AC 2010-1333: A PRACTICE LEARNING OF ON-BOARD DIAGNOSIS (OBD) IMPLEMENTATIONS WITH EMBEDDED SYSTEMS

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ABSTRACT

This study presents the impact of embedded system on the development of on-board diagnostics (OBD) implemented by engineering students. The engineering students need professional skills in engineering design for their future related works. We design a practice course to train students to integrate discipline-specific components into embedded systems and learn the subject-matter deeper through a vertical integration. Focusing on a specific and multi-disciplinary design project gives the students a helpful train to apply design principles, but they have difficulties in absorbing what they have learned and applying their learning to other projects. This course encourages students to integrate different and related knowledge into experiments, and it provides students training on the design details of OBD, electric circuit design, and embedded system. We designs a practical implementation course to teach multi-disciplinary skills of vehicle electronics in the OBD implementation based on embedded system. The study uses pre-test and post-test to examine the impact of the experiments. Most graduate students in vehicle engineering participated in the whole of this exercise. From the results of test, we can see that students have significant improvement on every concept category in this course, and students' responses are generally very positive.

INTRODUCTION

The vehicle production is an important force to push automotive industry forward. With the growth of vehicle production and consumer electronics, vehicle electronics become a recently highlighted topic in the automotive industry and need more trained engineers. These engineers need both vehicle and electronic knowledge, and require hands-on experiences of embedded system. For this they need a solid basic research background, applied R&D basis, innovation of marketable products and services. However, the curricula of vehicle electronics have not kept pace with the demands for vehicle electronic engineers, especially OBD engineers. The practical training of OBD implementation based on embedded system is often insufficient for vehicle engineering students.

Over the past few years we have been engaging in the study of student learning on embedded processors since MOE Subsidy Operational Guidelines for Advance System on Chip. This idea came from a teaching request, which is a material of experiments in an embedded system course needed by one of authors. We developed a material of embedded system applied on vehicle electronics. The vehicle electronics course is difficult to be developed, because the knowledge of it is related to electric circuit, sensors, hardware, and embedded software.

To minimize the gap between theory and practical implementation, this study designed a practical implementation course by integrating discipline-specific components. In this study we have developed an OBD implementation courses that consist of OBD concept, interpreter circuit, and embedded system. The course provides students trainings on the OBD design and comprehensive hands-on practices on embedded system. The experiments of this course require students to build and analyze embedded systems, and ask students to combine various components from different concepts. The educational objectives are as follows:

- Enhance students' thinking skills.

- Experience a variety of learning styles.
- Have professional skills in electrical, circuit, and embedded system.
- Encourage students to make connections between several components.
- Have students actively learn the skills of efficient and accurate experimentation.
- Improve student retention of experimental skills and facility with hardware.
- Present material in a systems and applications context to better emulate industrial practice.

Our concern to improve student learning through a practical implementation and to help students engage them in a deeper way. We examined different aspects of OBD implementation learning on graduate students in vehicle engineering. We began to learn what was important or not in vehicle electronics. The main problem is that as students graduated and then their learning was gone together. The solution was to develop a course on multi-disciplinary design using the OBD implementation based on embedded system as an example.

In addition to experimenting with embedded OBD systems, we encourage students for themselves to learn it for life. Students take responsibility for learning and choose the appropriate solution from their implementation experience to solve a problem. They realize that the perfect or ultimate solution does not exist but they are asked to improve the system continually. Given a simulated industrial problem with a set of reference information, students design their systems to solve this problem. To reach this goal, we compared our requirements with Kolb's learning cycle[1]: concrete experience (experiencing), reflective observation (examining), abstract conceptualization (explaining), and active experimentation (applying).

Therefore, we designed a learning environment that requires students to use all of the styles. At the beginning, students read the given problem and search the related references. Before developing OBD implementation, students read the manufacturer datasheets and instrument descriptions from this course. They should complete a term report including: (1) a specification that describes the requirement, (2) a plan for their procedure, and (3) diagrams of system architecture. Students are encouraged to discuss to each other, and the teams actively discuss the procedure in use. Based on the course design, students are asked to complete their own OBD implementation step by step. The students are expected to understand the practical aspect of an OBD, and have comprehensive exercises on OBD implementation based on embedded system. This paper presents the course and hands-on OBD implementation designs, and the teaching experiences and student responses.

LEARNING THEORY

In the process of experiments development, we reviewed the recent literature of engineering education about laboratory courses. We found that some universities have stand-alone courses dedicated to data acquisition for students in multiple disciplines[2-3]. However, they did not consider the material breadth for systems experiments. Other universities have open-ended project laboratories[4], and some offer innovative laboratory courses covering a topic applicable to multiple disciplines[5-8], which again did not offer the required breadth. Other universities integrate math, physics, and engineering fundamentals in open-ended projects and competitions[9]. These were closer to our needs, but we wanted more guidance and deeper knowledge of OBD, circuits, and embedded system. Some universities have designed unaided experiments for students to complete[10]. We believe coaching enhances learning. Institutions have reduced the cost of experimentation[11-12], and replaced experimentation with demonstrations[13]. In this study, we chose to provide enough requirements of industrial quality and a helpful hands-on environment for students.

We are primarily focused on improving student learning. By the notion of the "learning study" developed by Pang and Marton[14], we use educational research of vehicle electronics to evaluate our teaching initiatives and develop a deeper understanding of this context. By this approach, many applications, such as the topics of economic supply and Newton's Third Law for freshman physics students, had been applied on many education fields[15].

A learning study seeks to build innovative learning environments and to research into theoretically grounded innovations. It also aims to pool teachers' valuable experiences into some classroom activities to improve teaching and learning. We emphasize on the learning, not on the teaching methods. From this starting point our learning study went through the following stages:

- choosing an learning object;
- ascertaining students' existing understandings;
- planning and implementing classroom activities; and
- evaluating and revising the activities[16].

In this study we chose the learning object as students' practical implementation of OBD based on embedded system. The practical training of the vehicle electronics development such as circuit design and implementation is often insufficient for students. These engineers need both strong hardware/software knowledge and hands-on experiences of system-level programming. To minimize the gap between theory and practical implementation, this study develops a practical implementation course of embedded system. The course provides students trainings on the comprehensive hands-on practices of embedded system implementation with vehicle electronics. We then ask students to complete a practical project for improving hands-on experiences of vehicle electronics development. The improvement together with students’ responses was used to evaluate the course and indicates that what changes are needed for them.

Development of Course

The purpose of the course is to teach students how to complete large and multi-disciplinary design projects, and to bring the students "up-to-speed" on how to design a vehicle electronic device of OBD based on embedded system. The focus is on the design and integration of an OBD implementation based on embedded system. The course is divided into three parts: OBD, electronic circuit design and PCB board manufacturing, and embedded system.

A. On-board diagnostics, OBD

This part enhances students’ understanding of OBD and ability of accessing information from vehicle subsystems. By finishing the given homework in a good course design, students can know the importance and key aspects of OBD. Once the OBD concept is understood, the students can know how to access information from vehicle subsystems in different car. This part can help students find out a set of valuable information, for example, engine load value, engine coolant temperature, fuel pressure, engine RPM, vehicle speed, and etc.. When a vehicle has some problems, the above information can be used in troubleshooting. We must evaluate what various parameters can be addressed from OBD in the car.

On-Board Diagnostics, or OBD, is a generic term referring to a vehicle's self-diagnostic and reporting capability. OBD system can offer operation state or information of vehicle subsystems to the driver or repair technician. If a problem was detected, OBD-I would simply illuminate a malfunction indicator, or MIL. OBD-II implementations output a standardized series of diagnostic trouble codes or DTCs from a digital I/O port via standardized fast communications. It aids technician to rapidly identify and repair malfunctions in the vehicle.

OBD-II provides access to numerous data from the engine control unit (ECU) and offers a set of valuable information when troubleshooting problems in a vehicle. The SAE J1979 standard defines a method for requesting various diagnostic data and a list of standard parameters that might be available from the ECU. The various parameters are addressed by "parameter identification numbers", or PIDs. For easier reading of OBD-II PIDs' definitions, we use formulae to convert binary OBD-II output to meaningful diagnostic units.

OBD-II PIDs On Board Diagnostics "Parameter IDs", or P-codes, are a set of codes used to request data from a vehicle. Table 1 shows parts of the standard OBD-II PIDs as defined by SAE J1979. The expected response for each PID is given, along with information on how to translate the response into meaningful data.

Table 1. The standard OBD-II PIDs

Mode (hex)	PID (hex)	Data bytes returned	Description	Min value	Max value	Units	Formula
01	00	4	PIDs supported [01 - 20]				Bit encoded [A7..D0] == [PID 0x01..PID 0x20]
01	01	4	Monitor status since DTCs cleared. (Includes malfunction indicator lamp (MIL) status and number of DTCs.)				Bit encoded.
01	02	8	Freeze DTC				
01	03	2	Fuel system status				Bit encoded.
01	04	1	Calculated engine load value	0	100	%	A*100/255
01	05	1	Engine coolant temperature	-40	215	°C	A-40

Students are required to read the reference material and experiment problem. The classroom activities were accompanied by a worksheet of instructions and questions regarding what the students were seeing in the OBD material. They complete a report of questions, and are asked to understand the following items:

1: OBD concepts
2: OBD-II parameter identification numbers, PIDs
3: the mode of operation in the OBD-II
4: the communication protocol of OBD-II
5: how to access to OBD information

B. Electronic circuit design and PCB board manufacturing

The second part of the course focuses on the technical design and manufacturing of the interpreter circuit between OBD and embedded system. Students learn the function of the interpreter circuit and the skills of PCB manufacturing. The key point of this part is to know the basics of system design and understand what is required to manufacture a printed circuit board.

This guide describes our process for designing a new electronic circuit board, typically a microprocessor-based system. This same process is used for most products designed by us. When designing any electronic device, the first step is to identify the need of product, and then check that the functions are conformed or not. This part introduces students to the specification of device, circuit design, PCB layout, prototypes, pilot run and production.

OBD-II provides a data port, the J1962 connector, for the connection of test equipment. This port is used to obtain emissions-related diagnostics information, and in some cases can also be used to obtain real-time vehicle operating parameters. SAE standards specify that each group of bytes sent to the vehicle must obey specific data format. The first byte (known as the 'mode') always describes the type of data being requested, while the second, third, etc. bytes specify the actual information required (given by a 'parameter identification' or PID number).

This provides opportunities to practice and understand a typical manufacturer's data sheet (an important tool for practicing engineers). We design a circuit with ELM323 and few components to convert between the OBD data format and the standard RS232 serial data format, as shown in Figure 1. This allows any personal computer or embedded devices to communicate with a vehicle using only a standard serial port and a terminal program. We also engage students to create their own program by using this interface.

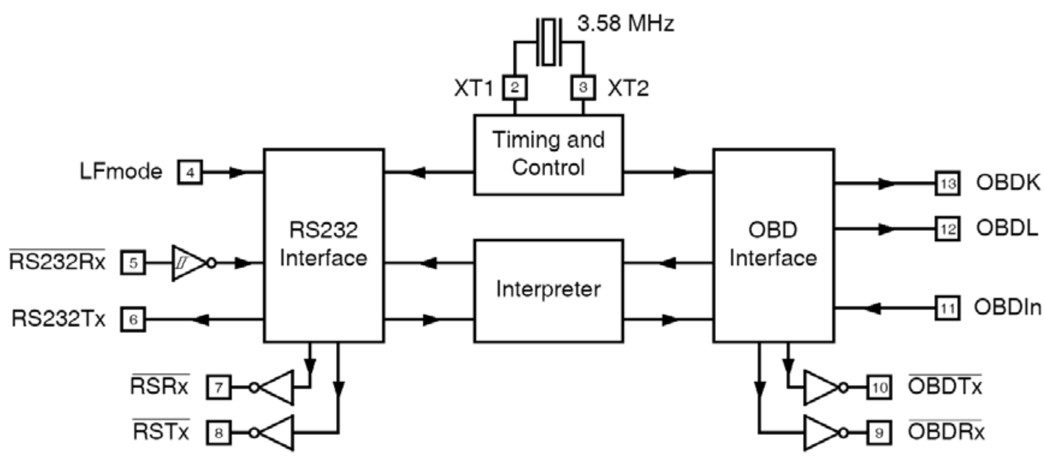

Figure 1. OBD to RS232 Interpreter Circuit

Since many graduate students do not know how to design a circuit or use a development tool, we ask students to design, build, and test OBD to RS232 Interpreter circuit during the course. Each student builds his own circuit to ensure that everyone can learn this skill. To encourage high-level thinking and life-long learning, we do not lead the students step-by-step through circuit construction. The students must design a circuit, draw a circuit diagram, select components from a kit, build the circuit, and test it. Figure 2 is one of the student products. The OBD to RS232 interpreter circuit connect the data port of OBD-II with embedded platform, as shown in figure 3.

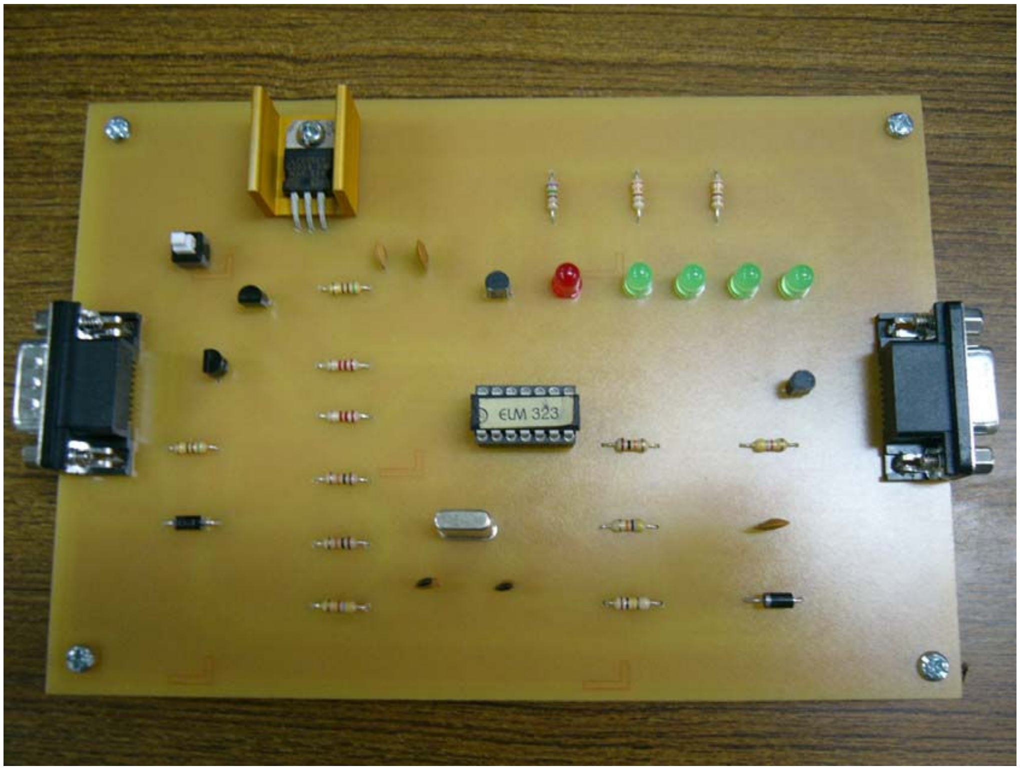

Figure 2. OBD to RS232 interpreter printed circuit board

Figure 3. a schematic of OBD implementation based on embedded system

C. Embedded system

This part provides students with the opportunity to gain the necessary skills for hardware and software design for embedded systems. It also introduces a representative family of microcontrollers that exemplify unique positive features as well as limitations of microcontrollers in embedded systems. The study ranges from simple microcontroller programming to complex application development. The topics related to the embedded system are including “Introduction to Embedded Systems”, “Microcontrollers”, “Software Architectures”, and “Programming, and Development for Embedded Target Systems”. Modern embedded software, developed by software experts together with others who understand the physical and engineering problems, deals with and formulates those problems. With the growing of embedded software applied on all sorts of products, traditional microprocessor software must consider the requirement of industry. This part addresses issues in developing embedded software. Developing software for embedded systems is where the skills of computer engineering and software engineering intersect.

Each student has a personal computer for software development and an embedded system development board as a target system. Students learn basic skills by a target system board with timers, A/D converters, D/A converters, and digital I/O ports. To integrate the product based on embedded platform, students should study the courses related to electronic circuit design and analysis, microprocessor.

This task requires students to build a larger embedded system by integrating the peripheral circuit. To develop the OBD implementation, students design an interface board on which the LCD module, button switch, and connectors are mounted. Students design a monitor circuit to display data from OBD, as shown in figure 4. Students can view the output from target system using the monitor circuit board. In the final stage, students use their learning of embedded system on integration of OBD implementation. They start by integrating the OBD, OBD to RS-232 interpreter circuit, embedded platform, and monitor circuit, as shown in figure 5.

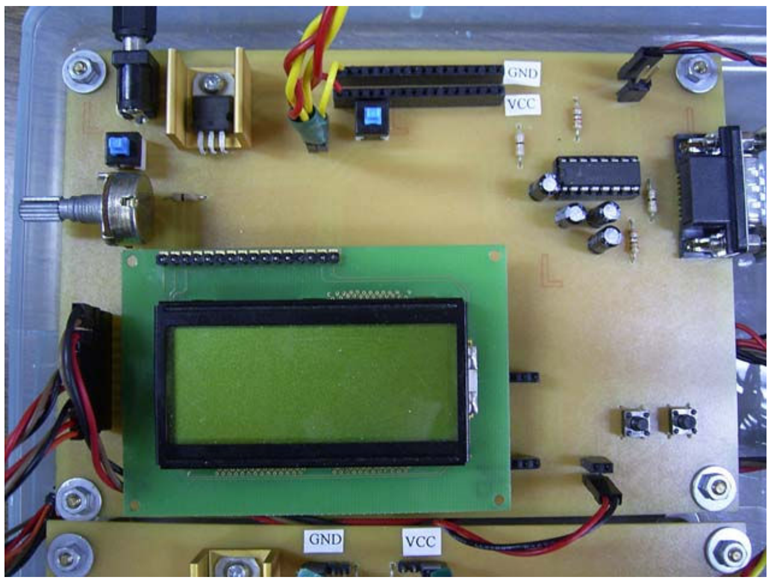

Figure 4. monitor circuit board

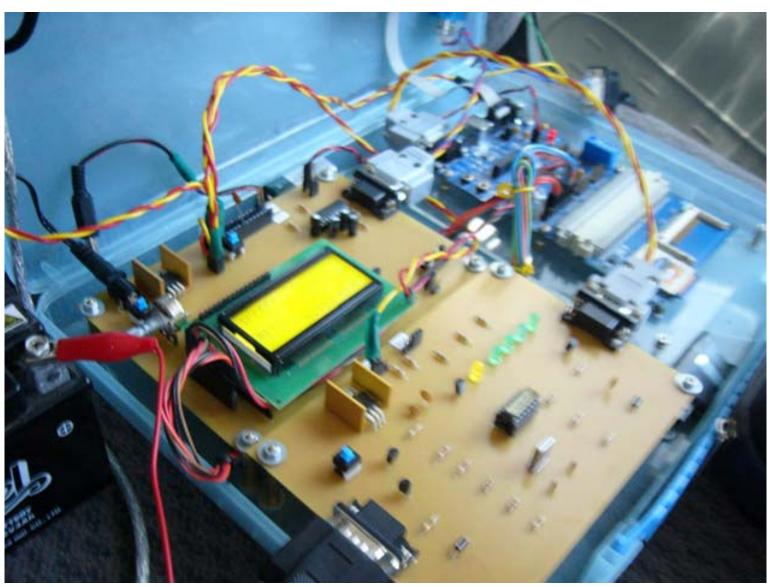

Figure 5. An integration of embedded platform and monitor circuit

There are several programming project assigned to the students. Students program the microcontroller to act as an OBD scan device and an independent system of performance diagnostic. We used C programming language to scan OBD through RS-232C. Students develop their experimental procedures and predict results prior to making tests. This process enhances their thinking skills, encourages them to understand the experiment, and facilitates troubleshooting.

ASSESSING THE IMPACT OF COURSE

The course is available to graduate students in institution of vehicle engineering. The students undertook the course during a semester. There were 11 students participated in this exercise, held in the laboratory with each student working on their own computer. A worksheet guided the students through each part of the course. Time constraint meant that we needed to select a subset of this inventory that would cover materials in the course on vehicle electronics. The test contains 25 questions/tasks to reflect their learning effect in this course.

Table 2 shows the results of this test listed by categories of questions. The lower-score categories on this item "% Passed" are "General OBD concept", "electronic circuit design and manufacturing", "Hardware interface", and "Development tool". General embedded system concepts were less problematic, and software programming was handled quite well. Thus, it was decided that the course should enhance the following four areas: General OBD concept, Electronic circuit design and manufacturing, Hardware interface, and development tool.

Table 2. Pass rate per category for the pre-test.

	Concept Category	Question/task No.	% Passed
A	General OBD concept	1,2,3,4,5	14.5
B	Electronic circuit design and manufacturing	6,7,8,9	22.7
C	General Embedded system concepts	10,11,12,13	45.5
D	Hardware interface	14,15,16,17	38.6
E	Software programming	18,29,20,21	65.9
F	Development tool	22,23,24,25	38.6

In order to evaluate the effectiveness of the classroom activities, we needed to investigate the impact of the course. After comparing the post-test with the pre-test on the same students, qualitative response was obtained from a questionnaire completed by the students. The post-test was done after the students had studied course.

Table 3 shows the change in proportions of students getting the correct answers in different categories. It should be noted that there was great change for the General OBD concept area, whereas there was what seemed to be a significant improvement in the areas covered by Electronic circuit design and manufacturing and Development tool.

It might be seemed that the improvements shown in Table 3 were simply due to the students having spent focused time on these topics through the course. The argument to this is that less improvement was shown in Category E, compared to significant shifts in Categories A, with roughly equal time having been spent on each of these categories. This argument could be due to the less understanding of OBD compared to the having been learned the material of Software programming.

Afterward the post-test students also completed the questionnaire about their experience of the learning. From Table 3 we see that catalog A was negligible compared to catalog C and E. Students' comments show that the software programming is difficulty to learn very well.

Table 3. Comparison of results per category.

	Concept Category	Question /task No.	% of students Passed		
			Pre-test	Post-test	Shift
A	General OBD concept	1,2,3,4,5	14.5	78.2	63.6
B	Electronic circuit design and manufacturing	6,7,8,9	22.7	59.1	36.4
C	General Embedded system concepts	10,11,12,13	45.5	68.2	22.7
D	Hardware interface	14,15,16,17	38.6	68.2	29.5
E	Software programming	18,29,20,21	56.8	70.5	13.6
F	Development tool	22,23,24,25	38.6	70.5	31.8

In order to see these significant categories from Table 3, we performed a question-by-question statistical analysis for differences in proportion. Nonparametric tests were conducted to examine differences in proportion within the class due to small sample sizes. We used two-tailed tests and required to calculate the $|z|$ value. If the value is greater than 1.96, it indicates that the two proportions are significantly different at the 5 percent level. All of the changes are significant at the 5 percent level.

When the questions on the category “General OBD concept” are examined in detail, it is clear that the students did improve significantly on any of them (see the z values in Table 4). The answers in the questions may be the students have common concepts about OBD. But they did not seem understanding of OBD in detail.

Table 4. Comparison of results for 'General OBD concept' questions.

Results (General OBD concept)	% of students passed		
	Pre-test	Post-test	z value
1: OBD concepts	54.5	100.0	-2.937**
2: OBD-II parameter identification numbers	0	63.6	-2.937**
3: mode of operation in the OBD-II	0	72.7	-2.934**
4: communication protocol of OBD	0	72.7	-2.936**
5: access to OBD information	18.2	81.8	-2.934**

** denote significance at the 0.05 level, based on two-tailed tests.

When the questions on category “General Embedded system concepts” are examined in detail, it is clear that the students improve significantly on most of them (see the z values in Table 5). Most students have in understanding of basic embedded system concept. But it seems that they do not understand enough the professional knowledge in depth.

Table 5. Comparison of results for 'General Embedded system concepts' questions.

Results (General Embedded system concepts)	% of students passed		
	Pre-test	Post-test	z value
10: embedded system concepts	54.5	72.7	-2.572**
11: embedded processor	54.5	72.7	-2.943**
12: embedded system architecture	54.5	72.7	-2.938**
13: embedded operating system	18.2	54.5	-2.941**

** denote significance at the 0.05 level, based on two-tailed tests.

When the questions on the category "Software programming" are examined in detail, it is clear that the students did not improve significantly on interrupt routine (see the z values in Table 6). Although most students have understood software programming, they did not enough understand programming of interrupt routine. An interrupt is an asynchronous signal indicating the need for attention or a synchronous event in software indicating the need for a change in execution. An interrupt causes the processor to save its state of execution and begin execution of an interrupt handler. An interrupt handler is used for servicing hardware devices. It is difficulty understanding and programming.

Table 6. Comparison of results for ' Software programming' questions.

Results (Software programming)	% of students passed		
	Pre-test	Post-test	z value
18: c language	72.7	81.8	-2.854**
19: interrupt routine	45.5	63.6	-2.937**
20: timer routine	54.5	72.7	-2.937**
21: communication routine	54.5	63.6	-2.938**

** denote significance at the 0.05 level, based on two-tailed tests.

Students' comments on the course were generally very positive. The one criticism was that the learning time of electronic circuit design and manufacturing is insufficient, because it was difficult to learn very well due to the time constraints in this study. Students' comments on catalog B indicated that this one is most helpful, although some had struggled to understand how to do the task. We also had some negative comments, for example, some students said that the hands-on OBD implementations are too difficult and heavy. Moreover, some students felt frustrated for the new assignment if they could not be able to complete previous one.

Other response from the questionnaire indicated that students have a strong desire to learn this course well. They also propose some suggestions, in which each of the parts could be improved and able to be played more time and functions.

CONCLUSIONS

This study applies learning theory to the development of OBD electronic device based on embedded *system* for use in teaching engineering. The particular course involved the teaching of OBD and embedded system, and based on constructivist theory we sought to investigate students' understanding of these concepts. The courses were designed using constructivist educational theory to inform the design of learning activities in order to facilitate conceptual understanding. The impact of the course was judged by subsequent responses to the same test used previously. These indicated that the course had indeed met their objectives.

This study caused students more and deeper learning, with obvious integration of topics and student excitement. Students made connections between courses and applied the knowledge to the experiments. Students agreed that they were better prepared for industrial practice. This study encourages students to accept responsibility for learning and shows them how to become independent learners. However, it is more difficult and time consuming than traditional courses.

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