'Introducing STEM to Primary Education Students with Arduino and S4A.'

P. Michalopoulos[1], S. Mpania[1], A. Karatrantou[2], Ch. Panagiotakopoulos[2]

[1] *School of Pedagogical and Technological Education (ASPAITE) Branch of Patras*
[2] *Department of Primary Education, University of Patras*

Abstract. *STEM education is aiming to the development of the scientific interest of students and their capability to solve authentic problems, given emphasis to the connection of Science, Technology, Engineering and Mathematics. At the same time simple applications of automatic control systems and robotic constructions are evolving as basic tools of modern life and they provide innovative tools in education as well. In this paper an attempt is made to introduce STEM activities to students of Primary Education supporting them working on simple constructions with Arduino and Scratch for Arduino. Within this framework students were asked to work in groups to design, construct and program their constructions following specially designed worksheets of increasing difficulty with the aim to finally create a Theremin. Analyzing students' work useful information can be derived on how they combined and used in practice knowledge from science, technology and programming and on benefits of educational robotics applications in the frame of STEM education as well.*

Keywords: *STEM Education, Educational Robotics, Arduino in Education, Scratch for Arduino*

1. Introduction.

STEM education regards to an integrated scientific approach according to which the four fields of Science, Technology, Engineering and Mathematics, form a whole where elements interact and affect one another. The STEM approach in education requires the use of innovative and alternative methods of teaching and learning, such as projects, laboratory practices and technological tools [19]. At the same time educational robotics is becoming the next step in education due to its innovative character and the hands-on experience it offers to students making them more receptive to learning stimuli. Educational robotics applications can become a significant educational tool in the STEM approach as students working with robotic constructions are involved in situations that require from them to use and apply knowledge from Mathematics, Science, Technology and Engineering and supported to develop a conceptual basis for the reconstruction of their knowledge [1, 3, 6].

In this paper an attempt is made to introduce STEM activities to students of Primary Education supporting them working on simple robotic constructions (simple automatic control systems) with Arduino and Scratch for Arduino. Within this framework students were called to work as young makers in an attempt to realize how technology works in real life and asked to work in groups to design, construct and program their simple automatic control systems following specially designed worksheets. Worksheets were of increasing difficulty and supported students to gradually construct and program more complex systems with the aim to finally create a musical instrument, a Theremin.

2. STEM Education and Educational Robotics

STEM education based on the idea of educating students in four disciplines - Science, Technology, Engineering and Mathematics - in an interdisciplinary and applied approach. Rather than teach the four disciplines as separate and discrete subjects, STEM integrates them into a cohesive learning approach based on real-world applications and situations. The objectives of STEM education, at all levels of education, include the development of the scientific interest of students and their capability to solve authentic problems aiming knowledge from Science to be used for the understanding of the natural world around. Moreover, students to be able to use new technological tools and understand how Technology affects the surrounding world, to realize the significance of Engineering in real world and how they are linked each other. It is also aiming students' abilities related to Mathematics, such as analysis, documentation, and problem solving to be improved, supporting them to cope with situations in their everyday lives [8, 9, 14]. In his framework STEM education serves efforts to increase students' interest in pursuing Science, Technology, Engineering and Mathematics Studies and Careers. For the success of STEM education programs, however, certain parameters have to be taken into consideration. These include a demanding content, a research learning environment, pre-defined educational outcomes, clear objectives, innovative educational scenarios and commitment and support from society as well [2, 13].

On the other hand, robotics since the late 80s has been used in almost all levels of education as an auxiliary tool in teaching various concepts of subjects such as Mathematics, Sciences, Engineering, Technology and Computer science and as a teaching subject as well [6, 10]. Robotic constructions are used in education as extracurricular activities and as educational activities aligned to the curriculum objectives supporting the development of the 21st century skills such as collaboration, problem-solving, creativity, critical thinking and computational thinking. Educational robotics is a dynamic and strong promising tool for STEM education. It is offering to students '*objects to think with'*, as Papert described [12] supporting them to realize how technology works in real life, to see computing in a different way, to cultivate computational thinking. It is offering to teachers strategies and tools to manage a shift from '*Black box'* approaches in education (where students act as consumers) to '*transparent box'* approaches (where students can work as constructors).

Many educational robotics kits are used in all educational levels such as Lego Mindstorms (RCX, NXT, EV3), BoeBot, Activity Bot, Arduino. In this research the Arduino platform was used for the construction of the simple systems and the software Scratch for Arduino (S4A) was used for the programming and control of the systems.

3. Arduino

Arduino is a low-cost open-source electronics platform based on easy-to-use hardware.

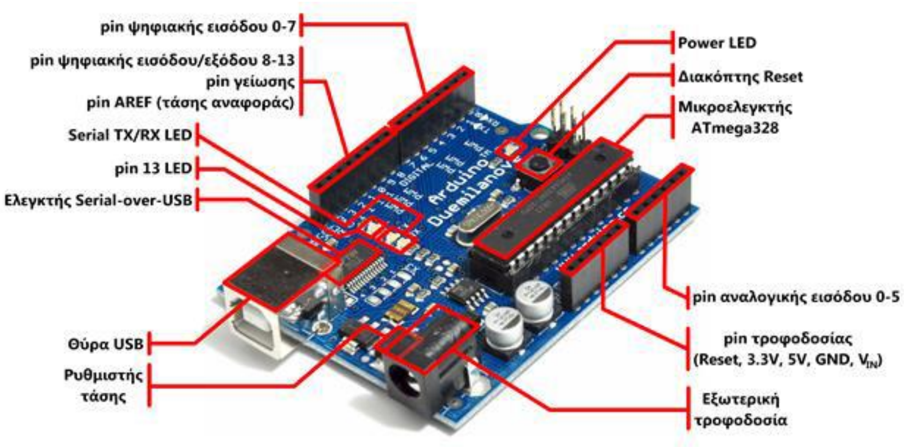

Figure 1. The Arduino platform

It is intended for anyone who wants to work on interactive projects, demanding basic programming knowledge and experience and minimum knowledge on electronics. Arduino '*senses*' the environment by receiving inputs from many sensors, and '*affects*' it by controlling lights, motors, and other actuators. It was created at the Ivrea Interaction Design Institute as an easy tool to be used by students without a background in electronics and programming. Nowadays Arduino has been the heart of projects, from everyday objects to complex scientific instruments. A worldwide community of students, hobbyists, artists, programmers and professionals has gathered around it and support novices and experts as well (https://www.arduino.cc/). During the last years Arduino is used in schools at all levels of education in many countries to support teaching and learning in science (physics, chemistry, biology), technology, computer science, supporting experiments in laboratories and by distance as well (4, 7, 11].

4. Scratch for Arduino

Scratch for Arduino (S4A) is a Scratch modification that allows users to program the Arduino platform. It includes new blocks for managing sensors and actuators connected to Arduino. The main aim is to attract young people to the programming world and to provide them a friendly interface interacting with a set of boards through user events (http://s4a.cat/).

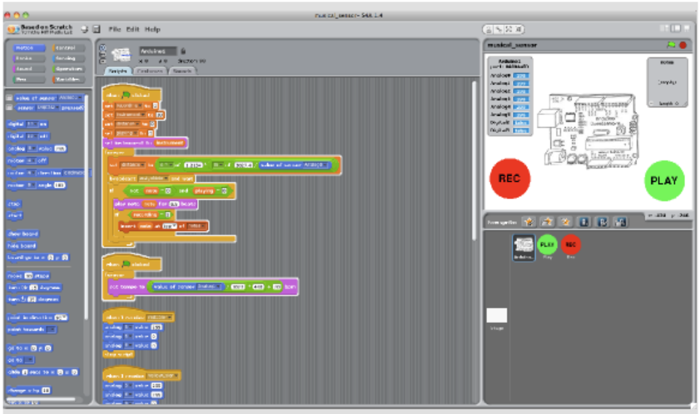

Figure 2. Scratch for Arduino: a typical screen shot

5. Methodology

The aim of the study was to introduce STEM activities to students of Primary Education supporting them working on simple automatic control systems with Arduino and Scratch for Arduino and to analyze their work in order to derive useful information on how they combined and used in practice knowledge from science, technology and programming. Additionally, useful data on the benefits of educational robotics applications in the frame of STEM education can be extracted.

Students while working on the specific worksheets with the aim to gradually construct a Theremin were expected to *recall and make use of knowledge from their science subjects, be familiar with and recognize basic electronic circuit elements, describe how a circuit works, be able to explain how a simple control system works, use basic programming structures, choose the appropriate programming structures to control their construction, realize that a connection among subjects of Engineering, Science, Mathematics and Technology exists, recognize applications of automatic control systems in everyday life, adopt positive attitude for innovation in everyday life.*

The research took place in a public Primary School in Patras. A total of eighteen (18) sixth grade students participated voluntarily in the study (eight (8) girls and ten (10) boys). The students were divided randomly into five (5) groups of three persons (2 groups) and four persons (3 groups) and the educational activity took place during three sessions in the Computers Laboratory of the schools (2 two-hour sessions and 1 one-hour session). Students of the sixth grade have coped with the widest range of subjects and have been taught about electricity, circuits and their elements (sources, lamps, switches and resistors), light and their basic properties. They are familiar with the Scratch programming environment and have used basic programming structures in simple programs.

The whole activity was based on Worksheets of increasing difficulty that supported students to gradually construct and program more complex systems with the aim to finally create a musical instrument, a Theremin. The 1st session started with a Diagnostic Questionnaire and a short discussion on the topic of robotic and automatic control systems. A demonstration of a Theremin made with Arduino helped them to understand what they should finally make and worked as a challenge. A familiarization phase with Arduino platform and S4A took place based on the 1st worksheet according to which students worked on a simple circuit with a LED and a resistor and discussed about the program to make it work. During the 2nd session, the 2nd and the 3rd worksheet was the basis for students' work. According to the 2nd worksheet students had to add a new element on the circuit, a switch to control the function of the circuit and modify their program using the control structure 'IF…THEN… ELSE…' in order for the circuit to work properly. The 3rd worksheet supported students to construct their Theremin using a photo-sensor (a photo-resistor) on the circuit and a variable in their S4A program. During the 3rd session a discussion about the whole activity and what they worked on, a discussion concerning applications of simple automatic control systems in everyday life and the evaluation of the whole procedure (Evaluation questionnaire) closed the procedure.

For the purposes of the study four data collection methods were used: monitoring (groups and members) and personal notes of the researchers, recording of groups' discussions, analyzing answered worksheets by the students while working, answering of short questionnaires before (Diagnostic Questionnaire) and after the whole activity (Evaluation Questionnaire). Three teachers-researchers were observing the discussions, activities and reactions among the students. They kept notes and made interventions when students needed help, adopting a supportive and facilitative role of students' work and learning. The Diagnostic Questionnaire consisted of seven (7) closed-type questions and students had to give anonymous answers about their gender, their previous programming experience, their interest in learning more in Programming and what they mainly used the computer for. The Evaluation Questionnaire was used to evaluate the overall procedure (the robotic kit as a tool, the programming environment, the learning outcomes) and consisted of seven (7) closed- type and six (6) open-ended questions.

6. Students' work and Findings

According to the students' answers to the diagnostic questionnaire, 17 students (94%) usually work a lot with computers (most of them for fun, for searching information needed for school projects, for communicating with friends) but none of them had an experience in programming more than what they programmed during school lessons. The majority of the students (17 students, 94%) think that programming is a difficult task. The demonstration of the Theremin at the beginning triggered their curiosity and their enthusiasm and their willing to start working immediately.

Starting working students were asked to draw an electric circuit according to what they already knew from their physics lessons aiming to recall necessary knowledge in order to discuss about the electrical elements and circuits they should construct later. All students drew correctly their circuits and only one group of students put the polarity of the source in a wrong direction. According to the 1st worksheet, students had to create a circuit on the breadboard based on an already designed circuit. All students recognized the resistor and the LED, a discussion took place on the role of the resistor in the circuit and in a very short period of time all groups of students created their circuits correctly. A program in S4A, that should turn on the LED for some seconds and after that should turn off the LED for some seconds, was given to them in order to describe and test its result on the circuit. Students had to modify the program (using the repeat structure without a condition – the forever block) in order to make the LED blinking continuously with a rate of their choice and all of them succeed it.

According to the 2nd worksheet students had to add a switch in the circuit. They drew the new circuit correctly and created it correctly too based on the already designed circuit. A program in S4A, which should turn on the LED when the switch was pressed and should turn off the LED when the switch was released, was given to them in order to describe and test its result on the circuit. A discussion about the role of the open-switch and the closed-switch as well as about the role of the control structure 'IF…THEN…ELSE…' took place. Most students faced difficulties with the control structure.

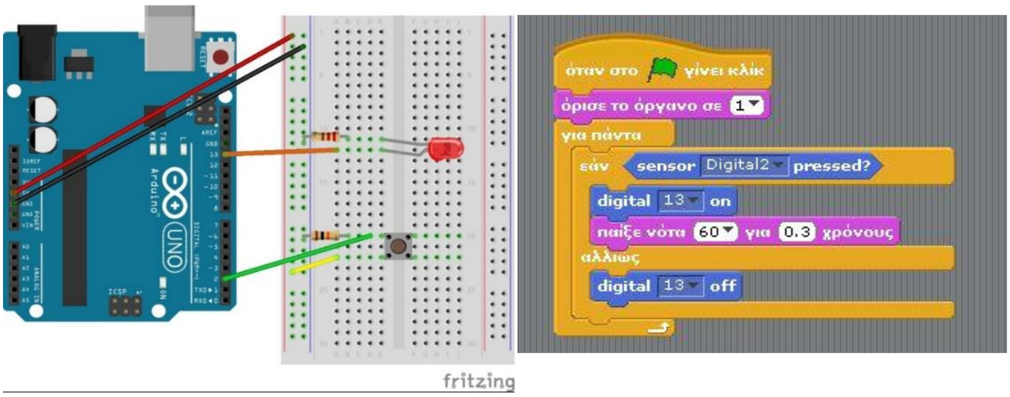

Figure 3. The circuit and the program for Worksheet 2

According to the 3rd worksheet students had to use a photo-sensor (a photo-resistor) to create and program a Theremin. They created the circuit based on the given design and made the program in S4A according the given one. They tested the result of the program on the circuit and a discussion took place on how the photo-sensor works, what it 'senses' and how, how it affects the circuit, what are the roles of the commands in the program. Many of the students faced difficulties to understand how the photo-sensor works. Students' ideas on what a photo-sensor is were intuitional and based on their initial impression when they saw the Theremin at the beginning of the activity: '*…it can realize the light above it…*', '*…it can understand when we have our hand over it…and how close...*', '*…when it is darker around the sound is heavy and when its lighter around the sound is higher…*'. Students introduced to the concept of 'variable' in programming to keep the characteristic value of the musical note the Theremin should play. Most students faced difficulties to understand what a 'variable' in programming is and what its role is.

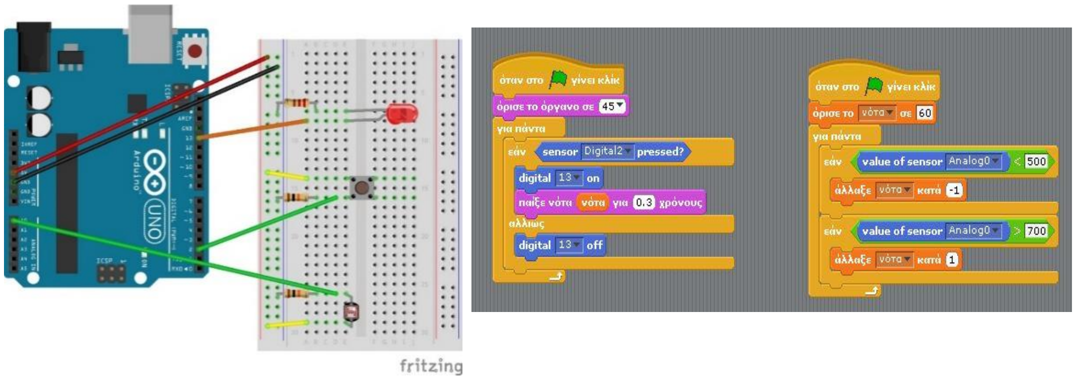

Figure 4. The circuit and the program for Worksheet 3

Students' answers at the assessment questionnaire showed that all of them liked the activity much and very much. Fourteen (14) of them (77.7%) would like to work on such constructions and applications again. Thirteen (13) students (72.2%) said they didn't face any difficulty, 3 students (16.7%) faced difficulties in programming and 2 students (11.1%) during creating the circuit. Most of them answered that *'…they did not face difficulties because we were a team and each one made something to complete the circuit and the program…'.* Answers concerning the programming structures used showed that all students seemed to understand and were able to describe how the repetition structure works and when it is used but only 5 of them (27.8%) could do the same for the control structure 'IF…THEN…ELSE…'. Most of the students gave descriptive but not accurate answers. Most students faced difficulties with the 'variable' in programming.

Answers concerning the elements of the circuits showed that all students could recognize all the elements used. Thirteen (13) of them (72.2%) could describe their properties and the role in the circuits they created, 4 students (22.2%) could recognize only the switch and the LED and only one (1) student could not give correct answers. Typical answers on the function of the elements in the circuit were: *'…when we pressed the switch the LED was on….the cables are connecting the elements of the circuit …the resistor is decreasing the current in the circuit…'*, *'…the resistor is decreasing the current. The cables are connecting different things and the switch let the current pass into the circuit…'*. It was difficult for them to describe the function of the photo-sensor. Most students could propose a new application*: alarms, a sensor at home to open doors and windows depending on light or temperature, automatic watering of plants, automatic faucet to wash our hands….*

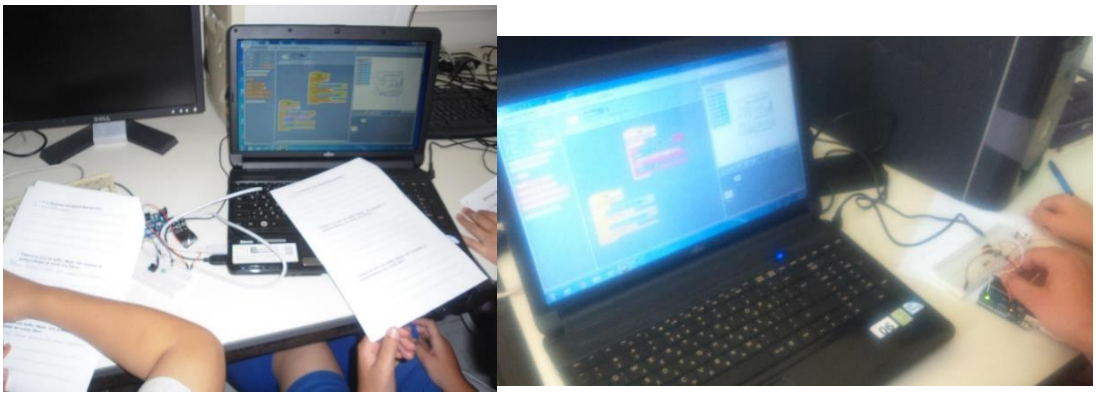

Figure 5. Students working

It is important to notice that the members of all groups worked in cooperation. Each member tried to contribute to the activity, there was a work and responsibilities sharing among members and leaders were appeared in most groups. In all groups discussion among members took place to find solutions and complete their task each time. Three groups asked for help from the teacher while working.

7. Discussion and Conclusions

In this paper an attempt is made to introduce STEM activities to students of Primary School supporting them working on simple robotic constructions with Arduino and Scratch for Arduino. Students are asked to work in groups to design, construct and program simple automatic control systems following three specially designed worksheets of increasing difficulty and guided students to gradually construct and program more complex systems with the aim to finally create a Theremin. Students worked during three sessions (5 didactic hours) on the activity in an attempt to be supported to realize how technology works in real life.

According to the data derived from the monitoring of students' work (groups and members), the personal notes of the researchers, the recording of groups' discussions, the analysis of the answered worksheets by the students and their answers on the short evaluation questionnaire useful information derived. All students worked effectively as members of their group. All students seemed to recall knowledge from physics about circuits and light, seemed to connect this knowledge with their work during this activity, designed and created circuits correctly. Most of them recognized the elements of the circuits and could describe correctly their properties and their role in the circuit. Most of them faced difficulties with the photo-sensor. All of them understood the role of the repetition structure in programs but some of them faced difficulties with the structure 'IF…THEN…ELSE…' and the concept of 'variable'. Most students could propose a new application using automatic control systems in everyday life and expressed their interest to work more on such activities.

Concluding, such kind of educational activities could be dynamic tools in the frame of STEM education and could raise student's interest and engagement in STEM through the use of simple robotic constructions on the basis of well-structured educational scenarios according to the needs of students each time.

Closing, it should be emphasized that improving the interest and motivation of students for STEM education is a complex issue. A range of new approaches need to be implemented and examples of good practice need to be mainstreamed. Since the Lisbon agenda was launched by the European Council in 2000, a lot of attention has been focused on Europe's need to foster a dynamic and innovative knowledge-based economy, not least by producing an adequate output of scientific specialists [5]. To achieve this goal we need to increase participation in Science, Technology, Engineering and Mathematics (STEM) studies and career. That means that we need teachers training on the field as well as suitable educational approaches, scenarios, material and practice.

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