AC 2010-415: IMPROVED STUDENT LEARNING OF MICROPROCESSOR SYSTEMS THROUGH HANDS-ON AND ONLINE EXPERIENCE:

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Improved Student Learning of Microprocessor Systems Through Hands-On and Online Experience

Abstract

This paper describes an approach to assess and improve the understanding of microprocessor systems for electrical and computer engineering students by developing measurement-based laboratory experiments. During fall semester of 2009, we assessed the level of understanding of microprocessor systems on a control group using five learning objectives. We measured the level of understanding using a set of assessment tools that included self surveys, weighted multiple choice questions, and short answer questions. These assessments set a baseline measure on the five learning objectives for our current microprocessor curriculum. In fall of 2010, we will introduce measurement-based laboratory experiments using logic analyzers on subsequent student groups and assess whether understanding of the five learning objectives improves compared to the control group. The measurement-based experiments will be introduced in two forms, hands-on and remote operation. Assessment data will be collected for both experiment groups to determine if the level of understanding of microprocessor systems can be improved by adding hands-on measurements and if a remote laboratory experience can maintain or improve the level of understanding compared to the control group.

In this paper, we report on the development of the assessment tools used in this project, including the creation of a grading rubric to achieve a finer resolution on the scores of the short answer questions. We also report on the preliminary data collected on the control group and the development strategy for the measurement-based laboratory experiments.

1. Introduction

A microprocessor is the fundamental building block of the modern digital computer. Computer systems have and will continue to be integrated into every aspect of our lives as we move further into the 21st century. At the turn of the century, the average American came into contact with an estimated 100 microprocessors per day[1]. This number continues to grow as microprocessors are deployed into even more systems that we interact with daily. Microprocessors make up approximately one-fourth of all semiconductor sales, contributing $58.3 billion (USD) to the global economy in 2006. This number is expected to grow over 10 percent per year throughout the 2000-2010 decade,[1, 2] taking the total microprocessor market to over $70 billion (USD).

Tomorrow's electrical and computer engineers will be tasked with using, improving, and further integrating microprocessors into everyday systems. Graduating engineers must possess the necessary understanding of how a microprocessor operates so that they can face the challenges of the next decade as society demands more complex and automated systems.

Currently, introductory microprocessor courses exist in nearly all undergraduate electrical and computer engineering curricula. These courses typically consist of a lecture and an associated laboratory. The laboratory gives students the ability to program the microprocessor and observe and alter its functionality on rudimentary Input/Output (I/O) devices such as LED's and buttons. While this laboratory experience is a crucial part of the understanding of a microprocessor, it does not provide the depth of understanding that can be achieved through measurement. Research has shown repeatedly that discovery learning improves the understanding of complex systems[3, 4]. Through measurement of microprocessor systems, students can experience hands-on discovery learning at a much greater level than simply observing LED's and pushing buttons.

Traditional undergraduate courses in microprocessor systems contain laboratories where students are given a task and are asked to program the microprocessor using either Assembly or C programming languages. The students can observe the operation of their program either through I/O devices (LED's and buttons) or through the use of software simulation tools. Typically, measurements are not performed due to a variety of factors. The first is that digital systems require the observation of many signals for the information to be useful (typically > 8). It can be logistically difficult to successfully make an electrical connection to this many signals using standard laboratory test equipment (i.e., an oscilloscope). In addition, most university laboratories do not have enough test equipment to make this many signal connections. Another reason measurements are not performed is that the amount of information that can be collected is overwhelming for a student just starting to learn about microprocessor systems. The raw information that can be collected using an oscilloscope cannot be intuitively decoded by the student.

As a result of the complexity of making a physical microprocessor measurement, efforts to improve student learning in this area have focused on adding more functionality to the off-line software simulation tools. This level of abstraction is considered by some educators as the future of microprocessor courses[5]. Many think that future engineers will not be concerned with the physical operation of the microprocessor; rather, they will only be concerned with the high-level view of systems and will allow compilation software to handle the integration of the functionality into a given piece of microprocessor hardware. This view of the future of microprocessor education is well suited for engineers designing systems using high-level programming languages[6]. However, it does not address the education of engineers who will ultimately design the microprocessors, the compilation software, or the underlying physical hardware for the computer system. For students who will pursue careers that require an intimate knowledge of the detailed operation of a microprocessor to be successful, their undergraduate education contains a large void due to the trend toward abstraction.

A logic analyzer is an instrument that gives visibility to many real-time digital signals. This type of measurement information gives students visibility into the detailed operation of a microprocessor. This level of visibility is something most undergraduate electrical and computer engineering students are not exposed to in their education. Laboratory experiments based on this type of test equipment exposes students to one of the few ways that students can physically measure the operation of a microprocessor in real-time. Modern logic analyzers have also been designed to be operated remotely via the internet. A logic analyzer can now be used not only as an instrument but as the development platform for embedded software design. This enables a remote microprocessor laboratory experience where students can develop software for a microprocessor on a development board and measure signals in real-time on the same board using a single piece of equipment. This capability contributes to a growing demand in undergraduate education, which is to offer a quality educational experience without having to be physically located on campus.

In order to evaluate whether including measurement-based microprocessor laboratory experience is worth the cost and development time, a baseline assessment must be made on a control group of students who do not have access to the test equipment. In this project, we developed assessment tools that were used to collect data on a set of five learning objectives on a control group of students during the fall of 2009. Our interventions (the use of a logic analyzer) will be implemented in the curriculum in fall of 2010 in an attempt to improve the student learning related to the learning objectives. The same assessment tools will be used on the subsequent cohorts of students in order to measure the impact of the interventions.

The first intervention used in this project is the inclusion of hands-on measurement exercises in the laboratory component of the microprocessor curriculum using logic analyzers. Our assertion is that by giving the students a hands-on measurement experience with the microprocessor system, their understanding of the low-level operation of a microcomputer will improve. The second intervention introduced in this project is the inclusion of online access to the laboratory experiments using the remote capability of the logic analyzer. Our assertion is that if the level of understanding can be maintained or improved using online laboratory experiments, we will be able to deliver digital engineering courses remotely with a meaningful laboratory component.

We will be able to compare student learning on the five objectives across the three groups: the baseline or control group, the group using the hands-on digital test equipment, and the group using the hands-on digital test equipment from a remote location. Figure 1 shows a graphical depiction of the control and experimental groups in this work.

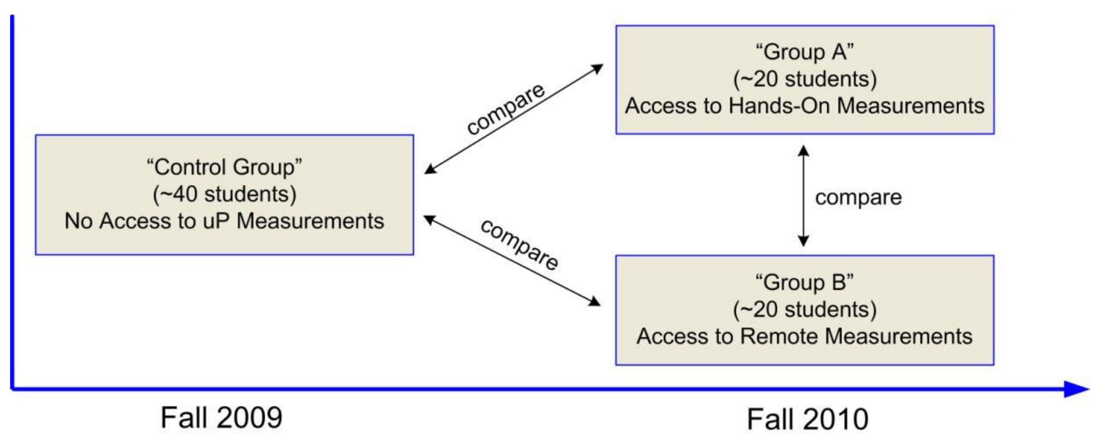

Figure 1. Assessment timeline for control and experimental groups in this project.

2. Assessment Tool Development

Five learning objectives were selected for this project. At the end of our microprocessor course, the students will be able to:

1) Describe the basic architecture of a stored-program computer;
2) Describe the addressing modes of a microprocessor;
3) Describe a typical I/O interface and understand its timing;
4) Analyze a timing diagram of the interaction between the microprocessor and memory;
5) Synthesize a timing diagram of a given READ/WRITE cycle between the microprocessor and memory.

For each of these five objectives, assessment tools were created that included self evaluation surveys, weighted multiple choice (MC) questions, and short answer questions (SA). The assessment data was collected using the quiz feature within the Design2Learn course management system. None of the data from these assessment tools will be used in computing the students' grade for the course. Each student was asked to consent form at the beginning of the semester indicating that their answers could be used in this project.

The introductory microprocessor course used in this project contains 11 laboratory exercises. Online quizzes were given after exercises 3-7 to collect information on the student understanding of the learning objectives. The following table gives the topic and order of the 11 laboratory exercises conducted in our microprocessor course. The table shows, for each lab session, the assessment tool used and the targeted objective(s) measured.

Table 1. List of laboratory experiments, targeted objectives, and assessment tools used.

Laboratory Experiment	Objective(s)	Assessment Tool(s)
1 – Introduction to uP HW/SW	-	-
2 – LED Parallel I/O	-	-
3 – Addressing Modes	1,2,3,4,5	Self Evaluation Pre-Survey
4 – Addressing Tables	2	1 Multiple Choice, 1 Short Answer
5 – Addressing the STACK	1 2	4 Multiple Choice, 2 Short Answer 2 Multiple Choice
6 – Reading/Writing External I/O	2 3	1 Multiple Choice, 1 Short Answer 6 Multiple Choice, 1 Short Answer
7 – External Interrupts	3 5	1 Multiple Choice, 2 Short Answer 5 Multiple Choice
8 – Multiple Interrupts	4 5	2 Multiple Choice, 2 Short Answer 2 Short Answer
9 - Timers	1, 2, 3, 4, 5	Self Evaluation Post-Survey
10 - Timers	-	-
11 – A/D Converter	-	-

Multiple measures of each objective will be used in order to overcome a statistically small sample size (20-40 students) and also to validate our results. We targeted developing at least four multiple choice questions and at least two short answer questions for each of the five objectives. A self evaluation question for each of the five objectives was given twice during the semester, once before performing the relevant lab exercises and once after. The following table gives the number of each type of assessment tool that was developed for each objective:

Table 2. Number of Weighted Multiple Choice and Short Answer Questions Per Objective

Objective	Multiple Choice	Short Answer
1. Describe the basic architecture of a stored program computer	4	2
2. Describe the addressing modes used in a microprocessor	4	2
3. Describe the functional operation and timing dependencies of a microprocessor I/O interface	7	3
4. Analyze a timing diagram of the interaction between a microprocessor & memory	2	2
5. Synthesize a timing diagram of the interaction between a microprocessor & memory	5	2

2.1 Self Evaluation Survey

A survey measuring student self perception of knowledge of the project objectives was developed, and students completed the survey in Desire2Learn during the third week of the course (after Lab 3) as well as at the end of the course. The survey asked students to evaluate, on a scale from 0 to 10, their understanding of each of the five objectives. The following table lists the self evaluation survey question for each objective.

Table 3. Self Evaluation Survey Questions Per Objective.

Survey Question	Objective
Based on everything you have learned in this course so far, evaluate on a scale from 0-10 your own ability to describe the basic architecture of a stored program computer:	1
Based on everything you have learned in this course so far, evaluate on a scale from 0-10 your own ability to describe the addressing modes used in a microprocessor:	2
Based on everything you have learned in this course so far, evaluate on a scale from 0-10 your own ability to describe the functional operation and timing dependencies of a microprocessor I/O interface:	3
Based on everything you have learned in this course so far, evaluate on a scale from 0-10 your own ability to analyze a timing diagram of the interaction between a microprocessor & memory:	4
Based on everything you have learned in this course so far, evaluate on a scale from 0-10 your own ability to synthesize a timing diagram of the interaction between a microprocessor & memory:	5

2.2 Multiple Choice Questions

We developed multiple choice questions targeting each objective. Our rationale for using multiple choice questions was two-fold. First, we wanted questions that would require some thought and actual knowledge of the subject, and we wished these to give us an accurate measure of the students' level of understanding of an objective. Second, by carefully designing the questions, the correct answers, and the distracters, we could more accurately evaluate student performance changes from one year to the next. We accomplished this by having answers that have weighted scores (i.e., 0 through 5 with 5 being the highest) instead of simply being right or wrong. For each of the multiple choice questions, the answers provided included one answer that was the best choice representing the most correct answer. This answer was assigned the most points (i.e., 5). Within the answer list were other choices (distracters) which were the 2nd best choice, 3rd best choice, etc., each with fewer points assigned. In creating this kind of multiple choice question, the best answer is generated first. The next choices are generated by making them about the same length, with the same grammatical structure, and plausible but with less detail, perhaps, than the best choice. This strategy gives us a grading scale that helps us understand not only how many students are giving the correct answers but also the degree to which students understand the topic. Students were required to read through each of the answers of the question in detail and choose which they felt was the most accurate response. An example of a multiple choice question implementing the grading rubric is given below:

Multiple Choice Question Example (Objective #1)

Which of the following most completely describes the function of the stack in a microcontroller?

A The stack is in ROM and is used to access constant data used in your programs.
(0 points)

B The stack is in RAM and is used to store temporary variable data and subroutine return addresses using indexed addressing modes.
(1 points)

C The stack allows you to have nested subroutines in your programs.
(2 points)

D The stack is used to store registers but you have to initialize the stack pointer register first.
(3 points)

E The stack is in RAM and is used to store temporary variable data and subroutine return addresses.
(5 points)

The answers were randomized in the Desire2Learn quiz system so that each student was given the answers in a different order during the quiz to remove any dependency between the objective score and the response location within the quiz.

2.3 Short Answer Questions

For each of the short answer questions, a grading rubric was developed, and the rubric was used by the graders. The grading rubric described what components the answer needed to contain in order to receive the corresponding amount of points outline in the rubric. The short answer questions were graded by several people in order to determine the inter-rater reliability of the rubric. All responses to the short answer questions were graded by two graduate students. In addition, two faculty members, one involved with the project and one not, graded ten student responses to each short answer question to verify the accuracy of the graduate student scores.

An example of a short answer question and the corresponding grading rubric is given below:

> Short Answer Question Example (Objective #2)
>
> Why would you use indexed addressing to find data in a table rather than some other addressing mode, such as direct addressing?
>
> Full credit (3 points)
> Indexed addressing allows the program to step through a table of data in a loop because instructions exist to increment or decrement the index register. The effective address of an indexed register is the contents of the register plus a constant, fixed offset. Thus in a loop one can step through a table and compare the known against its look-up value. Direct addressing, on the other hand, is an addressing mode that directly addresses a single memory location each time it is executed. The effective address cannot be changed by the program. To use direct addressing one would have to write a program that separately addressed each location in the look-up table.
>
> Partial credit (2 points)
> The effective address of the indexed addressing instruction can be changed in the loop where a direct address instruction cannot.
>
> Partial credit (1 point)
> Indexed addressing is easier to use than direct addressing.
>
> No credit (0 point)
> "None of the elements of a correct answer listed above are present"

3. Assessment of Control Group

During the fall of 2009, the assessment tools were used to collect data relating to the five learning objectives from the control group. At the time of the writing of this paper, the self evaluation survey and multiple choice questions had been evaluated and are reported. The collection of short answer data has not been completed.

3.1. Self Survey Results

The pre-survey and post-survey mean scores on the survey are shown in the table below, along with the results of a two-sample t-test, which was conducted to determine if there were significant differences (at $p \leq .05$) between pre- and post- student evaluations of knowledge of the above objectives.

Table 4. Results of Two-Sample T-tests Conducted on Student Survey Results from Pre- and Post-Surveys of Knowledge of Project Objectives

Objective	Pre-Survey Mean	N	Post-Survey Mean	N	*p* Value
Describe the basic architecture of a stored program computer	6.24	50	7.29	41	.018
Describe the addressing modes used in a microprocessor	8.50	8	8.63	41	.838
Describe the functional operation and timing dependencies of a microprocessor I/O interface	5.26	50	6.68	41	.002
Analyze a timing diagram of the interaction between a microprocessor & memory	6.12	50	7.51	41	.005
Synthesize a timing diagram of the interaction between a microprocessor & memory	5.50	50	6.80	41	.007

All of the scores except for the second objective showed a significant difference between pre-survey and post-survey, with students indicating higher ability in the post-survey. The results for the second objective were not significant, likely because only eight students answered that question on the pre-survey. It is unknown at this time why so few students responded to this question on the pre-survey.

3.2. Multiple Choice Question Results

As a measure of student performance on the multiple choice questions, we determined the proportion of students who chose the correct answer for each question. These results are shown in the table below, arranged by objective.

Table 5. Percentage of Students Choosing the Correct Answer for Each Multiple Choice Question

Objective	Question Number	N	% Answering Correctly
1. Describe the basic architecture of a stored program computer	1	48	58.3
	2	48	45.8
	3	48	81.3
	4	48	45.8
2. Describe the addressing modes used in a microprocessor	1	9	55.6
	2	17	58.8
	3	17	70.6
	4	44	52.3
3. Describe the functional operation and timing dependencies of a microprocessor I/O interface	1	44	65.9
	2	18	27.8
	3	44	25.0
	4	44	29.5
	5	44	47.7
	6	44	9.1
	7	45	31.1
4. Analyze a timing diagram of the interaction between a microprocessor & memory	1	43	20.9
	2	43	37.2
5. Synthesize a timing diagram of the interaction between a microprocessor & memory	1	45	71.1
	2	45	44.4
	3	45	46.7
	4	45	28.9
	5	45	62.2

The scores on the multiple choice questions can be used to directly compare any improvement in student understanding in the fall 2010 experimental groups once the measurement exercises have been introduced. Furthermore, overly high or low scores can be used to indicate a problem in the way that the question is phrased. The project team is in the process of reviewing the multiple choice questions and accompanying scores in order to determine if some questions should be either revised or eliminated.

4. Laboratory Experiment Setup

Each laboratory station in this project will be equipped with a Tektronix, TLA 5210B 34-channel portable logic analyzer. This piece of equipment allows 34 digital signals to be observed at clock rates up to 235MHz. This instrument runs Microsoft Windows® XP, which allows students to access the logic analyzer online using the Remote Desktop Connection feature of XP. A FreeScale HCS12 microprocessor module (APS12C128SLK) is used as the target device for this course. The module plugs into a PMBCUSLK project board which provides additional peripherals, USB programming, and observation points. The FreeScale CodeWarrior software development environment is used to program the HCS12 microprocessor. The software is installed on the logic analyzer so that students' programs can be developed and downloaded to the project board using Remote Desktop Connection. Two Tektronix P6410, 17-channel flying leads are attached to each logic analyzer and provide connectively to the microprocessor signals through pins on the project board. The 34 channels of the logic analyzer are sufficient to observe the critical signals between the processor and memory including 8 data lines, 16 address lines, 3 control signals, the bus clock, and the system clock. The following figure shows the laboratory setup for our microprocessor station. This equipment will be used to augment the existing laboratory experiments during the fall 2010 course.

Figure 2. Laboratory setup.

5. Summary

In summary, this project entails comparing student learning on five learning objectives relating to microprocessors, depending on the instructional mode. In the control group, the students do not have the advantage of measurement-based laboratory experiments; in a second group, students use the measurement-based laboratory equipment in the lab; and in the third group, the students access the measurement-based equipment remotely. Three different assessment tools are being developed to measure student learning: a self-perception survey, multiple choice questions, and short answer questions. Data from the three tools will add richness to our understanding of how the students are learning the material. We expect that the measurement-based laboratory experiments will improve student learning on the learning objectives, regardless of whether the student uses the equipment in the lab or remotely.

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