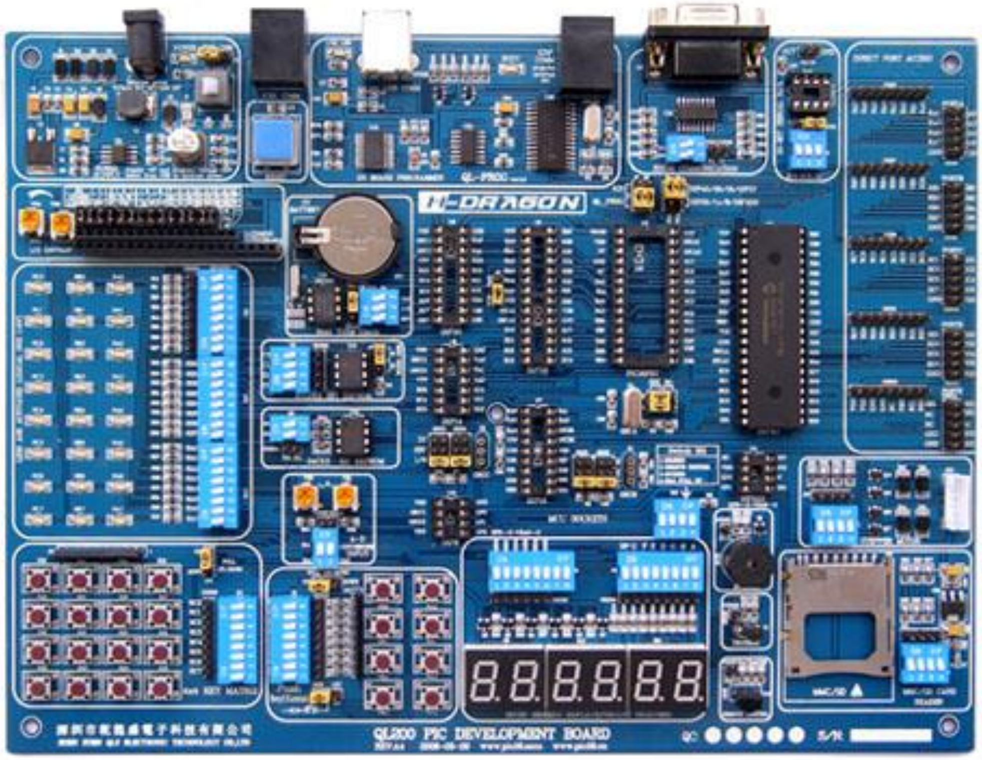

Figure 1 the QL200 trainer kit (QL200, 2016)

Figure 2 The portable trainer kit featuring the QL200 trainer board (QL200, 2016)

Programming instruction was a particular challenge within the context of a general engineering curriculum because students had only taken one introductory programming course and the platform in that course was MATLAB. Several lessons in the course were dedicated to the syntax of C programming including variable declaration, loop structures, and decision logic. Other course topics included digital input and output, analog to digital conversion, interfacing with sensors, interfacing with motors and motor control, writing to and reading from memory, writing data to displays, interfacing with a keypad, timing and timers, creating digital music, wired and wireless serial communication, selecting an appropriate microcontroller, and microcontroller applications.

Assessment of The Course After Initial Implementation

Students who took the course during the first two years of implementation stated that they liked the course and felt like they learned a great deal about how to program microcontrollers and appreciated the hands-on practice. It was also determined that many students ran out of time to complete the laboratory assignments within the two-hour scheduled lab period. Students took their trainer kits home with them regularly and were often seen around the engineering building working outside of lab time. Many students came to office hours and were often asking the same questions as other students.

In an effort to give students more guided hands-on practice and to help reduce the number of questions asked during office hours, the instructor decided to flip the classroom during the Fall 2015 semester. The flipped classroom technique has gained in popularity in recent years and was discussed at the most recent American Society for Engineering Education in well over 100 papers. Many traditional engineering courses have now been delivered in a flipped format including statics (Holdhusen, 2015), thermodynamics (Lemley, 2013), and engineering economics (Lavelle, 2015).

The main idea of a flipped classroom approach is that students explore course material outside of lecture time before coming to class and complete assignments that would traditionally be assigned as homework inside the classroom. Instead of delivering traditional lectures during the scheduled lecture period, the instructor recorded lectures and posted them to YouTube. Students were expected to watch the video lectures before coming to class during the lecture period. The time during the lecture period was then dedicated to more practice with course material. During some lecture periods, students completed worksheets with questions about course material. During other lecture periods, students worked on developing subroutines or circuits that would be used during that week's scheduled lab period. The flipped classroom freed up lecture time to be used to guide students and also helped to extend the lab period by allowing additional hands-on preparation during the lecture period before students attended the lab period. Each lecture period began with a question and answer session on the assigned online lecture and allowed the students to dig deeper into course material than was previously permissible under the traditional format. Students were also much better prepared for the weekly laboratory assignments because they had a chance to practice the material in the lecture period before they got the lab assignment that week. In previous offerings, the weekly lab assignment was the first time students gained any practice working with a particular course topic or writing code to perform functions.

Changes Implemented During the Flip

With the flipped classroom approach, nearly every lecture in the course was replaced by a YouTube video. Videos were recorded and every effort was made to post the videos at least 48 hours before the scheduled class meeting. Unfortunately, amidst many other responsibilities, some video recording was delayed and a few of the videos were posted the day before the lecture. A total of 19 in-class exercises were created. In most cases it was expected that these could be completed within a 50-minute lecture period. In some instances, the exercises took longer than a class period and students either completed the rest of the exercise as a homework assignment or in some cases used the next class period to work on longer assignments. Removing the lectures from the lecture period also enabled some portions of the weekly lab assignments to be completed prior to the assigned lab time; for example, during the week when students learned about motor control, the students were able to build a circuit with an h-bridge and a motor during the in class activity time allowing them to use the entire lab period to work on developing the motor control code to generate a proper pulse width modulation signal using the microcontroller's timer. The in-class exercise time also allowed the instructor to add a unit on soldering so students could both learn the skill of soldering and also prepare their sensors for the weekly lab without the instructor doing the soldering for them. Worksheet topics ranged from performing timing analysis on a block of code, writing a short function, or building a circuit.

Benefits of Implementation

The students liked having more time to ask questions during the lecture period when compared with previous semesters when there was not as much time for questions and answers. The students also seemed more actively engaged in class discussions. Previously, the students were assigned to read material from the microcontroller datasheet, but having a video to watch including sample code and explanation of how code worked on video enhanced student learning outside of class time. Previously, students were given sample code and the instructor stepped through the code with them, but with the explanation now available on video, the students could rewind the video and listen again to any parts of the explanation they did not understand the first time. The lab periods also were less rushed by having students split some of the lab assignments into in class assignments before reaching the weekly lab period. Students also seemed more prepared for lab because they already had a chance to write some code or answer some questions about course topics before coming to lab. Another benefit of posting the video lectures online was that students could revisit the lecture material when working through assignments or studying for tests, whereas a traditional lecture is given once and if students misunderstood part of it they don't have a chance to see it again. Students who were sick or had to miss class for any other reason also were able to catch up on lecture material.

Challenges of Implementation

Finding the time to record a video lecture three times per week was difficult. While the lecture slides were already prepared from previous semesters, revising them, recording a video lecture based on them, editing the videos, and posting the videos to the course management system website all took time. Creating a daily in-class exercise also added to the preparation time for each class period. The most time consuming task, however, was grading all of the in-class assignments. In previous semesters only a few homework assignments were given and the main grades students received were on the weekly lab assignments. Under the flipped format the students turn in up to three weekly in-class exercises in addition to the weekly lab assignment. Without TA support to grade the worksheets, it became very easy to get behind on grading the in-class assignments, reducing some of the benefit of the daily practice.

Student Opinions

On the end of semester assessment survey, students were asked several questions about the flipped class format. The following were some sample responses:

For the first time this year, the course was taught in a flipped classroom format. Did you like this format or would you have preferred the class remain in a traditional lecture format?

"I liked the flipped format because it gives more time to ask the instructor questions about assignments."

"Assuming the work load for the non-flipped version was the same, I don't see how all the work was completed. The in-class exercises gave me ample practice with the material and the online lectures were useful for rewatching"

"I enjoyed the format. Hands on is more important."

"I like the format. It's easier to work on the assignments in the classroom than at home."

"The class lecture reiterated main points from video and made difficult points more understandable."

Do you feel the in class exercises helped you to better understand course content?

"Yes. The in class exercises were directly related to the lab."

"Yes. They forced me to practice."

"Yes. They solidified or introduced topics before the labs."

"They helped as a way to understand the topics."

“Yes! The in class really aided in understanding and prepared us for the labs!”

Some students still felt like more could be done to improve the flipped classroom model. A few students commented that the online video lectures could incorporate a few more examples. Even with pulling some material out of the weekly lab assignments and having students work on it during the lecture period, some students still suggested that the course should have a three-hour lab instead of a two-hour lab. Every student in the flipped classroom section indicated that they liked the flipped format and there were no students who indicated that they would prefer a traditional lecture style.

Student Performance

In order to gauge the differences in outcomes of students taking the same course with a traditional format vs a flipped format, an identical final exam was given in Fall 2015 and Fall 2014. The Fall 2015 course offering included the flipped classroom format and the traditional 3 lectures and a lab format was offered in Fall 2014. Overall, the average was slightly higher in the flipped model with the mean exam scores shown in Table 1. As can be seen in the table, the mean and median scores improved under the flipped format. During the semester that was flipped, four students scored higher on the final exam than any student scored in the traditional format on the final exam. Unfortunately, three students out of 24 scored quite poorly on the final exam under the flipped format. One of these students rarely came to class and another worked full time while going to school and had a personal family emergency during the semester. During the Fall 2014 semester, one student scored very poorly on the final exam; this student suffered from severe attention deficit disorder and despite university accommodation was still not able to do well on course tests. Through examination of the standard deviation and mean of the data it was determined that the lowest test score in Fall 2014 and the highest test score and the 3 lowest test scores in 2015 were outliers as they were more than 2 standard deviations below the mean score. These outliers were eliminated for purposes of determining if the change in test scores were significant. Table 1 showcases the overall test scores under each format with the outliers included and with the outliers removed.

Table 1 Final Exam Statistics Comparison

	Traditional Format (Fall 2014)	Flipped Format (Fall 2015)
Overall Mean	76.7%	80.2%
Overall Median	76.7%	80%
Overall Range	[56.7%,90.7%]	[54.6%,99.3%]
Mean, Outliers Removed	78.3%	82.3%
Median, Outliers Removed	76.7%	81.0%
Range, Outliers Removed	[66.7%,90.7%]	[74.0%,95.3%]

Overall Improvement Statistical Significance

After removing the outliers from the data and performing a t-test, it was determined that the difference between the means was significant ($p<0.04$). It can thus be said that the overall improvement in final exam scores in the flipped classroom was significant.

Question- By-Question Analysis

The final exam was comprised of 18 questions. Some of these questions were short answer questions or multiple choice conceptual questions, some questions required analyzing code to determine how it behaved or performing computations, some questions required understanding register level logic and being able to read the datasheet, and some questions required writing code to perform a certain task. In some cases, students performed better in the traditional format and in other cases students performed better in the flipped format. The following tables tabulate the average scores earned on each question for non-outlier students. The tables group the questions by question type. Scores highlighted in green indicate that students performed better on average under the flipped format and scores highlight in red indicate questions where students performed better on average under the traditional format. The question by question data

Table 2 Short Answer or Multiple Choice Conceptual Questions

	Points Possible	Traditional Lecture Format Mean Question Score	Flipped Classroom Format Mean Question Score	Percentage Change
Question 2	5	5.00	5.00	0.00%
Question 4	5	4.63	4.90	5.40%
Question 6	5	0.94	1.95	20.20%
Question 7	2	1.94	2.00	3.00%
Question 11	5	4.75	4.30	-9.00%
Question 16	5	4.00	3.90	2.00%
Question 17	5	4.50	4.50	0.00%
Question 18	2	2.00	2.00	0.00%
Average Total	34	27.76 (81.65%)	28.55 (83.97%)	2.32%

Table 3 Data Sheet Reading and Register Level Logic

	Points Possible	Traditional Lecture Format Mean Question Score	Flipped Classroom Format Mean Question Score	Percentage Change
Question 3	16	15.31	15.7	2.44%
Question 8	6	2.81	3.70	14.83%
Question 12	5	3.06	3.45	7.80%
Average Total	27	21.18 (78.44%)	22.85 (84.63%)	6.19%

Table 4 Computation and Code Evaluation Questions

	Points Possible	Traditional Lecture Format Mean Question Score	Flipped Classroom Format Mean Question Score	Percentage Change
Question 5	18	14.69	14.35	-1.89%
Question 13	8	3.75	5.90	26.88%
Average Total	26	18.44 (70.92%)	20.25 (77.88%)	6.96%

Code Writing Questions

	Points Possible	Traditional Lecture Format Mean Question Score	Flipped Classroom Format Mean Question Score	Percentage Change
Question 1	15	12.75	11.75	-6.67%
Question 9	10	7.06	7.95	8.88%
Question 10	18	13.69	16.05	13.13%
Question 14	10	9.13	7.4	-17.25%
Question 15	10	8.06	8.70	6.37%
Average Total	63	50.69 (80.5%)	51.85 (82.3%)	1.84%

As can be seen in the tables above, when comparing outcomes for the flipped classroom format to the traditional lecture format, overall student performance improved on 12 of 18 questions. Student performance remained the same on 2 questions while student performance went down on four questions. In each category of question student performance overall improved. Improvement was particularly strong on questions that required understanding the datasheet for the microcontroller and computation questions. In all but one case where performance declined, the average declination was less than one point. Students declined in knowing the difference between interrupts vs data polling, tracing through assembly code and following values in specific registers, and writing code to display a particular value on the onboard seven-segment displays. Students showed the most improvement on questions addressing interfacing with memory, performing analog to digital conversions, and building circuits to interface external devices with the PIC. It is thought that the added hands-on activities helped the students become more comfortable with the hardware and C code. The decline in analysis of assembly code could be due to the fact that the students had much more extensive practice working with C code and may have forgotten more of the assembly code from the beginning of the semester.

Conclusions

The flipped classroom format does require additional work on the front end of the course to ensure that all lectures are recorded and exercises are created to allow students the opportunity to work with the course material. There is also an increased workload created by adding more graded assignments.

Based upon a survey of students, the flipped classroom was preferred by every student in the course. Students liked the ability to refer back to the lectures to study and they liked the opportunity to have more practice with course material during the lecture period. Final exam results indicate that there was a significant improvement in student performance on the exam in the section with the flipped classroom format when compared to final exam performance in a traditional lecture format. In general, the flipped classroom gave students more opportunity to interact with the microprocessor datasheet and more practice doing computations. It is not clear why students did worse on some code writing problems, but future offerings of the course plan to fill in some of these gaps.

Overall, the flipped classroom approach is an effective way to free up lecture time for students to practice course material and to have more time to ask questions. The added practice has in this instance lead to higher average test scores.

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