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# AN EFFICIENT MICROCONTROLLER COURSE WITH AN AFFORDABLE AND EASY TO USE DEVELOPMENT SETUP

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**ABSTRACT**: Microprocessors/Microcontrollers have been widely used in electronic products so they have been taught to electrical, computer and mechatronic engineering undergrads. Since medical electronics devices are also use microprocessors/microcontrollers, biomedical engineering undergrads should have knowledge and programming experience in microcontroller based systems. Due to this fact microprocessors/microcontrollers have been taught as a 5 hour/14 week lecture and laboratory course at the 5th semester in Başkent University Biomedical Engineering Program Ankara, Turkey.

The main difficulties in microcontroller programing course for a multidisciplinary program such as biomedical engineering are insufficient allocation in the curriculum, shortage of lab space and budget constraints. Also the complexity of the development setups and spending too much time to understand the setup instead of experimenting it are problems for students and instructors. Students lose their attraction while spending time to effectively use of development tools. For this reason an efficient microcontroller course with its laboratory and a project work is developed which puts emphasis on learning the futures of microcontroller based system and applying many instrumentation designs. In order to increase the efficiency of the course an affordable, easy to use and modular development board with a free compiler for 2K program code and a free programmer software are used and important improvements are applied.

Throughout the paper the details about the lectures, laboratories and development tools and their improvements are described. The methodology for active learning and syllabus design and determination of learning objectives are discussed. The efficiency of the course is tested by overall grades and responses of students. A remarkable success observed on the results.

**Key words:** Microcontroller education, instrumentation, biomedical engineering, high-level design tools

## INTRODUCTION

A microprocessor is a single integrated chip which can perform computation of programs to control a microprocessor based system. Although microprocessors have arithmetic, logic, control and timing unit and registers inside they are not capable of working alone because microprocessors need memory, input & output ports and bus systems in order to work properly. That's why a microprocessor based system should include at least those components. As a result microprocessor based system require many chips on a considerably large printed circuit board (PCB) with a power supply. The total cost of a microprocessor based system becomes high for a simple electronic device (Hamrita & McClendon, 1997; Hanson, 1981).

For a wide range of application microcontrollers are preferred instead of microprocessor based systems because with the development of integrated chip technology they become cost efficient and practical for many applications. Microcontrollers are a simple microprocessor based system so they have their own microprocessor, memory and input & output ports in a single chip also some of them may include many electronic circuits such as operational amplifiers, signal generators, analog to digital converters, sensors etc. Although they have simple

processing power many interface chips are included in a microcontroller so they are widely applied in almost all field of electronic products.

In microprocessor related course the main course objectives are usually to learn the microprocessors architecture and interface, to experience programming and to do practical applications. It is possible to cover these objectives by using a microcontroller. (Mayer, Jackson, & Lockley, 1995) Because of the complexity and high cost many universities have replaced their microprocessor related course to a microcontroller related course, by that way similar course objectives can be achieved with a more practical and efficient way. (Hamrita & McClendon, 1997; Ibrahim, 2014)

Microprocessors/Microcontrollers have become pervasive in many electronic products including biomedical electronic devices so it is important that biomedical engineering undergrads have experience with microprocessors/microcontrollers. Due to this fact there is a microprocessor course in Başkent University Biomedical Engineering Department, Ankara, Turkey and the course have been thought using a microcontroller since 4 years.

A microprocessor/microcontroller design which is capable of performing a particular job is called an embedded systems. To design an embedded system there should be an integrated development environment (IDE) and a programmer adaptor and software. An IDE consist of a smart text editor, compiler and debugger. These tools in IDE are for engineers to write programs, to compile it, generate a final form for the program that is suitable for execution on target microcontroller and to program the microcontroller. A program adaptor is a small hardware interface between IDE and microcontroller and a programmer software is a PC software which control programmer adaptor. There are many IDE and programmer adaptor alternatives for microcontroller applications. (Hass & Su, 2012)

Ongoing improvements in microcontroller technology lead to fast, flexible and low cost solutions, but increasing complexity challenges for students and instructors. Now microcontroller courses are usually difficult for students to understand and also difficult for professors to teach.

The reasons for a microcontroller course is hard and complex are:

- A microcontroller is a complex systems with a detailed, brand and model specific datasheet, programming reference and family reference materials which are over one thousand page.
- The specific integrated development environment and programmer adaptor and software for microcontroller application development require specific knowledge.
- A microcontroller design requires both programing and electronics knowledge.
- Microcontroller applications requires and embedded system design with some extra electronic components which requires extra knowledge in application domain.
- Microcontroller education requires a significant hands-on laboratory experience.

In order to deal with all these difficulties professors should spend a considerable amount of time for course preparation. Developing laboratory experience and configuring IDE for microcontroller education also requires even greater time. Even with a good course preparation it is almost always difficult for educators to teach and students to learn all of these subject in the short hours assigned to the course. (Ghosh, Mangat, Shinde, Date, & Sharma, 2013; Peng, 2009; Reese & Jones, 2010) In order to learn the application aspect of microcontrollers, students should know extra information which is specific for the used microcontroller, IDE and programmer adaptor. Due to all these facts a typical course can only focus on microcontroller architecture, assembly language and few very simple application (Mayer et al., 1995; Peng, 2009), but it is also important for students to have the ability to design and practice a microcontroller based system for different applications.

In order to design an effective microcontroller course the objectives should be defined according to the time, resource and purpose constraints.

According to the literature review and professors, students and employers responses it is important to practice applications than to learn the details of microprocessor organization for our biomedical engineering students we design the course. In this paper we report the course objectives and course syllabus. We described how we choose the microcontroller, IDE platform, programmer and demo board according to described constraints. We report the details of them. We define the advantages and disadvantages of them. One of the important disadvantage of demo board is only one peripheral component can easily connect to it because of its interfaces allow only one peripheral device. This is a big problem because for a simple sensor and inductor application it is only possible to connect one of them. So we design and manufacture a practical display board which can be easily interface with the demo board. With the display connection to demo board it is possible to apply many sensor to a practical, USB connected power supplied, cost effective and easy to use platform for programming

and testing the microcontroller application. We report the laboratory experiments. To demonstrate the improvement of the course we report and discuss some of the student's opinions course initial results of course objective achievements. Finally we define the future plans.

# COURSE DESIGN

Students who are enrolling to this course are sophomores who should already completed Circuits and Systems, Electronics, Computer Programming I-II and Electromagnetics Theory courses, and also they should complete the laboratory courses for Circuits and Systems, Electronics, Computer Programming I and II. The only pre-requisite for this course is Digital Design course and its laboratory. So sophomores for this course have some background on electronics, programming and digital design also they have hands-on laboratory experience on these subjects.

## Course Objectives

In an efficient microcontroller course with the time and resource constraints, course objectives should be:

- To learn,
o   The basics of computer organization and microprocessors.
o   The fundamentals of microcontrollers.
o   The main peripheral devices used in microcontroller based system.
o   Some extra peripheral devices for applications of microcontroller based system.
- To practice,
o   Applications as possible as many using microcontrollers.

## Weekly Course Plan

1-   Microprocessor definition, components, properties and working principles.
2-   Microprocessor based systems.
3-   Microcontroller definition, components, properties and working principles.
4-   Microcontroller based circuit design (Embedded Design).
5-   Editor, Compiler and Debugger.
6-   Embedded design with a well-known microcontroller.
7-   A high level programming language and it properties.
8-   Microcontroller based port activation and using applications.
9-   Microcontroller based simple control and indicator applications.
10-  More on high level programming language and it properties.
11-  Display and microcontroller applications.
12-  A/D converter applications using microcontroller.
13-  Interrupts and microcontroller applications.
14-  Serial communication protocols and microcontroller applications.

## Course Materials

In order to achieve the course objectives course materials should be organized as the following:

- A well-known, widely used and easy accessible microcontroller should be selected.
- A low cost, efficient and practical Development Setup with many application possibilities should selected.
- Resources for course, microcontroller, development setup and design examples should be easy accessible and reliable.

A low cost, efficient and practical Development Setup should have the following properties:

- IDE with a widely used programming language and its compiler.
- A practical Programmer and Demo Board which can be connected to USB without any extra supply.
- Lots of peripheral connections of sensor, controls and indicators for different application.
- In the Demo Board there should be a slot for interface with peripherals which makes the demo board a single board with the peripherals, no extra supply, no extra wiring etc.
- They do not require bread board so no wiring and connection problems which eliminates many errors.
- Resources: manuals, textbooks, example codes and designs.
- Development setup should be cost effective so students can use it in their home.

- Interfaces should be reliable and stabile for eliminating errors.

# DEVELOPMENT SETUP

In order to organize the development setup first is choosing the microcontroller. There are many constraints for choosing the microcontroller. It should be well known so students can access many applications, examples, program code. Professors and students should access the microcontroller and its family however some brands are not easily supplied in our country. C programming language is universal and the most used high level language for microcontrollers so it should support C language. According to all above constraints we decided to use PIC microcontroller of Microchip®. The second is choosing the IDE and programmer compatible with PIC microcontroller. The last is deciding the Demo board which is preferable for microcontroller applications.

**MikroC Editor, Compiler and Debugger**

Since we choose PIC microcontroller we should choose a development setup which is compatible with PIC microcontrollers. We have some constraints as described in course design section than we choose the products of MikroElektronika®. For the programming language we choose MikroC which is ANSI C programming code and MikroC Pro for PIC is an editor, compiler and debugger for PIC devices from MikroElektronika®. It is powerful compiler with advanced optimizations, lots of hardware and software libraries. It has a comprehensive help file and lots of ready-to-use examples designed. Its license is free for 2K of program which is very important because students can use it in their homes. ("MikroC Pro for PIC," 2015) Usually this kind of software's are expensive and students only able to use them in school. There is a 644 page manual, MikroC Pro for PIC Manual, for programming definition and examples which we considered one of the text book for our course and is very resourceful for students.
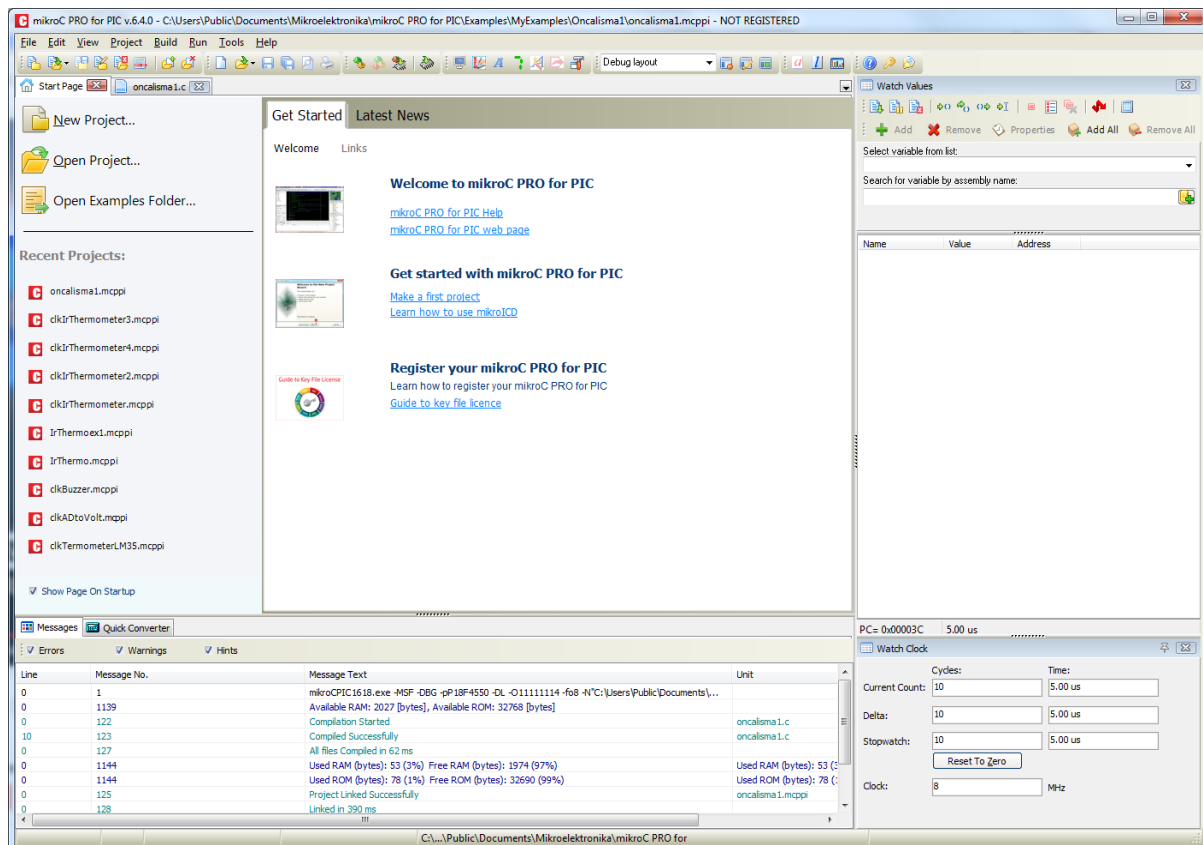


**Figure 1. The Screen Shoot of the MikroC Pro for PIC IDE.**

The Computer Programing I, II and their laboratory courses are mandatory for our students and in those courses C and C++ are thought as a programming language so our students already know the C programming language. According to the surveys taken over the past decades have shown that about %80 of the embedded projects uses C and C++ . (Barr, 2009)   Due to this fact C language for primary programming language seems reasonable. And MikroC is powerful and practical alternative. Also in MikroC Pro IDE it is possible to compline assembly language as well.

MikroC programming language is a ANSI C based programming language to control the PIC microcontrollers and in the MikroC Pro for PIC IDE there are several ready to use code routines which are called libraries which helps programmer to write programmers in a simple and fast way. A user could also create a custom library for custom purposes also codes could be written in PIC assembly language which is the human understandable version of machine language. Some of the build in libraries are given in Table 1.

**Table 1. Some of the MikroC Programming Language build in libraries**

| Library Name | Description |
|---|---|
| ADC | Analog to digital conversion library |
| Compact Flash | Compact flash card control library |
| EEPROM | EEPROM memory control library |
| Graphic LCD | Graphic LCD control library |
| LCD | LCD control library |
| I2C, SPI | I2C and SPI Serial communication protocol control library |
| Keypad | Keypad control library |
| Ethernet | Ethernet communication library |
| Button | Button control library |
| Multi Media Card | Multi Media Card control library |
| One wire | One wire communication protocol library |
| PWM | Pulse width modulated signal output library |
| Sound | Buzzer sound control library with PWM and pulse signal output |
| UART | UART communication protocol control library |
| USB HID | USB HID communication protocol control library |
| Standard ANSI C | Standard ANSI C libraries like math, constant etc. |
| Other | Other many MikroC specific libraries. |

**Pic Clicker Development Board**

As a demo board and programmer we decided to use PIC Clicker Development Board of MikroElektronika®, because it is compatible with MikroC Pro for PIC IDE, it can be connected to a PC with a USB port for programming, it costs only 19$ for the product and can be supplied from the website of producer with an international shipping cost of 9$ which is really cheap and the shipping time is one week. Also there are some Turkish companies who are selling the product with similar price. ("PIC clicker," 2015) It has a PIC18F47J53 microcontroller with many application possibilities, and a microbus for Click Boards which are application purpose sensor and control boards with over than 100 different possibilities. ("Click Boards," 2015) Click Boards are very useful application add on boards, in the laboratory example section some examples with their functions are shown. They can connect to MikroBus port easily. With these add on boards application board can be connected without any wiring which is very time consuming if wiring is needed. Pic Clicker Development Board is both for introductory and advanced application by using different Click Board.
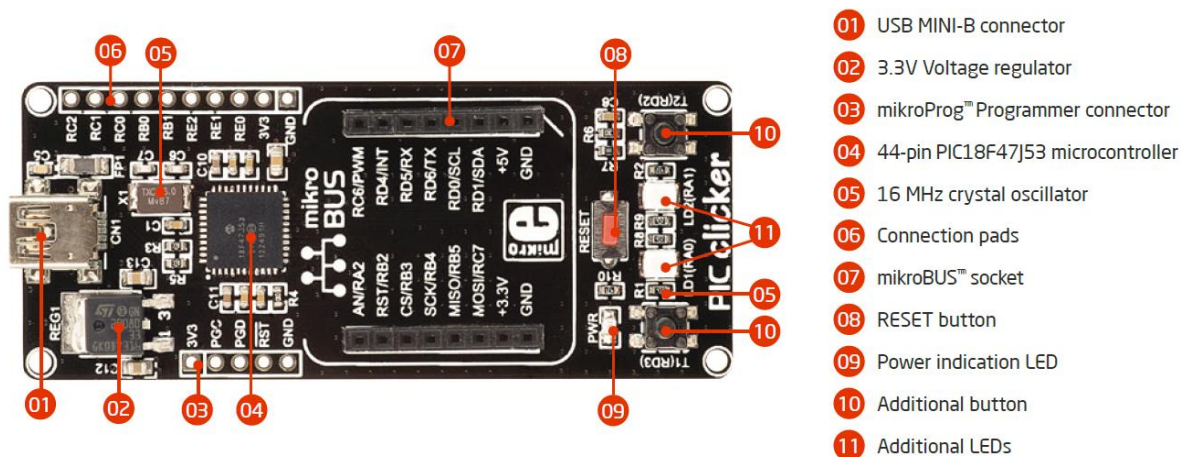


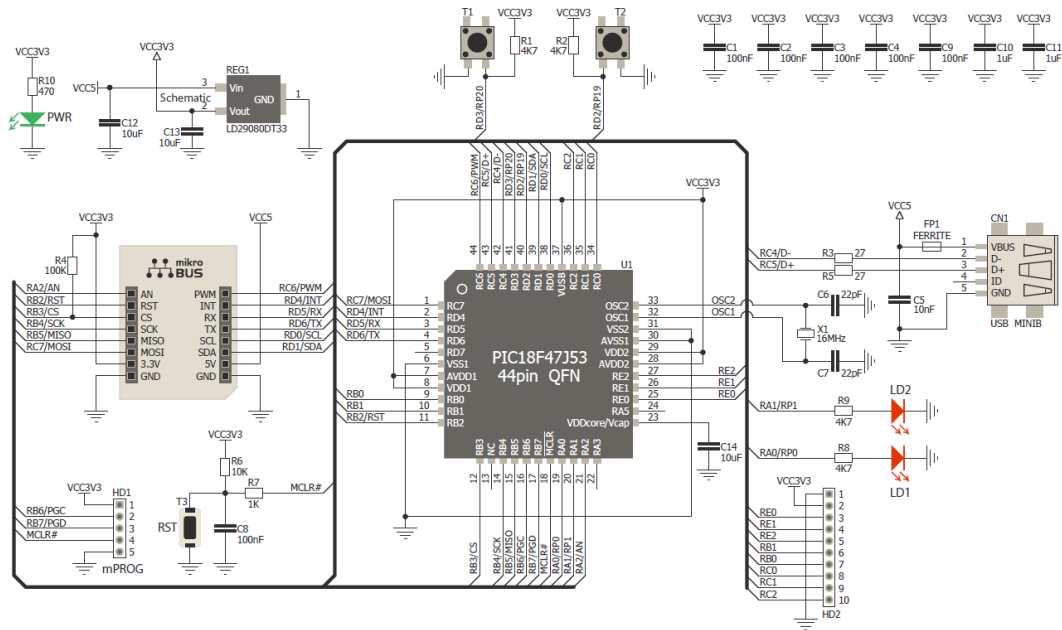**Figure 2. PIC Clicker And Its Components ("PIC clicker," 2015).**

**Figure 3. PIC Clicker Circuit Schematics ("PIC clicker," 2015).**

**LCD Display for Pic Clicker**

PIC Clicker Development Board and MikroC IDE are efficient, practical and cost effective microcontroller application development solution and MikroElektronica® produce over 100 click boards for different applications. But PIC Clicker has some drawback. It has only one port (Mikro Bus) for click boards so for a simple design with a sensor and display it is only possible to mount the sensor. Also MikroElektronica® does not produce a display solution for PIC Clickers. For this reason we develop our display solution which can connect to extra ports other than Micro Bus port. The simple 8 character liquid crystal display (LCD) costs 6$ and produced by Fordata Electronics Co. Ltd. China. (*Datasheet: Fordata Electronics Co. Ltd., FDCC0802C-RNNYBH-16LE, Specification Character Type Dot Matrix Module*, 2008) The LCD controller is a commonly used alphanumeric dot matrix LCD controller and the control interface and protocol is a de-facto standard for this type of display. The character set of the controller includes ASCII characters. (Wilmshurst, 2010)

The LCD board can be connected to other unused ports by that way Mikro Bus port still available for Click Boards.
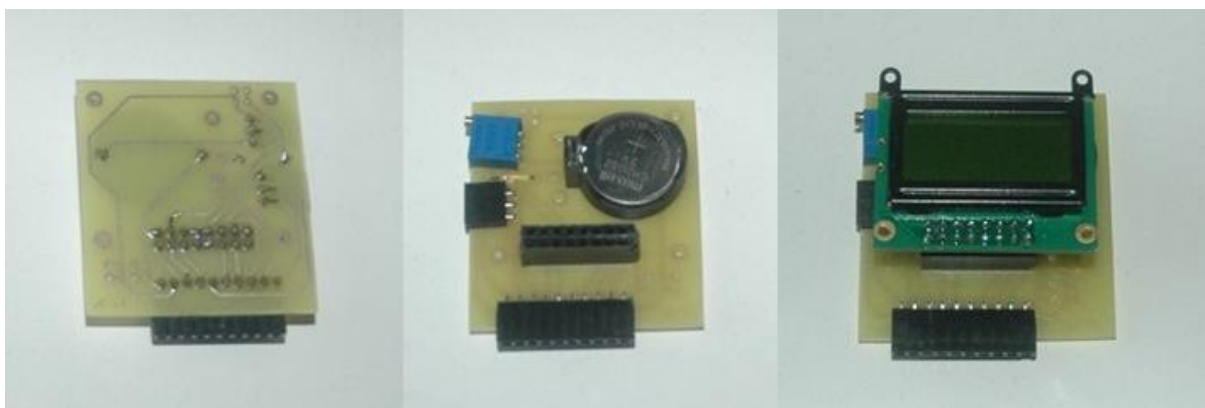


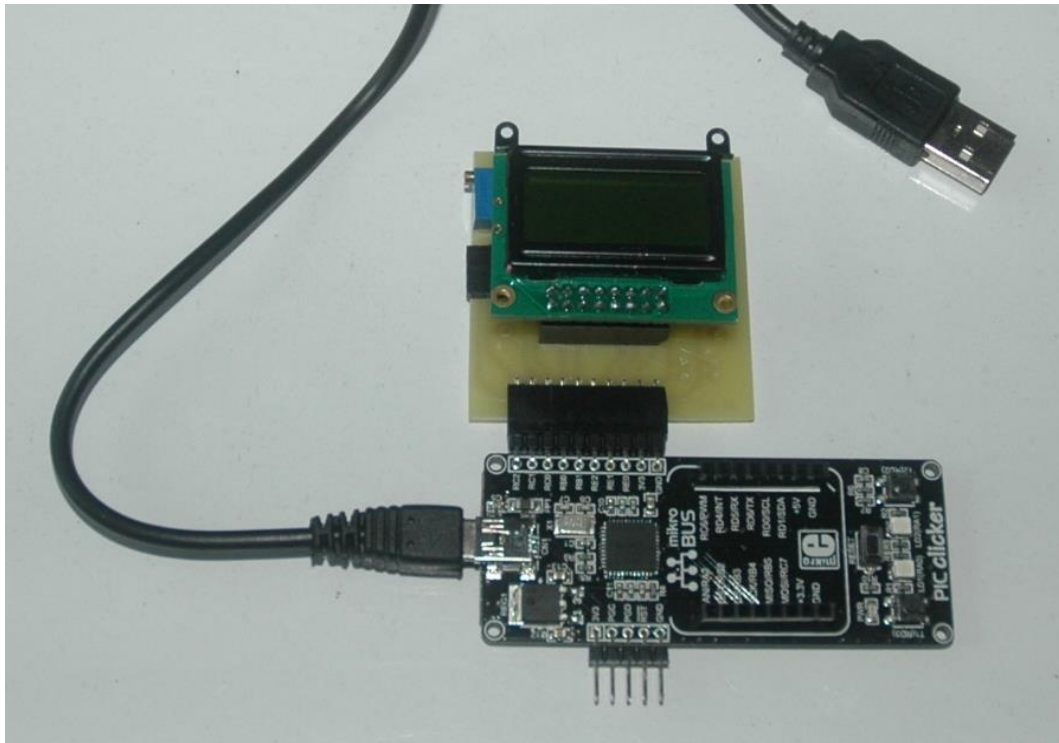**Figure 4. Designed And Manufactured LCD Display Compatible With PIC Clicker.**

**Figure 5. Development Setup consist of PIC Clicker Programmer and Demo Board and LCD display.**

**Pic Clicker USB Programmer**

After the program code has been written it needs to compile to form the executable machine code, which is name .hex code. This code is also a file and compiler produce it if there is no syntax error in the code. This file should be transferred to microcontroller's program memory so microcontroller could be able to run this code from its program memory, this transfer operation is usually called burning or programming. Programming is usually done with a specific adaptor which is the connection between microcontroller and PC and programmer software which runs on PC. By using PIC Clicker as a programmer and Demo Board we do not need an extra adaptor, but we still need a programmer software to send the .hex file to microcontroller. MikroC Pro for PIC IDE has a programmer software with required driver for PIC Clicker. The microcontroller can be programmed with bootloader which is preprogrammed by default for PIC Clicker. To transfer .hex file from a PC to microcontroller (mikroBootloader USB HID) is used which is shown in Figure 6.



**Figure 6. Programmer Software in MikroC Pro for PIC.**

# LABORATORY EXPERIMENTS

The laboratory experiments are designed for the students so they can program a microcontroller and test the program. The topics covered in laboratory experiments can be categorized as features and properties of development tools, addressing modes, mathematical operations, interfacing concepts and applications.

For each laboratory experiments a custom prepared handouts were provided. In this handouts there are the objectives, explanation and introduction information for the experiment also a preliminary work is expected from students which consists of pseudo codes and questions. Before each laboratory a quiz is asked to the students about the laboratory preliminary work and theory concepts. This handouts are for students to work before laboratory and optimize the laboratory hours. While laboratory session professor and teaching assistant helps and questioned students about their designed and evaluate their performances. At the end of the laboratory each students and sometime groups with two students prepared a report about their design and explained details. The laboratory quizzes, preliminary works, laboratory progress and reports are evaluated all equally as the laboratory grade.   The laboratory description is reported in Table 2.

**Table 2. Description of Laboratory Experiments**

| Laboratory Number | Title | Details |
|---|---|---|
| **Lab 1** | Introduction to Integrated Development Environment (IDE) | Students are introduced with the editor, compiler, debugger, and programmer. They code simple programs and obtain .hex file to be programmed for microcontroller. |
| **Lab 2** | Introduction to Development Board | Students are introduced with the programmer and demo board. They design simple application and program the microcontroller. |
| **Lab 3** | Port Usage as Input and Output. | Simple button and light control application. This components are already on the PIC Clicker, they learn how to control the ports, input and output. |
| **Lab 4** | Buzzer Control Application | This is the first laboratory experiment which a Click Board is used. Students are introduced with the Mikro Bus and interfacing the PIC Clicker with Click Boards. Buzzer click board is connected to PIC Clicker and Sound library of MikroC programming language is experienced. Sound library uses pulse width modulation concepts which is a useful concept for microcontroller design. |
| **Lab 5** | LCD Application | Students learn how to control to LCD screen. They apply simple application where they display their names, they shifted screen so whole name could be displayed. Also they designed a counter with stop, pause, up and down counting option. They also learn timing concepts. |
| **Lab 6** | A/D conversion Application | A/D conversion is almost a must for microcontroller application most analog sensor outputs analog voltage value so it should be converted to digital and displayed. We designed a simple potentiometer Click Board and used in this experiment which functions as a voltage divider and student could observe the voltage value on LCD. |
| **Lab 7** | Interrupt Application | Interrupt is one of the very important concepts in microcontroller programming. Students are asked to design a counter which is controlled by hardware interrupts. Its virtual simulation is also applied. |
| **Lab 8** | Infrared Thermometer Application | Infrared Thermometer Click Board is connected to Mikro Bus and communicated using I2C protocol to communicate with the micro controller. Students are experienced about the I2C communication protocols in this experiment. |
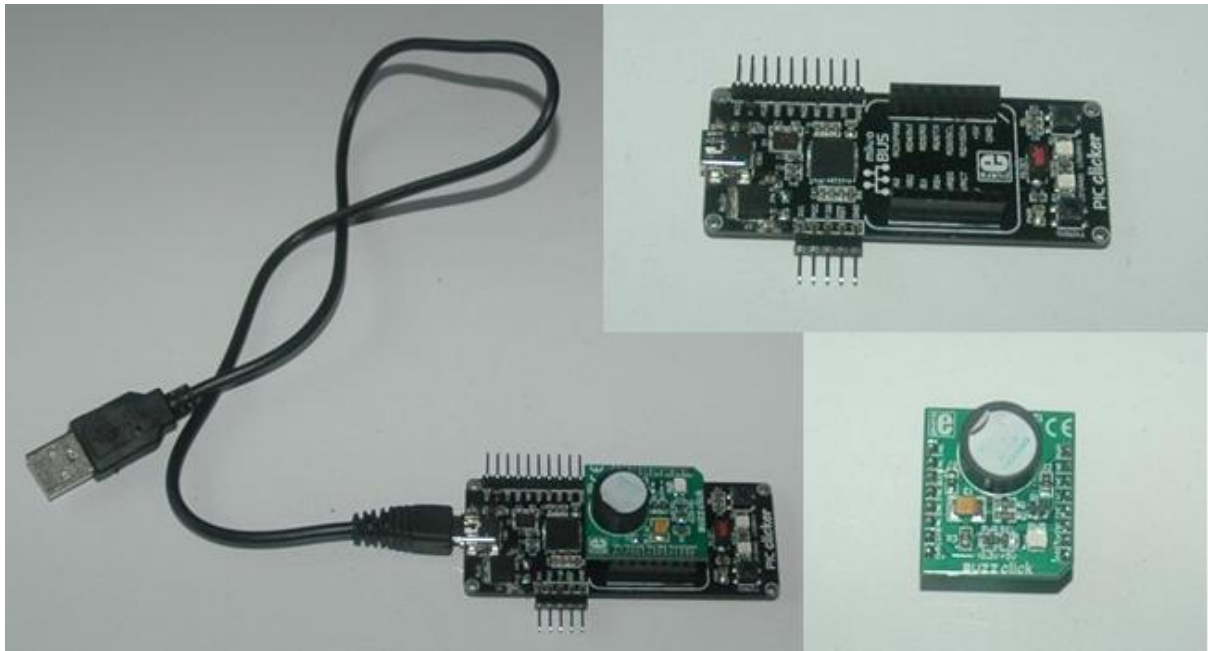
**Figure 7. Buzzer Click Board (Right Bottom), PIC Clicker (Top) And Buzzer Click Board Connected To PIC Clicker With A USB Connection To Programming (Left).**

In Figure 7 PIC Clicker itself can be used in Lab 2 and 3 because it has 2 led light and 2 buttons on itself which are used for experiencing input and output. Buzzer Click Board in used in Lab 4. USB connection makes it very practical to program and supply power to devices. In Figure 8 all of the required hardware for the laboratory experiments are shown.
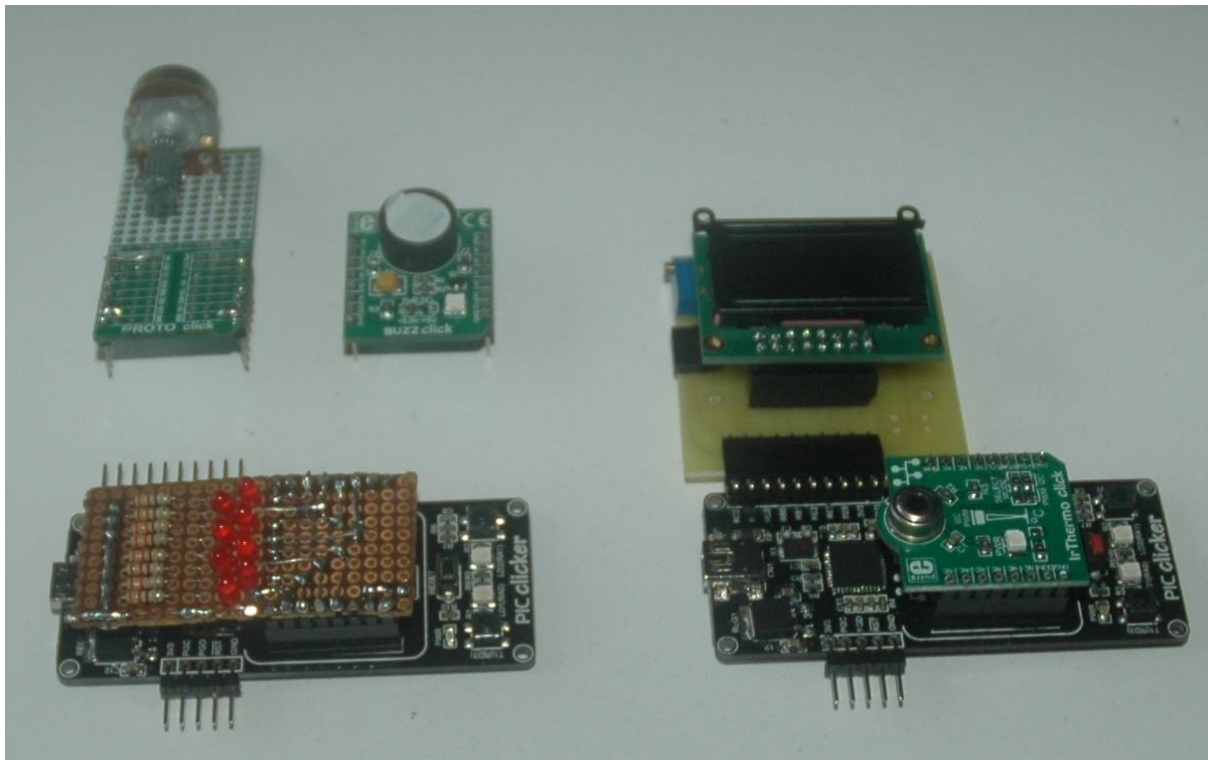


**Figure 8. A Custom Made Potentiometer Voltage Divider Click Board (Top Left), Buzzer Click Board (Top Middle), A Custom Made 8 LED Light Click Board Mounted On A PIC Clicker (Bottom Left), A Custom LCD And Infrared Thermometer Mounted On A PIC Clicker (Right).**
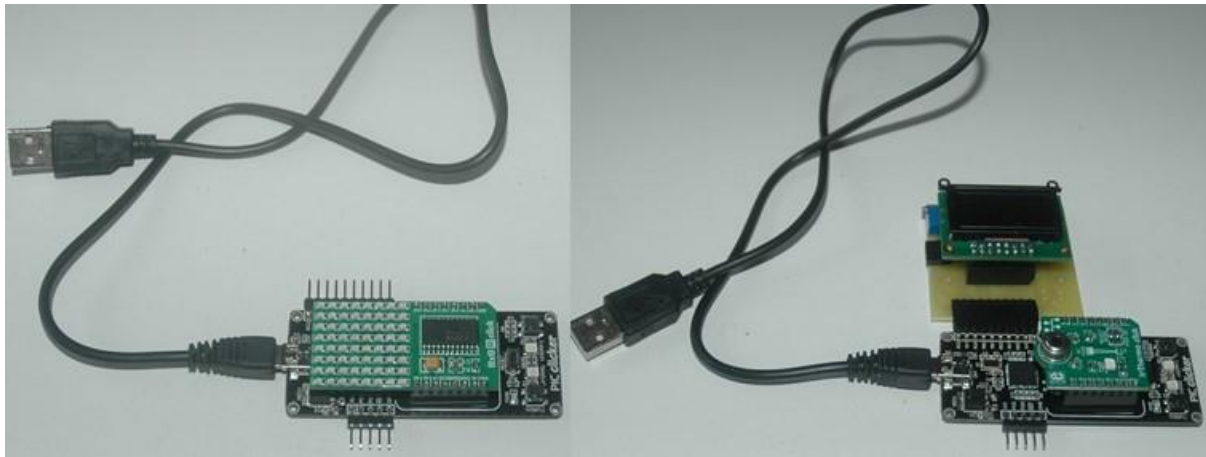
**Figure 9. An 8x8 LED Light Click Board Mounted On A PIC Clicker (Left) And Infrared Thermometer Mounted On A PIC Clicker (Left) With USB Connections.**

In Figure 9, two different possible application is shown both uses serial communication protocols but in the first one there is no need to a display which is better for early laboratories. In the second configuration a complete infrared thermometer solution is shown, it is used in the last laboratory experiments students able to measure their body temperature and ambient temperature.

## ASSESSMENTS

The learning outcomes of the course are, at the end of the course students should be able to:
1- To understand the fundamentals of microprocessors, microprocessor based systems and microcontrollers.
2- To state the fundamentals of electronic design with a microcontroller.
3- To experience with a modern programming language.
4- To experience with a modern IDE and programmer (development tools).
5- To experience at least four different application of microcontroller design.
6- To do a microcontroller based design individually or as a member of a team.

We have tested those learning outcomes by quizzes, midterm and final exam, laboratory grade and performance grade. The results of satisfying the learning outcomes reported in Figure 10. From the results almost all of the outcomes are satisfied above 60%. Which is an adequate results for a difficult course. 1 and 3 outcomes are satisfied above 70% this mostly shows students success on theoretical subjects. 4 is satisfied at %78 which is the highest one because development tools are really simple and practical. 2, 5 and 6 are around %60 which are mostly related to hand-on experiments, mostly hard part.
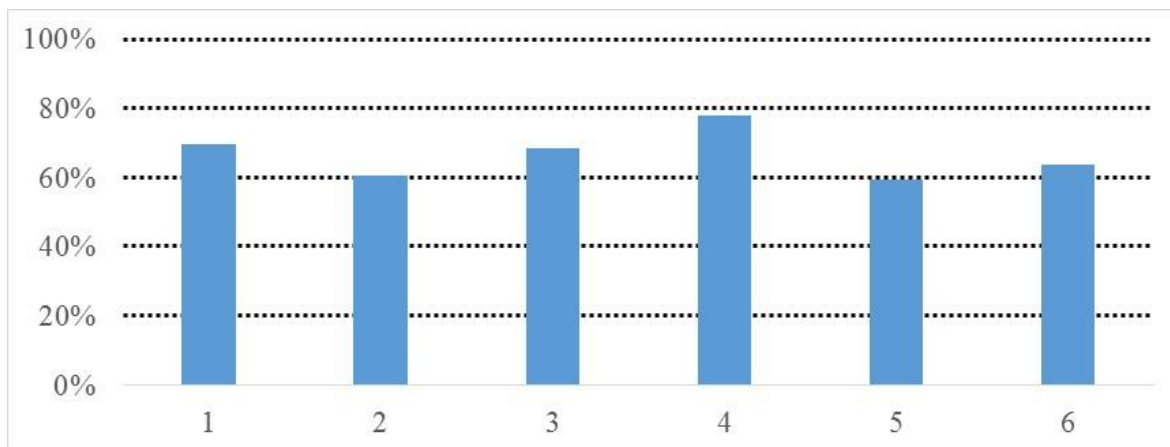


**Figure 10. The Results Of Satisfying The Learning Outcomes, According To Student's Grades.**

## STUDENT OPINIONS

The student's feedback has been generally encouraging. One of the positive feedback form student's evaluations that they like the development setup and praise that they can make a whole working device. They also reported that course combined theory and hand-on learning. In the evaluation their opinion their motivation for this course is highly motivated. (According to the survey on students motivation. Question: Did you motivated for the course. (1) Did not motivate, (2) Fairly motivated, (3) Motivated, (4) Very motivated, (5) Highly motivated)

The cost of the development setup is affordable for students so most of the students obtained the setup after the course which shows the motivation of them to design microcontroller applications.

## CONCLUSION

In this study we survey the literature, address the problems in microcontroller education and offer course objectives for a microcontroller course. In order to achieve those objectives effectively under the constraints of time and cost we choose a development setup and improve it. We have also developed laboratory experiments for the development setup.

For the development setup we use a free IDE software for 2K of program code; MikroC Pro for PIC which has its own programmer and use a programmer and demo board; PIC Clicker. We also use many Click Board which are for different applications can be connected easy to PIC Clicker using Mikro Bus interface, like a brick design. We add an LCD display to development setup in order to widen the application range which is custom made LCD board. It can be mounted to PIC Clicker by using other ports than Mikro Bus so does not block other Click Boards. It is unique for our development setup so by this display circuit it is possible to do many applications using click boards and pic clicker. In some lectures and laboratories a virtual simulation software is also used for design purposes. In microcontroller courses usually the development setups are complex and expensive, our setup is simple and cost effective, which led us to spend more time on applications.

The assessments according to the students satisfying of lecture outcomes and students opinions. They both shows a remarkable satisfactory results. One of the main gain of this course is that students are highly motivated. In the future we are planning to add more applications and a project work.

Our improvements of this course are ongoing, further development will be reported in the future publications.

## ACKNOWLEDGMENTS

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