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An Interactive Simulator-based Pedagogical (ISP) Approach for Teaching Microcontrollers in Engineering Programs

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ABSTRACT

Microcontroller is a required course in most Electrical, Computer, and Mechanic Engineering (Technology) programs at U.S. universities. Most engineering courses (e.g., microcontrollers), by nature, introduce abstract concepts, definitions, and models, and use primarily lectures and readings (words, symbols) to transmit information. This traditional engineering educational method has its unique advantages but also serious shortages. In this paper, we analyze the features of the traditional engineering education method and investigate two major reasons that may cause students not to learn engineering curricula, and try to remedy them by proposing an interactive simulator-based pedagogical (ISP) approach for enhancing the teaching and learning process, without compromising the depth or breadth of course materials. Demonstration examples are presented. The effectiveness of the ISP approach is evaluated from both the questionnaire-based assessment and the outcome-based assessment. The ISP approach can be incorporated into a variety of educational settings.

Key Words: Interactive simulator-based pedagogy (ISP), Verbal-based teaching, Visual-based teaching, Microcontroller.

INTRODUCTION

Microcontroller is a required course in most Electrical, Computer, and Mechanic Engineering (Technology) programs at U.S. universities. Most engineering courses (e.g., microcontrollers), by nature, introduce abstract concepts, definitions, and models, and traditionally use such verbal-based teaching style as lectures and readings (words, symbols) to transmit information (Barbe, & Milone, 1981; Felder, & Silverman, 1988). Students may further enhance their understanding of the concepts that are explained by the instructor through more practical homework assignments. During the lab component portion of the course, students physically wire sample designs from the lab manual, test the microcontroller circuit, debug assembly code, verify related functions, and thus acquire hands-on hardware and software experience.

With the advancement of technology and the rapid increase of Internet applications, engineering education is changing to embrace an exciting multitude of tools (e.g., a huge number of free-downloadable educational simulators) aiming to resolve the pedagogical challenges. In the meantime, perhaps the laboratory equipments are becoming complex (difficult to be grasped by students) and too expensive for purchase, training, and maintenance (e.g., frequent hardware and software updating). Currently, there is a trend that many electronics and computer courses are switching to use software simulators for complementing lecture-based notes and laboratory instructions. The interactive demonstration of many abstract concepts in microcontrollers significantly improves the students' understanding and gives them as close as possible a real hands-on experience.

Recent research indicates that the purposeful use of computers and related software in classroom instruction can indeed enhance student outcomes (Milheim, 1995; Archer, 1998). Interactive simulation supports applied learning by encouraging students to investigate exploratory questions and yield less 'messy' data (Baggott La Velle & Nichol, 1998). According to Newton and Rogers (2003), simulations and other technology tools can add value to science study in two ways: (a) through intrinsic properties of the software; and (b) through potential student learning benefits such as improved understanding.

However, using simulations effectively in teaching is not a simple thing (Baggott La Velle, McFarlane, & Brawn, 2003). Besides grasping the complex and interrelated processes of a subject, the instructor needs to carefully consider the pedagogical, technological, curricular and contextual knowledge transformation. Integrating various aspects into a software simulator to create an effective teaching instrument requires a great deal of time and energy, but the benefit for students is immeasurable.

In this paper, we analyze the features of the traditional engineering education method and investigate two major reasons that may cause students not to learn engineering curricula (See the third section for details), i.e., (a) some discrepancy may exist from the teaching content to the instructor's presentation form, within present engineering education; (b) some gaps may exist between what students are taught and what they expect to learn. Then, we attempt to remedy the pedagogical deficiencies by proposing an interactive simulator-based pedagogical (ISP) approach for enhancing the teaching and learning process, without compromising the depth or breadth of course material. Unlike the verbal-based teaching approach (Barbe, & Milone, 1981; Woolner, 2006), the ISP approach emphasizes the visual-based teaching method (Cohen, Ebeling, & Kulik, 1981; Markel, 1998; Woolner, 2006). Demonstration examples, based on selected microcontroller course contents, are presented to show how the ISP approach is used for enhancing teaching and learning. The effectiveness of the ISP approach was validated from both the questionnaire-based and the outcome-based assessments. The ISP approach can be incorporated into a variety of educational settings. The simulator involved can be used by instructors for interactive demonstration of microcontroller concepts and techniques, and developing laboratory-based and course project-based activities. The simulator can also be used by students for solving their homework assignments, laboratories, or other extracurricular activities, which may significantly improve their understanding of course materials.

The remainder of the paper is organized as follows. The next section analyzes the traditional educational approach of microcontrollers and its advantages and disadvantages. The third section introduces the interactive simulator and investigates two major reasons that may cause students not to learn engineering curricula as well as the possible remedy using the ISP approach. The fourth section demonstrates several examples to show how the microcontroller simulator is used for enhancing teaching and learning. The fifth section performs a questionnaire-based assessment and an outcome-based assessment to evaluate the effectiveness of the ISP approach. The last section presents conclusions.

TRADITIONAL EDUCATION OF MICROCONTROLLERS

Traditionally, microcontroller is taught through lectures and labs (Johnson, & Wise, 1999; Martínez-Torres, Toral, Barrero, & Gallardo, 2007). The lectures are focused on theoretical aspects listed in the outline of the course. The instructor explains as clearly as possible the concepts, theorems, and tools, such as microcontroller hardware architecture and assembly language programming, and then provides some examples of how they are used to solve problems. Classroom interaction is also used between students and the instructor for questions and comments that seek clarifications and further elaborations. The accompanied lab session includes a certain number of labs that are carefully selected and designed by the instructor to reinforce the materials presented in the lectures. In each lab, the students are required to carry out certain experiments (individually or in groups) with real circuit components to build specific applications and instruments to do measurements, debugging, testing and verification.

There are many different methods to assess the learning outcomes such as homework assignments, in-class quizzes, mid-term and final exams, practical lab assignments, and sometimes a course project (Echempati, & Sala, 2013). These methods aim to assess the students in the following aspects: (a) their understanding of the theoretical concepts; (b) their capability to use the concepts they learned to solve problems; and (c) their capability of hands-on experience in experiments.

This traditional engineering educational method has its unique advantages, as described below.

- The instructor's delivery and the students' reception of the knowledge are focused on specific printed documents, e.g., textbook, printed notes, and handouts. This is helpful for the students to concentrate on the knowledge required for the course in a limited time period (a semester). It is also relatively easier for them to grasp the course outline. Students can further enhance their understanding of the concepts introduced in the textbook and explained by the instructor through practice of homework problems and lab exercises (Ernst, 2008).
- The instructor can carefully organize the study materials in a clear logical order, from simple to complex, from easy to difficult, and from old content to new content. Actually, most textbooks are organized in such a way. Thus, the students can solidly grasp the key problem-solving concepts and flexibly utilize it for new problems.
- Hands-on experiment capability and cooperation training can be obtained for the students through individual and team-work lab assignments and course projects, which are required to be completed in a fixed-time schedule.
- Course assessment can easily be carried out in various ways. Assessment items are designed to test the student performance against a set of learning objectives designated in the course outline. The specific learning outcomes required by ABET (ABET, 2011) are also measurable, e.g. the ability to design efficient assembly programs that satisfy a specific practical application.

This traditional engineering educational method also has its disadvantages. Some are described as follows.

- **The traditional approach can make it difficult for students to assimilate abstract concepts.** Like most engineering courses, microcontrollers require solid mathematical foundation, which involves many abstract concepts and new theories, e.g., efficient algorithms, memory caching and disk caching in microcomputers. In microcontrollers, most instructors have no option but to teach the abstract concepts of microcontroller hardware architecture and the assembly programming language according to what is given in the textbook. The students just receive them by rote memorization. They have little time to think in-depth for an understanding of the concepts; they have no imaginative breakthrough-point either. The reason is probably as follows. For most college students, although they have been using computers for quite a few years and they are familiar with playing computer games, they are actually encountering the computer internal hardware architecture and the assembly language for the first time in their studies. They possess no foundation of prior knowledge that can be used to decode the new concepts and create an image of understanding. As a result, the following undesirable situation might occur. The instructor may invest a large amount of his/her time and energy on class while the students, nevertheless, may be left feeling completely in the dark on the subject. Thus, some new educational technologies should be added for assisting students in their learning of such engineering curricula as microcontrollers.

- **The traditional approach does not offer enough time to make adequate linkage to industrial applications.** Engineering courses are mostly application-oriented. The students in this field should grasp enough hands-on experience during college that they will be able to apply it to industry when they graduate (ABET, 2011). However, this objective is often hard to reach due to the lack of time for discussing some useful advanced concepts and tools that are currently being used in industry. The reason can be summarized as follows: (a) The time allocated for a regular college course is limited in a semester. (b) In such a limited time, the instructor needs to deliver many basic concepts and techniques that are required by the course outline; he/she has not enough time to introduce new technologies that are valued by industry. (c) In this traditional education mode, the students excessively depend on the instructor and the text-book as the main source of knowledge; they are not able to further self-study the emerging industrial technologies based on the foundation knowledge they have learned. Hence, some new educational technologies should be added to make the learning process much easier so that the aforementioned academic goal can be reached.

INTERACTIVE SIMULATOR-BASED PEDAGOGICAL APPROACH

Due to the above deficiencies of traditional education in microcontrollers, we propose an interactive simulator-based pedagogical (ISP) approach to enhance the teaching and learning process. As reported by previous researchers (Rouvrais, & Gilliot, 2004), the learning process is clearly improved by the use of real dynamic simulations with the possibility for the users to change behaviors through parameter modification (e.g., variation of speed, pausing, data entries, zooming on results). In engineering curricula, such simulations include for example experimentation, demonstration of properties, validation of theoretical concepts, depiction of phenomena or examples. In the following, a simulator for the Intel 8051 microcontroller is briefly introduced along with the engineering education issues and the benefits of the ISP approach are then discussed.

The 8051 Simulator

There are many simulators, free or licensed, for the Intel 8051 microcontroller chip. Most of them can show the internal state of the registers, memory and the port pins while code is being debugged; they also have graphic representations of peripherals that can be used interactively to

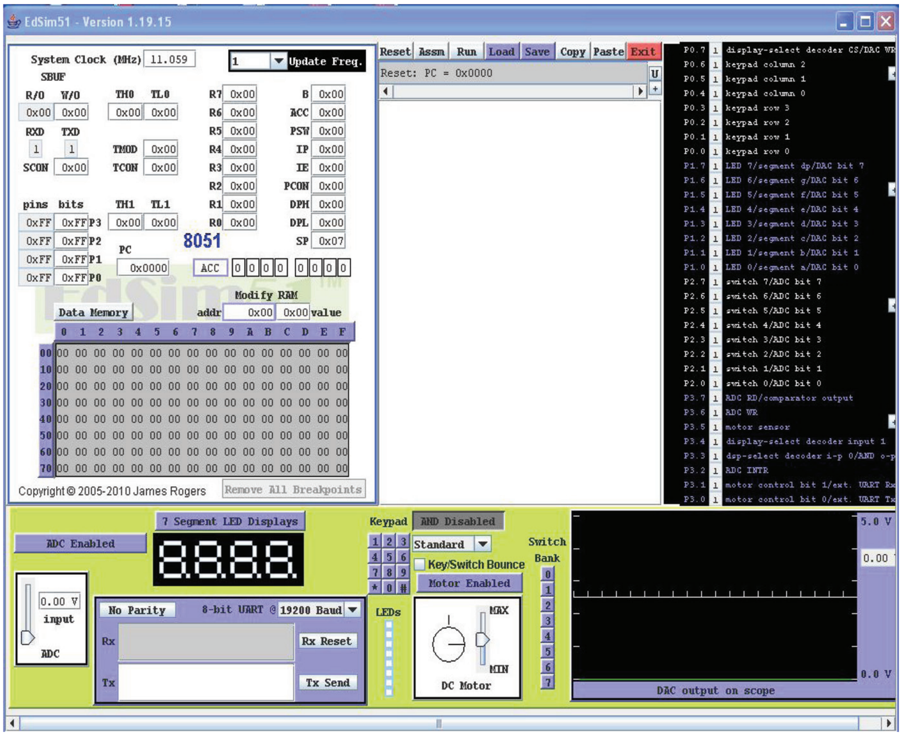


Figure 1. Screenshot of the EdSim51 Simulator Panel.

communicate with the 8051 chip. The teaching of microcontroller systems differs from institution to institution. At our institution, the curriculum specifies assembly language programming as a fundamental method for the design of microcontroller software. We recognized the advantage to students of free development tools so we chose "EdSim51" targeting the 8051 family of devices. EdSim51 is a free educational simulator from which students can learn most popular applications such as scanning a keypad, multiplex 7-segment displays, and controlling a motor and counting its revolutions. It is worthy to note that while EdSim51 has proved very successful, other simulation tools may have their merits.

The screenshot of the simulator panel is shown in Figure 1. The top left box gives the user access to all the Intel 8051's registers, data memory (click to change to code memory), allows the processor clock to be set, and shows the status of pins. The center textbox is a code editor where the user can either load an assembly program or write the code directly, and assemble the code in either single-stepped or entire-run style. On the right is a list of the 32 port pins and what each one is connected to. The bottom panel shows all the peripherals that are connected to the 8051 chip. The peripherals such as 7-segment displays, motor and keypad are allowed to be incorporated in the simulation. The LED bank and 7-segment displays are two widely used output devices in assembly programming applications. Many applications can be designed and simulated using the tool. Since it is a freeware, students can expand their work at home.

Engineering Education Issues and the ISP Approach

By using the interactive simulator-based pedagogical approach, the instructors are expected to create effective and exciting learning environments for students. It is well known that the goal of education is to prepare students to become active participants in creating knowledge and developing skills rather than passive recipients of information. The instructors should prepare the students to be able to apply what they have learned to generate new ideas, products, or processes, rather than just show what they have learned for a given subject. This is very critical to the student's future career development and lifelong learning, especially for engineering education, since the rapidly changing technologies require engineers to continually update their knowledge over their entire life. In fact, lifelong learning is an important topic in the ABET accreditation criteria 3(i) "a recognition of the need for, and an ability to engage in life-long learning" (ABET, 2011).

With rigorous disciplines like engineering, the ability to keep students motivated to learn new things is really challenging. Many similar questions have been and are being asked by educators and possible solution scenarios have been proposed (Felder, & Silverman, 1988; Hawks, 1998; So, & Brush, 2007; Hanson, 2012). At our university, the engineering students are a minority of the whole student population. There may be many different reasons that caused this result. This paper does not intend to provide an exhaustive analysis of the reasons; rather it will put forward some possible reasons and try to remedy them by using the proposed ISP approach. Based on our investigation, we find the following two major reasons that may cause students not to learn engineering (technology) curricula:

a. **Some discrepancies may exist, from teaching content to the instructor's presentation form, within present engineering education**. As mentioned earlier, most engineering courses, by nature, introduce abstract concepts, definitions, and models. Instructors deliver the learning contents primarily through speaking and words/symbols written on PowerPoint slides, handouts, and chalkboards. However, the majority of engineering students perceive the world by observing and gathering data through the senses (McCaulley, 1976; Yokomoto, & Ware, 1982). They like facts, data, and experimentation, rather than concepts and theories. In addition, based on our experience, most college students like visual-based teaching rather than verbal-based teaching. They feel bored with long verbal explanations. Their preferred presentation forms are visual demonstrations, including pictures, diagrams, flow charts, animations, and videos. As a result, students become bored and inattentive in class or even miss a class, and thus do poorly on tests, get discouraged about the courses, and drop from the curricula and change to other majors.

Solution Scenario

The ISP approach: Instructors can use the simulator involved in the ISP approach for the interactive demonstration of microcontroller hardware operations and assembly code execution; students can use it for helping doing their exercises and assignments and for improving their understanding of microcontroller concepts. The simulator panel can provide visual-based presentations. Through the interactive demonstrations, abstract concepts in microcontrollers could become concrete facts to students.

b. **Some gaps may exist between what students are taught and what they expect to learn**. Based on our investigation, many engineering students expected "concrete", "new" and "real" techniques - that they perceived may be currently used in industry - rather than delivery of abstract concepts and theories. As a result, the learners exhibited suspicion regarding their education: "Is this what I expect to learn for an engineering degree?" and "Are they (abstract concepts) useful for me to work in industry?" Hence, it is perhaps to be expected that the instructors are frequently frustrated by such class issues as low attendance, incomplete assignments, etc.

This negative result may be due to the student failing to appreciate the real value of what they are learning. What should we expect to learn from engineering education in a college? Is it just some facts ("dead" knowledge) or the ability to learn new things ("live" knowledge)? An Association of American Colleges report in 1985 recommended that the central theme of any curriculum should be to teach students "how to learn" (Wirth, & Perkins, 2008). This type of learning enables students to become lifelong learners, especially with the recent explosion of knowledge and technology. Students could utilize what they learned to discover what they do not know and to create new things. To reach this high-level learning objective, students must grasp the basic, abstract conceptual foundation knowledge. The foundation concepts must be understood before they can be applied to new applications. In other words, solid foundation knowledge is the prerequisite for creating new ideas. On the other hand, the techniques students believe to be current or future engineering practices will eventually become out-of-date. At such time, how will those with little ability to learn new things cope?

Solution Scenario

To fill this gap, two things must be done. First, the students must change their thoughts about "learning". This is a big project. The whole university, from the administration to the department and individual faculty members, must devote much attention to this. Second, professors should amend their traditional teaching style to try to cater to the student's particular needs, once the predetermined education requirements are completed. The proposed ISP approach could be instrumental in helping us reach this goal. We know that engineering education is application-oriented. It makes sense that students are interested in learning the most recent applications. However, it is too expensive to help students get hands-on experience through fashionable and real applications or even “not-so-real” experimental systems. Simulation is a good substitute for giving students as close as possible the real hands-on experience with very low cost, even no cost (Most microcontroller simulators are available freely on the Internet). Students can use their foundational knowledge to design different applications (which may be related to civil use or industrial use) and simulate them on the software simulator as well as do performance evaluations. Students can have their thoughts and ideas on a subject implemented through simulations. This, in turn, greatly activates their learning interests in the subject, and hopefully reduces their boredom with the class.

There are many other advantages to the ISP approach. For example, with regard to the aforementioned “lack of time” problem, in traditional engineering education styles, due to the limited time allocated for a regular course, it may be difficult for the instructors to introduce new technologies that are valued by industry. However, based on our experience, the ISP approach can solve the “lack of time” problem. It provides the visual-based teaching instead of verbal-based teaching. Some abstract, complicated concepts or processes that are hard to be understood under the verbal-based teaching (even after lengthy explanation) can be easily understood by using the visual-based teaching in a very short amount of time. Specifically, for the microcontroller CPU (central processing unit) operation, the simulator can show students the internal value change of the registers inside the CPU for the abstract register operation. For the abstract assembly program execution, the simulator can show students the step-by-step instruction execution and its corresponding change inside the memory.

Clearly, the students can immediately understand what’s going on for a subject through the interactive demonstration. By using the ISP approach, we found that it is always possible to find extra time to do some interesting civil or industrial projects, cater to students’ particular needs (e.g., Project 3 in fourth section) and thus activate their learning interest. It is worthy to note that, for most microcontroller experimental (evaluation) systems with real circuit components, one can only watch the final results through the output display devices (e.g., LEDs, seven-segment displays, LCD); little intermediate results and internal change of the CPU functional units can be watched. Some devices provide the capability to step-in, see internal values, and track variables, but they need additional hardware. Moreover, simulators used by the ISP approach are beneficial to learning through other aspects such as their reduced expense, easy availability, and lower setup time (important for not stalling the lecture).

In summary, the ISP approach can be incorporated into a variety of educational settings. Instructors can use it to complement their lectures for interactive demonstration. Instructors can also use it to develop laboratory-based activities and for course project based activities, which involve student team-work training, lecture content reinforcement, and comprehensive knowledge application. Finally, students can play with the simulator at no cost on their own time, either at their homes or at school, for their study assignments, laboratories, or other extra-curricular activities.

DEMONSTRATION EXAMPLES

In this section, we demonstrate several examples to show how the simulator is used for enhancing teaching and learning, based on selected contents from the microcontroller course.

Project 1

Specification: Use the 8051 simulator and write assembly code to multiplex the numbers 1, 2, 3, 4 on the four 7-segment displays Disp3, Disp2, Disp1, Disp0 respectively (See Figure 1).

This project requires that students be familiar with the logic circuit of the 8051 simulator and write the assembly instructions to implement the goal. The implementation process involves both microcontroller hardware architecture and assembly programming skills. In completing this project, the students showed great interest in their microcontroller studies through classroom discussions and team-work experience. Through the step-by-step execution of code, the students obtained omnidirectional in-depth understanding on the internal operation of the assembly instructions, value changes of related ports, and graphical representations of the 7-segment display outputs. In the screenshot of Figure 2, the current instruction executed is at 0021, the command code of number 4 (i.e., 1001 1001B) has just been sent to Port 1. This can be seen by P1 (with value 99) on the left side of the panel. On the design, control signals P3.4 = 0 and P3.3 = 0 select the device Disp0. This can be seen by the P3 value “E7” (i.e., 1110 0111B, where P3.4 = 0, P3.3 = 0). Thus, the number 4 is seen on Disp0.

Project 2

Specification: Implement a counter on the simulator to continuously display numbers 0 to 9 on one 7-segment display. Each number waits a delay time and displays the next number. After reaching number 9, it waits the delay time and goes to display number 0. Use timer technique to implement the delay.

The project involves an important aspect of microcontrollers: Timer Operation. By using the ISP approach, the students can enhance their assembly programming skills through loop operation, subroutine and function call. A screenshot of the implemented counter is shown in Figure 3, where

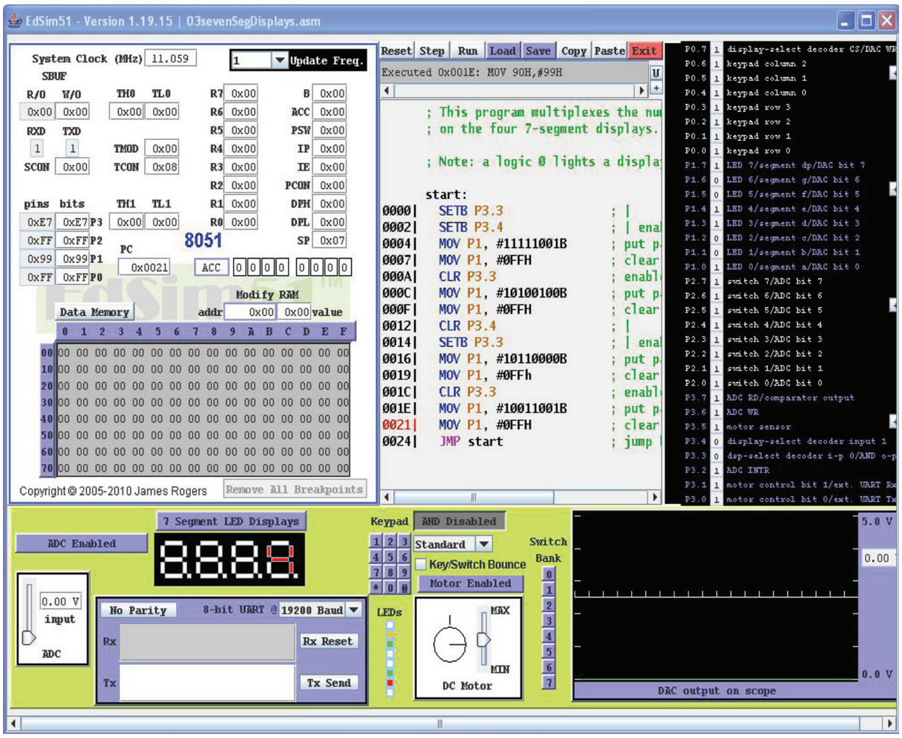


Figure 2. A screenshot of the simulation result for Project 1.

number 6 is being displayed. The loop operation involves an iteration structure for problem solving. Based on our experience, the students often feel the sequence structure to be intuitive but somehow struggle with the iteration structure. Through the ISP approach, the students can observe the iteration structure step-by-step on the simulator. For example, in the AGAIN loop of Figure 3, the students can clearly see the instructions between addresses 006D and 007C to be repeated until the value of register R7 becomes 0 (Initially R7 = 10).

Project 3

Specification: Design a three-zone burglar alarm system using Intel 8051 I/O ports. If any zone is intruded, the system will activate the ALARM and indicate which zone is intruded. If more than one zone is intruded, the system can also indicate which zones are intruded.

This project shows a practical application for the microcontroller. It requires that students understand how to design a burglar alarm system using the 8051 microcontroller including its hardware connection, software implementation, and functional testing on the 8051 simulator. The students can benefit a great deal from the project, such as becoming familiar with the course contents, obtaining

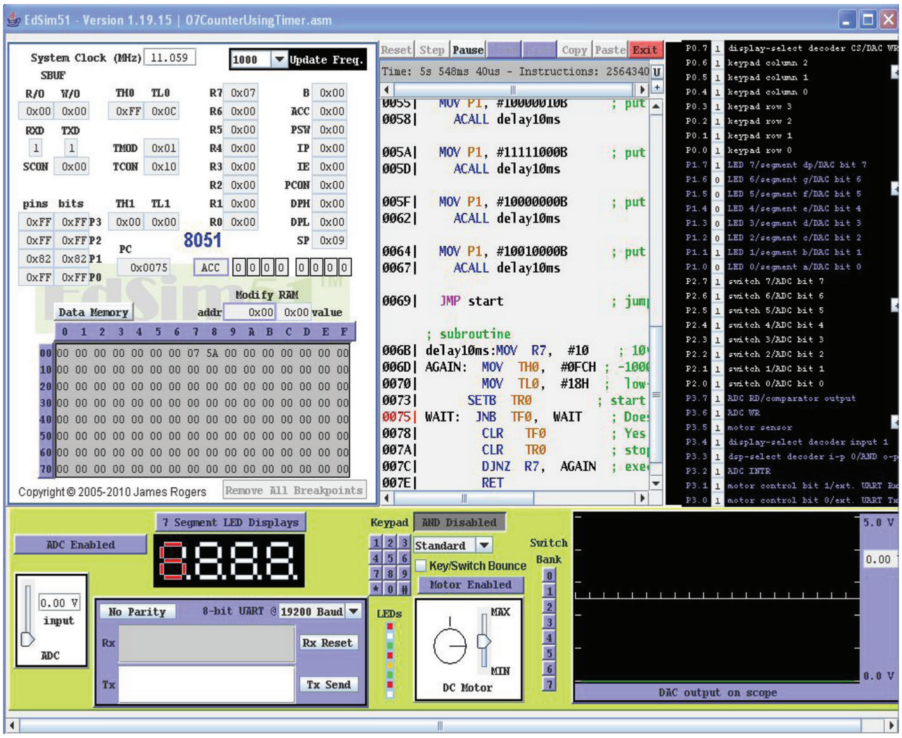
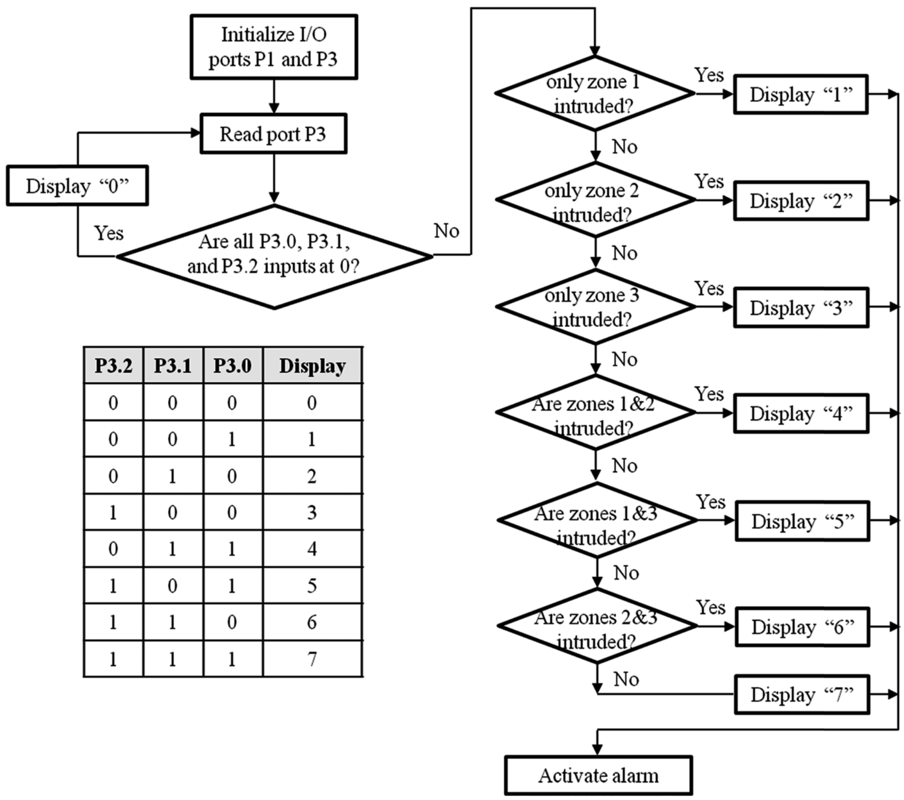


Figure 3. A screenshot of the simulation result for Project 2.

hands-on experience in design and implementation of a microcontroller application, activating their learning interest and curiosity in microcontrollers, and capturing team work experience. The student-teams need to show their work by both hardware design and software design.

For the hardware design, the student should draw a hardware-connection diagram for the burglar alarm system. Under normal conditions, the ALARM is OFF and a 7-segment display shows "0". If one or more zones are intruded, the sensor(s) will drive a logic signal to the corresponding port pin(s), then the ALARM is activated to sound and a 7-segment display shows a corresponding number. A possible design is described as follows. If any of the zones 1, 2, and 3 is intruded, then the corresponding number (1, 2, or 3) is displayed; If zones 1 & 2 are intruded, then "4" is displayed; If zones 1 & 3 are intruded, then "5" is displayed; If zones 2 & 3 are intruded, then "6" is displayed; If zones 1 & 2 & 3 are intruded, then "7" is displayed.

For the software design, a flow chart and the corresponding assembly code should be completed. One solution is shown in Figure 4. The code continuously polls the three input zones. If one or more zones are intruded, then the ALARM is sounded and the 7-segment display shows a corresponding number, indicating the intrusion of the zone or zones.



P3.2	P3.1	P3.0	Display
0	0	0	0
0	0	1	1
0	1	0	2
1	0	0	3
0	1	1	4
1	0	1	5
1	1	0	6
1	1	1	7

Figure 4. Flow chart of the burglar alarm system.

A screenshot of the implemented burglar alarm system is shown in Figure 5, where it displays "5" and sounds ALARM, indicating that zones 1 and 3 are intruded.

ASSESSMENT RESULTS AND DISCUSSION

Assessment is an effective and necessary step to evaluate a new pedagogical approach. This is useful for the continuous improvement and perfection of the new pedagogy. In this section, we perform a questionnaire-based assessment and an outcome-based assessment to evaluate the effectiveness of the ISP approach.

Questionnaire-based Assessment

The students were given a questionnaire and were informed that it was anonymous and aimed at improving their learning process. The questionnaire contained 6 questions about the simulator and its effect on the teaching and learning process, as shown in Figure 6.

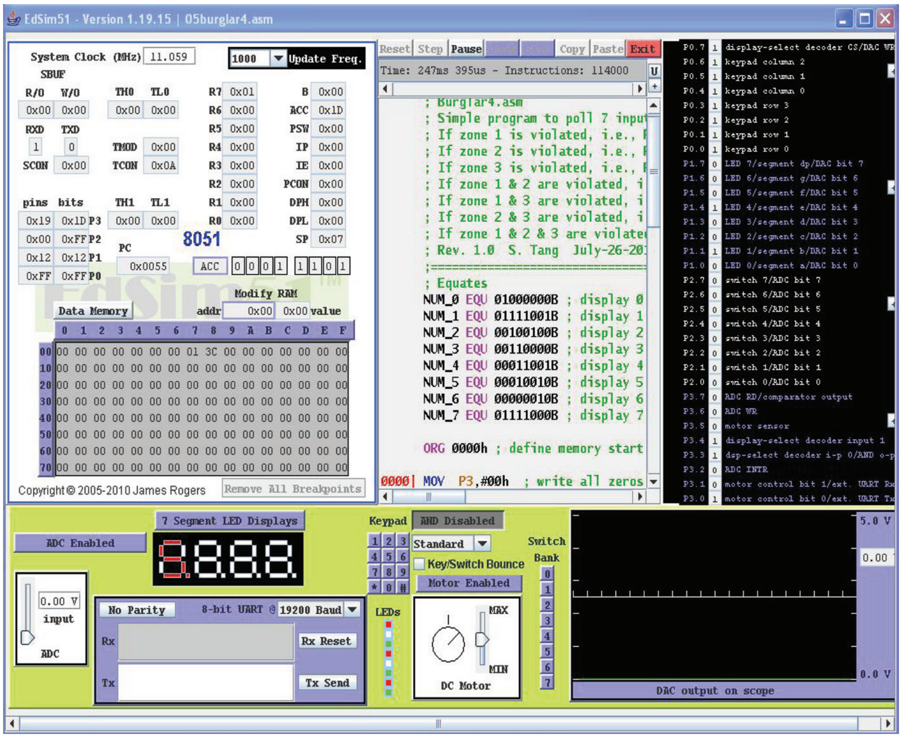


Figure 5. A screenshot of the simulation result for Project 3.

The questionnaire was conducted at the middle of a semester with 16 anonymous surveys returned. The assessment results are summarized in Table 1. For example, for the 1st question, 62.5% of returned surveys said that the interactive simulator is "very helpful" for their understanding of the lecture contents; 25% of returned surveys said "helpful"; 12.5% of returned surveys said "No effect"; and no one reported a "Negative effect". Their comments for the ISP approach are many and varied. The following lists some. One student commented "I am not good at understanding abstract process, the simulator can show me the detailed process, and through it the lecture becomes easy." Another student said "It's awesome that I can see the internal change of registers and memory locations." A student who chose "very positive" for the 4th question wrote "The interactive demonstration makes me feel comfortable in understanding the lecture in class, and I don't take much time to do homework."

Outcome-based Assessment

For the outcome-based assessment, we performed two pairs of quizzes (Quiz 1 and Quiz 2; Quiz 3 and Quiz 4) with all multiple choice problems for the entire class of 20 students. Quiz 1 and Quiz 2 correspond to the contents from different sections of the same chapter. Quiz 1's section was

1. How do you assess the effect of the interactive simulator on your understanding of the lecture contents?
   (1) Negative effect (2) No effect (3) helpful (4) Very helpful
   Briefly explain your answer:
2. How do you assess the effect of the interactive simulator on your completion of the study assignments (e.g., home work, lab exercises)?
   (1) Negative effect (2) No effect (3) helpful (4) Very helpful
   Briefly explain your answer:
3. Where do you often use the simulator for assisting your learning?
   (1) Never use (2) Only at school (3) Only at home (dorm) (4) Both school and home (dorm)
   Briefly explain your answer:
4. How do you assess the effect of the interactive simulator (performed at lectures) on your attendance to this class?
   (1) Negative effect (2) No effect (3) Positive (4) Very positive
   Briefly explain your answer:
5. How do you estimate the overall effect of the interactive simulator on enhancing your academic achievement in this class, based on your perception so far?
   (1) Not enhance (2) Not sure (3) Enhance (4) Highly enhance
   Briefly explain your answer:
6. How do you recommend the interactive simulator for teaching and learning in this class?
   (1) Not recommend (2) Don't care (3) Recommend (4) Strongly recommend
   Briefly explain your answer:

Figure 6. The questionnaire for assessing the ISP approach.

delivered without using the ISP approach and Quiz 2's section was delivered by using the ISP approach. Each quiz has 10 multiple choice problems. One point is gained for the correct answer and zero is gained for a wrong answer. The two quiz problems were carefully selected to have a similar level of difficulty. To decrease the randomness of the assessing results, we repeated a similar experiment in another chapter with Quiz 3 and Quiz 4. Quiz 3's section was delivered without using the ISP approach and Quiz 4's section was delivered through the ISP approach.

The test results with a normalized grading system are shown in Table 2. It can be observed that the result of Quiz 1 is not satisfactory. Only 12.5% of students received an 'A'; a total of 43.75% of students received an 'A' or a 'B'; and a total of 75% of students got an 'A', 'B', or 'C'. There were 12.5% of students with a grade of 'D' or 'F', respectively. However, from Quiz 2 results, which were obtained by using the ISP approach, one can find that the student scores were greatly improved. A total of 31.25% of students received a grade of 'A'. A total of 75% of students received an 'A' or a 'B' and a total of 93.75% got an 'A', 'B', or 'C'. Only 6.25% of students got a grade of 'D'; and no one failed the test. A similar result can be found from Quiz 3 and Quiz 4.

The above tests show that the ISP approach considerably improves the student academic achievement. Therefore, the effectiveness of the ISP approach in enhancing teaching and learning

Q # 1	Negative effect	No effect	helpful	Very helpful
Result	0	12.5%	25%	62.5%
Q # 2	Negative effect	No effect	helpful	Very helpful
Result	0	6%	50%	44%
Q # 3	Never use	Only at school	Only at home (dorm)	School and home (dorm)
Result	0	18.5%	12.5%	69%
Q # 4	Negative effect	No effect	Positive	Very positive
Result	0	25%	56%	19%
Q # 5	Not enhance	Not sure	Enhance	Highly enhance
Result	0	13%	31%	56%
Q # 6	Not recommend	Don't care	Recommend	Strongly recommend
Result	0	6%	38%	56%

Table 1. Questionnaire-based assessment results.

was roughly assessed. It can be expected, with a larger class of student population and/or more test samples, more accurate assessment results will be obtained.

One difficulty (or weakness) of performing the outcome-based assessment is that the testing problems of Quiz 1 (or Quiz 3) and Quiz 2 (or Quiz 4) are hard to design with exactly the same level of difficulty. An alternative is to apply same testing problems to two different groups of students. But another problem arises: how to obtain two separate groups of matching potential ability for the experiment. Moreover, this way may discourage the group by not using the ISP approach. Fortunately, it is not necessary to quantitatively evaluate the accurate advantage of the ISP approach over the traditional approach. To demonstrate the benefits of using the ISP approach, the above rough assessments are sufficient to show its value.

grade / st. no. / quiz	A	A, B	A, B, C	D	F
Quiz 1	12.5%	43.75%	75%	12.5%	12.5%
Quiz 2	31.25%	75%	93.75%	6.25%	0
Quiz 3	12.5%	43.75%	81.25%	12.5%	6.25%
Quiz 4	37.5%	81.25%	93.75%	6.25%	0

Table 2. Outcome-based assessment results.

CONCLUSIONS

The traditional engineering educational method in microcontrollers has its unique advantages but also serious drawbacks. In this work, we analyzed the features of the traditional engineering education method and investigated two major reasons that may cause students not to learn engineering curricula, and proposed an interactive simulator-based pedagogical (ISP) approach for enhancing the teaching and learning process, without compromising (conversely, reinforcing) the depth or breadth of course material. Demonstration examples were presented based on selected microcontroller course contents. The effectiveness of the ISP approach was assessed from both the questionnaire-based assessment and the outcome-based assessment. The assessment results showed that an overwhelming majority of students enjoyed the ISP approach and strongly recommended applying the ISP approach to teaching and learning.

It is worthy to note that the ISP approach does not eliminate the need for the hands-on experimental experience with real electronic circuits and devices. On the contrary, the ISP approach is able to strengthen the real experimental experience through some unique features that the latter does not have. Most engineering courses are currently accompanied with a lab session. In fact, the combination of the ISP approach and the real experimental counterpart can result in a more powerful learning experience. Note also that although the ISP approach is presented through a specific course of Intel 8051 microcontroller, the proposed approach has more general principles, which can be directly applied to other Electrical and Computer Engineering curricula as well as easily extended to other engineering disciplines.

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