Custom microcontroller platform increases student satisfaction, engagement and learning

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Structured Abstract

BACKGROUND

Many platforms exist for teaching microcontroller skills, however some of these platforms have drawbacks for teaching third year electrical engineering students, especially students that do not yet have programming skills. In the past, some universities have developed custom platforms. However, custom platform development was hampered by high manufacturing costs. In addition, these efforts have required large coordination efforts between multiple programs as well as industry donations. With the advent of affordable 3-D printers and computer controlled PCB milling machines, it is no longer as difficult to design, develop and build a custom microcontroller platform. This paper describes the custom microcontroller platform developed at Central Queensland University. In addition, this paper describes how this change in platform improved student satisfaction, engagement and learning. This paper will be of interest to those that teach microcontroller concepts.

PURPOSE

The goal of the project was to develop a microcontroller platform that is more suitable for teaching and learning and thus improve student satisfaction, engagement and learning.

DESIGN/METHOD

Instructor observations and student feedback from three offerings of the course are compared to determine if students are more satisfied with the course content and format. Student grades from three offerings of the course are compared to determine if the portion of students receiving P, C, D, and HD marks improves.

RESULTS

Analysis shows the following outcomes are associated with the introduction of the custom microcontroller platform: 1) student satisfaction is improved; 2) student grades improve as a higher proportion of students earn H and HD and, 3) student engagement increases as measured by instructor observations.

CONCLUSIONS

Developing a custom microcontroller platform improved student satisfaction, engagement and learning by providing students a less frustrating experience and more time to learn basic microcontroller concepts as compared to the term using the industry standard microcontroller platform. Given the availability of low cost 3-D printers and computer controlled PCB milling machines, other engineering programs could choose to develop their own custom microcontroller platforms.

KEYWORDS

Microcontroller Platform, 3-D printer, PCB Milling machine

Introduction

Many industry standard platforms exist for teaching microcontroller skills, however some of these platforms have drawbacks for teaching third year electrical engineering students, especially students that do not yet have programming skills. In the past, some universities have developed custom platforms to cater to the needs of their students.

Virginia Tech (Nunnally 1996) used an in-house developed hardware kit, along with software development tools acquired from outside sources to teach microcontrollers to electrical and computer engineering students. Each student received a case with LEDS, two hex input displays, 2x16 LCD panel, 4x5 keypad matrix, and other support chips. In addition, a 25 pin connector was included. The author used the Motorola 68HC11, the Intel 8051 and the Microchip PIC family. The system could be used on 13 standard experiments. Unfortunately, the author provided very little description of how well the system helped students learn, nor any student reports on using the system.

Garcia-Zubia et al. describe a remote laboratory for teaching PIC microcontrollers as well as others (Atmel, Freescale, DSP, CPLD, FPGA). The custom experiment board uses a PIC18F97J60 where the student programs his or her project. The input board is also based on the PIC18F97J60.

Stolz et al (2005) describe a custom laboratory microcontroller hardware evaluation board for use at the University of Detroit Mercy (UDM-EVB). They chose to teach their entire introductory course in assembly language as their students learn C as seniors. The UDM-EVB is unique in that the peripherals are chosen to specifically support a 15 week laboratory course and the circuitry is electronically robust for student use. They included a broader range of I/O devices than typically found on most evaluation boards. The authors had Motorola make 50 units after two prototype validations. They also developed a 10 chapter lab manual so the lab could be independent of class.

Nooshbadi and Garside (2005) wanted a lab with modern equipment that could also realistically teach more about modern design constraints such as data-intensive and control-intensive tasks as well as resource sensitive tasks (e.g. conserve battery power). The authors (one in England and one in Australia) collaboratively designed an ARM-based embedded development board to lower costs and they arranged to have each $1500 chip donated.

Beckerleg & Collins (2005) also developed a custom microcontroller platform to best fit their electrical engineering curriculum. Dawes et al. (2008) describe a custom microcontroller platform that even advanced high school students are able to use for projects that may attract them to the field of engineering.

The desire to design and use a custom microcontroller platform is well established. Previous authors have had to work with chip manufactures or work with a PCB fabrication facility. Now with the advent of affordable 3-D printers and PCB milling machines, engineering educators can design and manufacture their custom microcontroller platforms. This paper describes the custom self-fabricated microcontroller board developed and used at Central Queensland University.

Background

Central Queensland University (CQU) offers two unique degree pathways in engineering – one with a Co-op experience (the dual award program Bachelor of Engineering (Co-operative Education)/Diploma of Professional Practice (Engineering) (Jorgensen and Howard 2005) and one with Distance Education option, but no Co-op option (Bachelor of Engineering). Approximately 27 percent of the CQU enrolled engineering students (19 percent EFTSL) take their courses as part of the distance education program. Both of the degree options integrate Project Based Learning (PBL) in all years of the degree program (Howard and Jorgensen 2006).

Students who choose the distance program tend to be older and be currently employed in an engineering-related field. Their schedules tend to be quite different than on campus students because of their employment. Many courses have a “residential school” week where distance students come to campus and participate in community building activities as well as begin course projects (Martin & Devenish 2007).

The ‘Embedded Microcontrollers’ is a third year 12 credit course in the electrical engineering stream of CQU undergraduate engineering program. The course has high learning demands on the students, as the students enter the class with no required prior programming experience. By the time they complete the course, students have to demonstrate that they can successfully program a microcontroller for specific tasks.

Historical data on course student feedback shows that there had been a consistent lower satisfaction for this course until 2009. The first author started to coordinate and teach this course in year 2010 and received similar student feedback as the previous instructor. At this point the first author started to analyze the student feedback and identified the possible sources of student frustration for this course. He then tried to address each difficulty systematically.

Purpose of Developing the CQU PIC Development Board

The goal of the project was to develop a microcontroller platform that is more suitable for teaching and learning and thus improve student satisfaction, engagement and learning in the Embedded Microcontrollers course. Course feedback from students revealed that the main reason for their low satisfaction was the knowledge and skills gap between their prior learning experiences and level of experience demanded by the hardware development platform used in the course.

In response to the student feedback in year 2010, the teaching team decided to change the hardware platform to an easy to learn system for beginners. The essential task of this new hardware platform development was to make it easy for a beginner to understand and learn, while providing enough hardware interfacing capability to implement a real world task required by the course learning outcomes.

Until 2010, this course was taught using Texas Instruments’ MSP430 microcontroller development kit which was based on an industry standard 16bit microcontroller MSP430FG4618. This industry standard development environment is appropriate for a person with high level programming skills and at least mid-level microcontroller skills. However, this development environment was not suitable for the CQU EE undergraduate cohort which had no prior computer language programming or microprocessor or microcontroller experience. Students commonly complained that the MSP430 system was too hard for them to use. An additional drawback of the MSP430 system was that it had its own proprietary LCD display, which did not provide students experience in programing an industry standard general purpose HD44780 based LCD.

In order to change the microcontroller platform for the ‘Embedded Microcontrollers’ course, two decisions needed to be made: what hardware platform and which level of microcontroller to use. First three different microcontroller families were considered: PIC, ARM, and AVR. Due to the simplicity of architecture, supporting text and the software development environment, the teaching team decided to choose PIC microcontrollers. Then the next task was to decide the level of microcontroller (8bit, 16bit, or higher). In this case, the priority was to choose a platform with features that help students learn the basics. Thus high-end processing power and the bus width were not important features. These criteria pointed to using an 8bit processor.

As summarised in Table 1, none of the commonly available development kits had boards with all the desired features. Thus, the course coordinator decided to develop a custom CQU PIC Development board and microcontroller kit. The first column of Table 1 lists the desired features of a microcontroller for the “Embedded Microcontrollers” course. The next column lists the attributes of the platform used in the 2010 offering of the course. The next two columns indicate how two other platforms addressed those feature criteria. The last column in Table 1 shows the final features of the custom CQU PIC Development Board.

Table 1 CQU PIC Development board desired features: Comparison of three different microcontroller platforms

Desired Feature	**Platform 1** **TI MSP430** *(Platform used in 2010 offering of “Embedded Microcontrollers”)*	**Platform 2** **Explorer 16 development board** *(considered by not chosen)*	**Platform 3** **PIC18F starter kit** *(considered by not chosen)*	**CQU PIC Development Board** *(developed)*
Easy to Program	No – The programming has a steep learning curve.	No – as this is a high range microcontroller and is not suitable for a beginner	Yes	Yes
Contains a Standard LCD	No – only a proprietary device available	Yes	No – an organic LED	Yes
7 – segment display	No	No	No	Yes
RS232	Yes	Yes	No	Yes
Bus-width (8bit preffered)	16	16	8	8
Analog in	Yes	Yes	Yes	Yes
Built-in motor controller	No	No	No	Yes

CQU PIC Development Board

The custom microcontroller platform was designed to have the features listed in the first column of Table 1. Both software and hardware components are described below.

Hardware

Figure 1 shows the custom microcontroller platform using the PIC development kit. The new hardware platform was developed around a mid-range PIC microcontroller 18F4321. The course coordinator selected the 8bit microcontroller in order to have enough digital I/O ports, analog inputs, and USART capability. In addition, the 18F4321 has a good text book available (Rafiquzzaman 2011). The port D was chosen as the 8bit data bus for the HD44780 compatible industry standard LCD with control bits connected to port E. The same port D 8bits were used to drive a two-digit seven-segment display unit running through BCD to seven segment converters while chip enable lines of these chips were connected to port E. In this manner the student can select which display he or she wants to use at any given time. Port D was also made available as a digital output port for general purpose interfacing through a pack of 1k resistors for protection. Four analog inputs were provided on the new development board as general purpose independent inputs for analog sensors. They have the inherent 12bit digital resolution through the built in SAR ADC in the PIC 18F4321.

Four bits of Port C have connections to four press button switches on board and the other four bits of the port C are connected to four LEDs on board. The LEDs and the switches provide a great opportunity for students to use them as their user inputs and status indicators. In addition, the LEDs and switches are very good hardware debugging tools. Two of the lines going to LEDs are connected through a set of jumpers where they can either be connected to the LEDs or to the RS232 driver IC. Once the jumpers are put on the RS232 side, the CQU PIC development board can be successfully connected to any outside serial device, but the number of LEDs is limited to two under this condition.

The CQU PIC development board has a 4.0MHz crystal oscillator connected on board which can be enabled or disabled by software. If selected, the oscillator will work as the external clock source for the microcontroller or otherwise the user can configure the microcontroller's built in clock from 32kHz to 8 MHz. The chosen 18F4321 has five built in timers and the CQU PIC development board has provisions to provide external clock for some of the timers through relevant port pins.

A dedicated motor driver IC which has two H-Bridge circuits is connected to four bits of Port B trough a set of jumpers. The user can decide whether to use these port B bits for motor controlling or to use them as general purpose digital I/O. The motor controller IC can drive two independent DC motors or a single stepper motor.

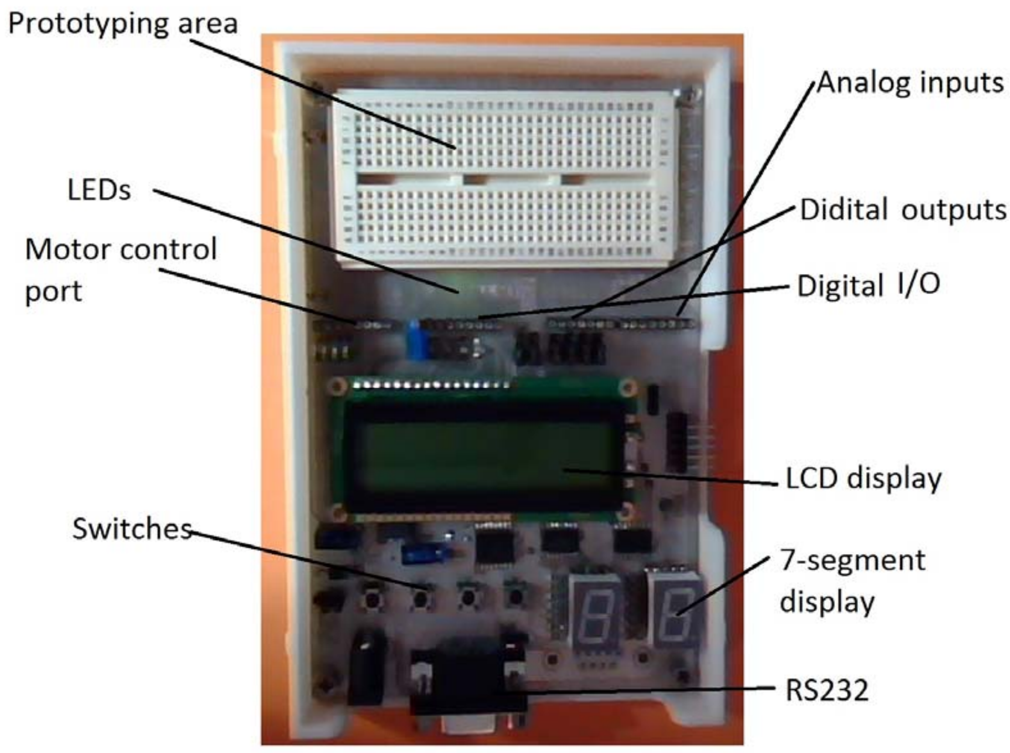

Figure 1: The developed CQU PIC Development board inside its case (without the case lid). The microcontroller is on the other side of the circuit board.

The newly-designed development kit enable students to explore the following features: analog inputs; digital inputs/outputs; methods to communicate with the outside world through RS232, display menu, messages or output on a LCD; display data on two-digit 7-segment LED display; and accept external clock inputs for internal timers/counters. These multiple features make our design very versatile so that students have the freedom to use as many peripheral devices as they want.

Software

The development software used with the CQU PIC development board is MPLAB IDE from Microchip, the manufacturer of PIC microcontrollers. With this IDE, there are different choices and options for high level language usage. At CQU we use the C compiler MCC18, which is also from Microchip. This language and compiler was chosen to reduce the chances of incompatibilities between the IDE and the C language compiler.

The MCC18 compiler has all the header files needed for embedded microcontroller development with PIC 18F4321.. The only newly developed header file was the CQU_PIC_LCD.h. The purpose of this header file is to recognize the data and control bits used on the CQU PIC development board. One benefit of this additional “home grown” header files is that students learn about the purpose and use of header files.

Course Content and Delivery

The course content and delivery has also changed to cover the high level language and microcontroller essentials in first three weeks. This coverage provides the essential knowledge students need to program a microcontroller in a given environment. Students are provided with many examples in class as well as short videos to walk them through programming essential hardware parts of the development kit.

The microcontroller platform is introduced into the course after the third week of the term during the residential school for distance students. All on campus students are encouraged to attend this CQU PIC development board introduction along with the distance students. Demonstrations include software installation and programming individual tasks with the CQU PIC development board. Students practice these tasks and establish a solid foundation for investigating further opportunities. They then explore and develop their capabilities with the development kit for the remaining nine weeks of the semester.

As part of the PBL course, once students are familiar with the high level programming language and microcontroller essentials, they are given the task of developing a real world system using the CQU PIC development board. The project is an open ended problem and students need to use almost all digital I/O ports, analog inputs, the RS232 port, and displays in their project to produce a product to address the problem. Students are also required to provide a user manual and a technical manual for their final product, in addition to the program listing.

Results & Discussion

The course outcomes can be viewed from three different points of view: course grades, student feedback and instructor observations.

Course Grades and Student Satisfaction

Figure 2 shows the grade distribution for ‘Embedded Microcontrollers’ for term 2010, before the CQU PIC development platform was introduced and for terms 2011 and 2012, the first two terms to implement the CQU PIC development platform. A higher proportion of students earn HD (High Distinction) and D (Distinction) grades after the CQU PIC development platform is introduced. Fifty percent of the students earned HD in 2012. This rate of success is much appreciated by the CQU administration. Please note that 20 students took the course each term and each term 2 students withdrew. The number of distance students that completed the course each term was 1 in 2010, 8 in 2011 and 8 in 2012.

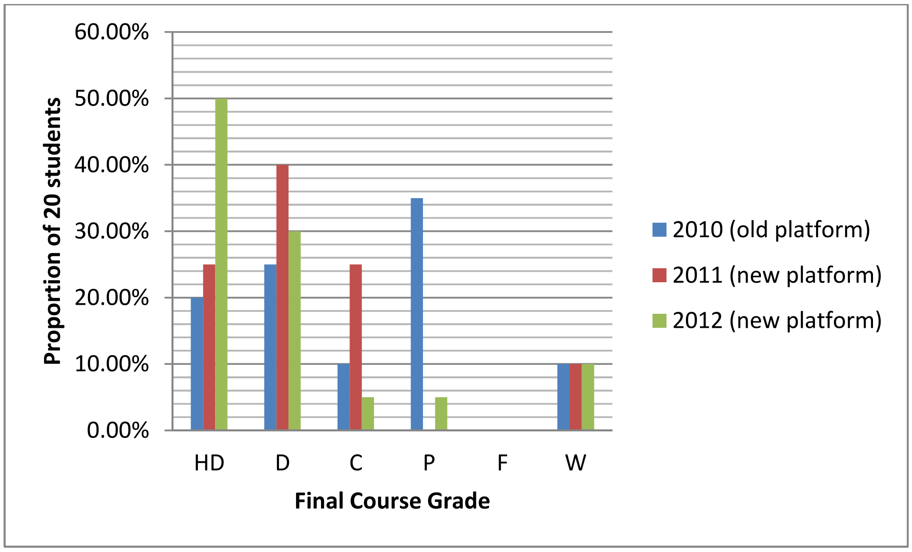

Figure 2. The grade distribution for Embedded Microcontrollers for terms 2010 (N=20), 2011 (N=20), 2012 (N=20). The CQU PIC development board was first introduced in 2011.

Table 2 shows how the student satisfaction ratings improved through the three year period and how those values compared to satisfaction rates compared for all engineering courses offered at CQU. Year 2010 the course incorporated the Texas Instruments MSP430 development system. The CQU PIC development board was first introduced in 2011.

Table 2. Overall satisfaction of students for 'Embedded Microcontrollers' course (where 5 represents "extremely satisfied"). The CQU PIC development board was introduced in 2011.

Year	**2010**	**2011**	**2012**
Embedded microcontrollers student satisfaction	2.5	3.2	4.2
Student satisfaction for all CQU engineering courses	Data not available	3.8	4.0

Student Satisfaction Feedback

Below are samples of typical student feedback from when the course used the old platform.

- *'The choice of micro-controller was very poor as it was too sophisticated for an entry level user.' (2010 student feedback)*
- *'This course is the first real exposure which students studying engineering get to code. The issued text however is meant more for people who already have a grounding in C programming.' (2010 student feedback)*
- *'The MSP430 experimental kits had a number of firmware issues which caused difficulties with programming.' (2010 student feedback)*

In response to the feedback survey question '*What are the best aspects of your course?'* an example of typical 2011 student feedback follows:

- *'The Microcontroller board developed in house by CQU is good, but being the first run for this course, it still needs some bugs ironed out.' (2011 student feedback)*

The hardware development system was revised to include more features in 2013.

In response to the feedback survey question '*What are the best aspects of your course?'* an example of typical 2012 student feedback is:

- *'Residential School, Teaching Staff, PIC Development Board.' (2012 student feedback)*

This final type of student feedback is gratifying. The teaching team felt it had made a good decision to move to a custom microcontroller platform.

Faculty Observations

The new hardware platform was designed, developed and fabricated in-house and therefore the teaching team has 100% understanding of what it is and how it works. This understanding further enables the team to develop assignments and wrap the project around well-known hardware with confidence. The teaching team can handle any student query regarding the CQU PIC development board.

Each year, before the class is taught, the boards are carefully tested before they are given to students. At times, (about 1 in 10) manufacturing defects are found and need to be rectified before the boards are provided to the students.

Student engagement has improved with the introduction of this new platform as they know that this hardware was developed in CQU. Students never hesitate to ask questions related to the development system. This increased engagement has resulted in the students developing much more sophisticated projects than in previous terms. In the 2012 offering of the course, the project outcomes were of particularly high quality. This improvement can be directly credited to the flexibility of new development system and the teaching team's familiarity with the system.

The student attitude toward learning has an impact on the overall success of the class. The instructor has noted that if there are at least four students that are keen to learn the material and willing to put the time in to learn the material, the entire class performs at a higher level. The instructor sets up a classroom culture with the expectation that students will share what they learn on the course discussion boards. In fact, the instructor encourages students to focus their learning on one aspect of the CQU PIC development board and then use the discussion boards to share and learn from other students about other aspects. If there is a critical mass of motivated students on the discussion boards, the entire class benefits. Thus the instructor has seen the class performance fluctuate, depending on the number of motivated students.

Each term students provide feedback on the CQU PIC development board and suggest enhancements. This year the first major revision to the board has been implemented. Multiple enhancements to the CQU PIC development board were based on student input/feedback from prior semesters.

Limitations

While there is an observed improvement in student grades and satisfaction, this improvement cannot be solely attributed to the inclusion of the CQU PIC development Board.

Another source of improvement of students' grades and satisfaction over the three terms is the instructors' gain in pedagogical knowledge over the same period. Each time the instructor taught the course, he had a better understanding of what concepts are difficult for the students. Thus, he could modify his teaching method in subsequent classes to better convey those difficult concepts.

The make-up of the student cohort could be different each term and thus contributed to a change in performance. As well as the instructor could tell, there was not great variation in each student cohort. However, as discussed above, a critical mass of motivated students does seem to impact student achievement.

Summary

Developing a custom microcontroller platform helped improved student satisfaction, engagement and learning by providing students more time to learn basic microcontroller concepts and with less frustration compared to the term using the industry standard microcontroller platform. The students were empowered with their new programming skills to develop sophisticated final projects.

The platform is designed and manufactured on the CQU campus using the engineering program's 3-D printer for the case and PCB Milling machine for the board. Student motivation and curiosity is increased when they realize that the equipment they are using was designed and manufactured by the teaching staff. This home grown approach could be easily adopted by other programs.

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