

# High School Stem Curriculum and Example of Laboratory Work That Shows How Microcomputers Can Help in Understanding of Physical Concepts

Jelena Slugan, Ivica Ružić

**Abstract**—We are witnessing the rapid development of technologies that change the world around us. However, curriculums and teaching processes are often slow to adapt to the change; it takes time, money and expertise to implement technology in the classroom. Therefore, the University of Split, Croatia, partnered with local school Marko Marulić High School and created the project "Modern competence in modern high schools" as part of which five different curriculums for STEM areas were developed. One of the curriculums involves combining information technology with physics. The main idea was to teach students how to use different circuits and microcomputers to explore nature and physical phenomena. As a result, using electrical circuits, students are able to recreate in the classroom the phenomena that they observe every day in their environment. So far, high school students had very little opportunity to perform experiments independently, and especially, those physics experiment did not involve ICT. Therefore, this project has a great importance, because the students will finally get a chance to develop themselves in accordance to modern technologies. This paper presents some new methods of teaching physics that will help students to develop experimental skills through the study of deterministic nature of physical laws. Students will learn how to formulate hypotheses, model physical problems using the electronic circuits and evaluate their results. While doing that, they will also acquire useful problem solving skills.

**Keywords**—ICT in physics, curriculum, laboratory activities, STEM.

## I. INTRODUCTION

THE teaching methods in high school classes are the same as they were in the past, where teacher often stands in front of students and talks about problems or concepts. Although a class can be interactive, most of the time, only a few of the students choose to actively participate.

Importance of the practical part of teaching is presented in the concept of learning formed by Edgar Dale in 1946. Fig. 1 shows The Learning Pyramid which was researched and created by the National Training Laboratories. It shows us that one of the best learning methods is practice by doing. In these situations, the teacher guides students in the learning process.

In recent decades, computer technology has changed the world around us in many ways. This change brings significant opportunities to improve our teaching processes and curriculums. For this reason, this optional subject was developed, aimed at 15 and 16 year old students attending high school. The main goal was for them to be able to use

microcomputer technology for exploring nature and problem situations in everyday life.

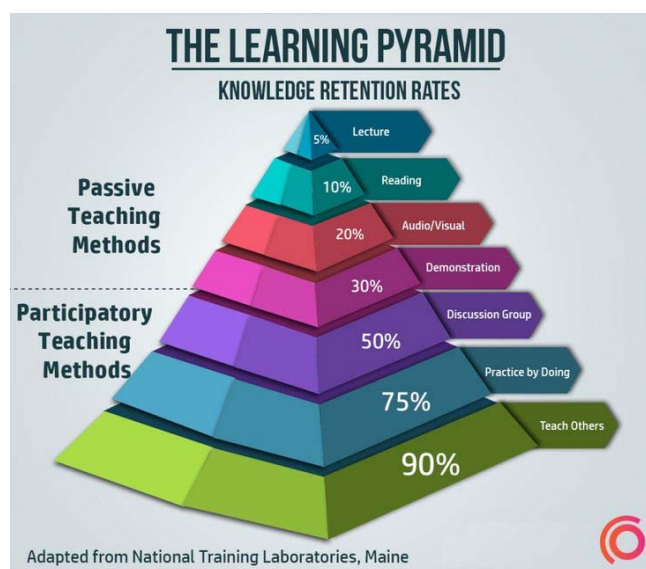


Fig. 1 The learning pyramid [4]

The experiment is an indispensable part of the process to understanding the nature and the world that surrounds us. This approach encourages development of cognitive abilities, as it encourages creative and scientific thinking. Acquired knowledge and adopted skills enable responsible participation in discussions.

## II. DESCRIPTION OF THE OPTIONAL SUBJECT MICROCOMPUTERS IN PHYSICS

### A. Domains in the Organization of the Subject Curriculum

Our students have changed radically. Today's students are no longer the people our educational system was designed for. Today, things like computer games, Internet, cell phones, computer gadgets and instant messaging are integral parts of students' lives. The new generation of students is referred to as Digital Natives, while others who are not born in the digital world, but are trying to adapt, are called Digital Immigrants [5]. Reference [5] shows the difference between today's teachers and students. Students are unlikely to adapt to teachers, so teachers have to design new ways of learning acceptable to new generations. Implementation of technology in the teaching process is one of best way to attract students.

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By combining ICT and physics, the subject Microcomputers in physics was created.

The subject Microcomputers in physics prepares students for further education and lifelong learning. The main aims of this subject are:

- 1) Encourage interest in microcomputer concepts and understanding of measurements, natural phenomena and concepts.
- 2) Develop critical-logical and systematic thinking.
- 3) Develop experimental skills through the study of the deterministic nature of physical laws.
- 4) Formulate research questions and hypotheses.
- 5) Systematize and analyze data.

The content of this subject has four domains or concepts that are recognized in every entity and theme.

Domains cover the entire knowledge of physics, and they are also interspersed with each other and therefore individual physical themes can appear in multiple domains.

Domains:

- 6) Motion: Motion is a change of body position relative to the reference system in time intervals. In this domain, the student explores the motion based on the concept of shift, path, velocity, acceleration, and energy conservation laws, and then graphically shows the motion.
- 7) Electrodynamics in the Circuit In this domain, the learner experimentally applies the knowledge about the parts of the circuit.
- 8) Use of electronic circuits: In this domain, the student learns basic concepts of computer work, electronic circuits and additional devices/sensors. The student learns how to choose and use the appropriate digital technology, data processing software, and analysis of results.
- 9) Naturalistic Literacy: Natural literacy is a prerequisite for understanding natural phenomena. Developing scientific literacy, conducting experiments is a precondition for ethical and social use based on knowledge and skills [1].

#### *B. Arduino Project for Improvement STEM Education in Physics*

This subject is based on the use of devices such as Arduino, Raspberry Pi or Zolertia. The purpose of the subject is to attract students to the application of information technology in the research of physical phenomena. It is important to increase the electoral content of physics in high school.

For the execution of the subject we use microcontrollers, most notably Arduino environment. The microcontroller is an electronic circuit. Its task is to automate a certain action. Generally, this is a circuit that has analog and digital inputs, and outputs. The defined internal logic procedure determines the signals at the outputs depending on the input signals. The microcontrollers are points on the electronic circuit to which one of the many sensors is connected. The role of the sensor is to translate the physical states from the environment into the corresponding electrical signal. This input signal (one or more of them) is logically processed within the microcontroller. The result of this action makes the output of the microcontroller – another signal (analog or digital) that can trigger operation on

another device connected to the output. The output from the microcontroller is therefore also a point of attachment on the electronic circuit.

The microcontroller in its physical form is what we usually call a "chip". One example of circuits and procedures that we are surrounded by daily:

Example 1: The microcontroller in the fridge constantly measures the temperature (the temperature sensor is connected to the input). Each time the temperature rises above a certain limit, the microcontroller drops the compressor engine connected to its output. The refrigerator compressor goes off when the temperature sensor measures the temperature below the default setting. The procedures written in the microcontroller are short program codes that repeat without interruption as long as the microcontroller is plugged into a power source [2].

In Example 1, this code, written in human language, looked roughly like this:

Step 1. Read the sensor temperature.

Step 2. If the temperature exceeds 10°C, the compressor will start working.

Step 3. If the temperature is lower than 8°C, the compressor will stop working.

Step 4. Go Back to Step 1.

This procedure would maintain a temperature in the refrigerator between 8°C and 10°C.

Figs. 2 and 3 show examples of microcontrollers.



Fig. 2 Microcontroller type 'Atmel'



Fig. 3 Microcomputer type 'ATMega32'

To make the microcontroller work, it needs to be supplied with power, with its sensors connected to the required input and output devices. It is also necessary to find a way to enter logical procedures into the working memory (programming the microcontroller). When this is done, such an extended circuit looks like some of the examples shown in Figs. 4 and

5.

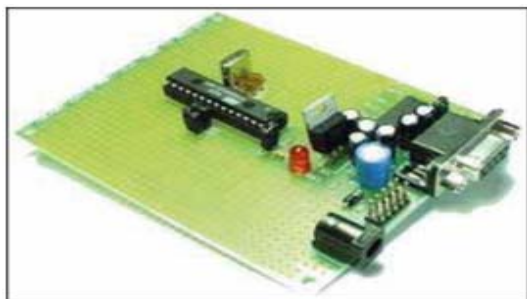


Fig. 4 Hand-made electronic circuits with microcontroller

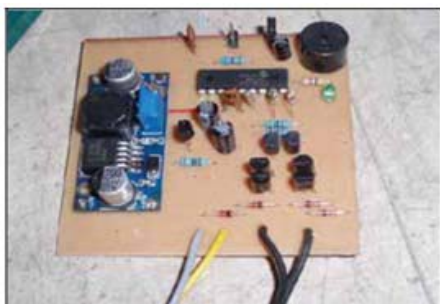


Fig. 5 Hand-made electronic circuits with microcontroller

There are several ways of connecting inputs, outputs, or reprogramming for each of the microcontrollers. Every way depends on the experience of the person doing it, and in each case, requires certain skills. Historically, lack of experience in working with electrical circuits was a serious obstacle to working with microcontrollers. However, this changed with appearance of the Arduino platform.

The Arduino Platform is a standardized electronic circuit that not only has a microcontroller but also a complete electronic environment. It has ready-made solutions for its inputs and outputs, standardized power supplies and perhaps the most important of all, it has a standardized programming environment for the built-in microcontroller called Arduino IDE. Using the Arduino platform, users no longer need to develop an electronic circuit around a microcontroller. Because of this, the Arduino Platform is accessible to users with no practical experience in electronics.



Fig. 6 Arduino Uno Platform

Arduino was conceived and developed in 2005. It soon gained popularity due to its ease of use, the ability to develop additional modules and relatively low prices. Arduino hardware is whole electronic hardware or any material used in Arduino platform design. The Arduino hardware consists of Arduino devices, Arduino shields and sensors. As mentioned above, Arduino devices are electronic devices that are made up of a microcontroller and an elementary electronic environment that provides simple communication with a microcontroller (Fig. 6).

Due to the extensive application of microcontroller (Arduino) in households, industry, computing, entertainment and education, many additional electronic shields have been developed to facilitate the development of the required electronic circuits. All of them are commonly connected to any basic Arduino device. They also have a common and basic Arduino idea that they are easy to use and cheap. Figs. 7 and 8 show examples of Arduino shields



Fig. 7 Arduino shields to display data on LCD screens



Fig. 8 Arduino shields for GSM mobile communication

The sensors (and other components) are simpler electronic devices, but their role is similar like Arduino shields. They contribute to the basic Arduino device to measure the physical phenomena in the environment. An example of the sensor is the ultrasonic sensor in Fig. 9.

The next important component, without which no measurement would be possible, is software for Arduino.

For the successful operation of the microcontroller, signal processing procedures have to be defined. Those procedures determine the dependence of the output signals in relation to the inputs. The instruction code that we enroll in Arduino's microcontroller is Arduino software. The programming process of any Arduino device is facilitated by the existence of a unique environment in which the required programming code can be developed. This environment is called Arduino IDE (IDE: Integrated Development Environment). It is a



computer software application (computer program) used to write code, to test it, and to transfer the code to the Arduino device memory. This requires a connection between the computer on which the code is written in Arduino IDE [6] and Arduino itself - this connection is most commonly realized through a USB cable.



Fig. 9 Ultrasonic sensor

### C.Examples of Exercise: Parking Sensor and Velocity of Sound

The subject consists of 13 exercises, which are performed in groups of two or three. At the end of each exercise, there are a few questions to answer. An example of one exercise is parking a car with a distance sensor. This exercise uses an ultrasonic sensor to measure the distance from the obstacle. The distance is displayed on the screen. The electric PIEZO and LED diodes are also added to the work unit, which warns the driver through sound and light when an obstacle is too close.

Available Elements: 1 Arduino, 1 USB cable, 1 Development board, 1 Resistor of 1 kΩ, 1 ultrasonic sensor, 1 LED diode, 1 PIEZO electric cable harness [2].

#### Exercise Procedure:

- 1) Connect the elements according to the accompanying scheme of the compound.
- 2) On the computer open the program "ARDUINO".
- 3) Enter the program code in the program.
- 4) Go to File => Save and save the project named ECHO SENSOR.
- 5) Run the program.

The ultrasonic sensor works on the principle of traveling the beam. The transmitter imitates a short ultrasonic signal that travels to the barrier and back. The barrier distance is obtained by:

$$d = \frac{v \cdot t}{2}$$

where, d – distance, v – velocity and t – time [3].

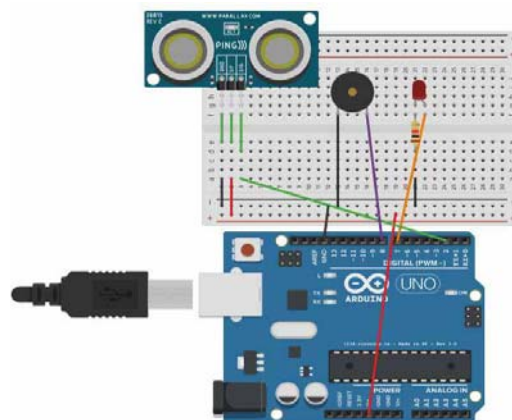


Fig. 10 Connection scheme of Arduino plate and additional module

A good example of a microcontroller application in physics is determining the velocity of sound.

The required material is:

- 1) Arduino Uno device with cable to connect the Arduino to computer,
- 2) Ultrasonic Sensor (HC-SR04),
- 3) Rule,
- 4) Wire Strips,
- 5) Object, has bodies like small boxes,
- 6) Calculator,
- 7) Computer, Arduino software (IDE), and
- 8) Development Plate.

The HC-SR04 Ultrasonic Module has two transmitters: one is used as a loudspeaker that converts electrical impulses into sound waves and emits them at a frequency of 40000 Hz. The second loudspeaker serves as a microphone for receiving an ultrasonic wave that reflects (rejects) the body. The clock mechanism records the time when the device has sent the ultrasonic pulse and stops when the microphone receives the impulse from the body. The time has come to take the time that the sensor sound passes the way to the body and goes back.

Program code for this exercise (Velocity of sound):

```
int trigPin = 13; // set pin 13 as trig pin
int echoPin = 7; // set pin 7 as echo pin
int time;
void setup() {
  Serial.begin(9600);
  pinMode(trigPin, OUTPUT); // set trig pin as output, we send pulse through this
  pinMode(echoPin, INPUT); // set echo pin as input, we detect echo through this pin
}
void loop() { //sending 10 microsecond width pulses, frequency ~ 40KHz
  digitalWrite(trigPin, LOW); delayMicroseconds(2000);
  digitalWrite(trigPin, HIGH); //trig pin
  delayMicroseconds(10); //pulse width 10 microseconds
  digitalWrite(trigPin, LOW); //trig pin offtime = pulseIn(echoPin, HIGH); //pulseIn(), function return time in microseconds//print time on the serial monitor
  Serial.print(" Time taken for the pulse to travel: ");
  Serial.print(time);
  Serial.println(" microseconds");
}
```

```
delay(2000);  
}
```



```
Echo | Arduino 1.6.12  
File Edit Sketch Tools Help  
Echo  
// Pin 13 has an LED connected on most Arduino boards.  
// give it a name:  
int puls = 2;  
int udaljenost;  
int led = 7;  
int buzzer = 8;  
const int distmin = 25;  
  
// the setup routine runs once when you press reset:  
void setup() {  
  // initialize the digital pin as an output.  
  
  pinMode(puls, OUTPUT);  
  pinMode(led, OUTPUT);  
  pinMode(buzzer, OUTPUT);  
  Serial.begin(9600);  
}  
  
// the loop routine runs over and over again forever:  
void loop() {  
  pinMode(puls, OUTPUT);  
  digitalWrite(puls, LOW);  
  delayMicroseconds(5);  
  digitalWrite(puls, HIGH);  
  delayMicroseconds(5);  
  digitalWrite(puls, LOW);  
  pinMode(puls, INPUT);  
  
  udaljenost = (int(pulseIn(puls, HIGH) / 2) / 29);  
  //-----  
  Serial.print("Udaljenost je ");  
  Serial.print(udaljenost);  
  Serial.println(" cm");  
  if (udaljenost <= distmin)  
  { digitalWrite(led, 1);  
    digitalWrite(buzzer, 1);  
  }  
  else  
  { digitalWrite(led, 0);  
    digitalWrite(buzzer, 0);  
  }  
}
```

Fig. 11 Program code for Arduino (Parking sensor)

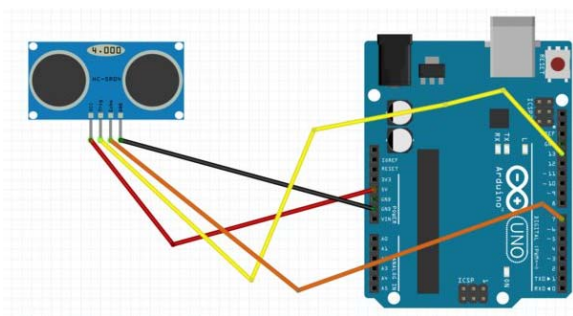


Fig. 12 Connection scheme of Arduino plate and additional module

Before we start experimental measurements and notes of measured values, all of this is done at room temperature. The sensor is placed on a straight line with a 0 cm mark. Place the object (box) in the appropriate position on the ruler so that the distance between the sensor and the box is 5 cm. After that, the program is running.

The monitor shows the total pulse travel time of the sensor and back to the sensor, the measured data are recorded in a pre-prepared table. Subsequently, the subject moves for a 10 cm scale and then records the time on the serial monitor of the computer. The procedure is repeated for 10 different path

lengths.

#### D. Data Analysis and Experimental Results

The sound velocity in the air as a function of  $T_c$  temperature is given by:

$$v = [331.4 + 0.61 * T_c] \text{ m / s}$$

$T_c$  is temperature in degrees Celsius. If the temperature changes, the velocity of sound changes. Using this formula, students calculate the velocity of sound and write down their score, and then compare it with the values obtained in Table I.

Table I records the data obtained by measuring and using the following formula, which calculates the velocity of the sound.

$$v = \frac{2d}{t}$$

Finally, when students determine all 10 measurements, they conclude that the speed is slightly different, and therefore, must include a relative error. In this way, students do not only remember the value of the velocity of sound, they determine it themselves. In the end, they conclude that the sound velocity changes with temperature change, and how the error of measurement always exists.

TABLE I  
 MEASUREMENTS RESULTS

Number of measurements	Distance (d) (centimeters)	Time (t) (microseconds)	Velocity of sound
1.			
2.			
3.			
4.			
5.			

### III. RELATIONSHIP BETWEEN EDUCATIONAL AREAS AND OTHER SUBJECTS

The subject Microcomputers in physics synthesizes practical skills and professional knowledge of physical, chemical and biological sciences and the use of information communication technology (ICT). The subject Microcomputer in physics assumes the use of information and communication technology, thus contributing to the development of digital literacy. It enables students to use natural sciences, recognize natural science issues, and make evidence-based conclusions.

### IV. LEARNING AND TEACHING THE SUBJECT

The main principles of learning and teaching subject Microcontrollers in Physics are focused on the development of students. The student is an active participant in the learning process, a responsible young person who will become a responsible citizen with a developed naturalistic way of thinking. The student will know how to approach the problem, as well as develop the ability to work in a team. However, all tasks and projects are adapted to the age and cognitive abilities the target students.

The working atmosphere needs to be inspiring, creative,

comfortable and stimulating. Considering that the underlying objective is researching physical concepts through microelectronics, the laboratory is an ideal learning and teaching environment; while part of learning and teaching will take place outside the classroom, where it will measure different parameters in the environment. Fieldwork is a form of experiential learning in which a student is confronted with reality; the value of fieldwork increases if it is conducted interdisciplinary, because it promotes interrelationships and enables a comprehensive experience and an understanding of life around it.

Content of the Microcomputer in Physics module teaches at the 2nd and 3rd grade of secondary schools for a total of 35 hours per year.

### V. CONCLUSION

Life has become unthinkable without technology. Children nowadays learn to use electronic devices long before they learn to read and write. On the other hand, adoption of technology in teaching is rather slow. The project Modern competence in modern high school was designed to address this problem. The project enables students to participate in classes more actively, be more independent and develop better understanding of the school materials. By connecting ICT and physics, students will hopefully develop further interests for subjects from the STEM area. Programs like this should be seen as a guide of how technology can help us shape the future of education. Unfortunately, because of cost and required additional effort, the success of similar programs in schools very often depends on the enthusiasm of individual teachers.

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Full list of her projects and papers can be find on <http://cv.oss.unist.hr/preview/document/46/competition?lang=en> and detailed CV can be find on <http://cv.oss.unist.hr/preview/document/46/cv?lang=en>

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Actual projects:

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- 3) Database of teachers ([cv.oss.unist.hr](http://cv.oss.unist.hr)), 2013 – onwards
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- 5) Mentoring final / diploma thesis ([mentor.oss.unist.hr](http://mentor.oss.unist.hr)), 2013 – onwards

Full list of his projects and papers can be find on <http://cv.oss.unist.hr/preview/document/4/competition?lang=en> and detailed CV can be find on <http://cv.oss.unist.hr/preview/document/4/cv?lang=en>