DidacTronic: A Low-cost and Portable Didactic Lab for Electronics

Kit for digital and analog electronic circuits

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***Abstract*—This paper presents the DidacTronic, a development and prototyping kit for digital and analog electronic circuits. DitacTronic is a portable and low-cost platform whose goal is to include students from electrical engineering courses and high school students in the innovative world of technology and motivate them to learn by doing design work. A device like this allows them to see concepts presented in theoretical classes, such as physics and electronic, put in action. DitacTronic permits that because it's a portable lab. Oscilloscope, measurement equipment, and basic components are included in this platform. The DitacTronic connects with tablets and smartphones, through Arduino's Bluetooth module, so that the students may use them as a visor to monitor signals, inputs and outputs from DitacTronic or other circuits. Students and professors worked together to overcome one of biggest challenges in the Brazilian Universities: the gap between theory and practice. Therefore, the solution needs to be simple, cheap and replicable. There are many expensive solutions available, but they are not affordable to everyone, everywhere. The research team hopes to disseminate DitacTronic and its principles. The IEEE SIGHT PUC Minas supports this project and is sharing with many engineering students.**

Keywords— portable lab; education; electronic; Arduino; mobile devices; prototyping.

I. Introduction

Science and Mathematics education is considered to be a challenging topic around the world. Engineering is based on math and science topics and the success of every engineer is stricted related to the depth of their knowledge on their fundamental concepts. The use of Physical[1] or Virtual[2][3] Learning Objects has been shown to be efficient in these fields[4][5]. Such objects can link theoretical knowledge with student's reality and the empirical world, making the concepts more tangible.

Fig. 1. Banner presented in the FIC (Curricular Integration Fair), at PUC Minas on May 2016

As years goes by, innovative technologies appear and are introduced to enhance learning of Physics and other Sciences' concepts by young high school students or even by college undergraduate students. However, these new resources can be expensive and sometimes unaffordable. The use of electronic tools can be used to improve science and math education in high school, as electronic covers some topics of chemistry, mathematics and physics, preventing future engineering

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students from possible problems in learning. This paper reports the creation of a learning environment capable of assisting high school students in less affluent situations and the building of an electronic laboratory to help undergraduate students to study and apply physical concepts beyond the realm of electromagnetism and semiconductors. As mentioned before, many tools used nowadays are too expensive[5] for public schools or students who want to access them everywhere, so every tool used in the project described in this paper is for free download and use. But the main point is: how to create an easy-to-implement, low cost, customized and portable kit or lab for electronics? The lab here described is a plug-and-play kit that interconnects a hardware (Arduino board) to some components boards (such as the LEDs module, push-buttons modules).

The Arduino board has been used in undergraduate level courses recently, such as in engineering disciplines [7][8] and computer science[9][10]. Even in chemistry courses this board has been used[11][12]. As Arduino-like boards are very cheap[13][14], they are spread nowadays and in information needed to use them can be found easily on the Internet[10]. The kit permits the user to see the theoretical concepts in practice- it can be used in classes to verify electrical circuit laws and relations, making them more solid and tangible. The kit was also presented in an engineering fair at PUC Minas, in the scope of a subject called TAI in Telecommunications (TAI stands for Integrative Academic Work). By appearing in this exhibit it showed the students the potential of this lab in action through some experimental activities proposed by the authors. The banner presented in this fair is shown on Fig. 1. This work was a continuation of an academical research in a similar discipline called TAI in Electronics, which showed a great potential, with some technical limitations. Therefore, the efforts made here in this project made the expected results come out.

II. TACKLING THE PROBLEM : TWO DIFFERENTS APPROACHES

A. Trying to solve future problems

Working such subjects with teenagers from public high schools in this way may motivate them to go to a University or to a technical career, guiding them to a career that probably wouldn't be chosen by most of them. The inspiration of discovering what they are able to do in the real world with knowledge can totally change the point of view of a school subject[15][16] and possibly break distorted notions of the reality around a discipline[15]. The use of applied concepts can also help the teacher identifying logical or mathematical problems the students may have[9].

The student's environment is full of learning objects that could be applied in educational use. Toys, recyclable objects, smart phones, tablet, and many other technology gadgets[17] might be used to enhance knowledge in classroom[18][19]. Seeing real objects in action on projects involving science and math shows them how useful and solid the concepts are and enhance learning[4]. We planed some class experiments to show them some physical phenomena in action, covering some electromagnetic concepts, the mathematical relationship involving them, and the technological world of electronic (STEM – Science, Technology, Engineering and Mathematics). In [20][21] it is possible to see the importance of introducing embedded systems in High School level, mainly in countries in development[22]. That is a different approach when we compare with computer programming logic in elementary or high school education[23][24].

B. Dealing with the problem we have today

Fig. 2. The workshop presented to the freshmen class of Electronic and Telecommunication Engineering class

As already said, the use of technology can support the teaching of physical contents such as electronic[25]. In order to verify this, an Arduino Workshop was freely offered to two electronic engineering classes from the first year, reaching around 30 students, in 2 to 4 hours to introduce electronic concepts, devices and components, and how to make projects using them in a breadboard. In the Fig. 2 it's presented a moment from this class when the students were instructed about the electrical circuits connections in the breadboard.

All the resources used in this class are free to download and to use, such as the Arduino IDE, the Electronic CAD Fritzing and the Android App Bluetooth Electronic. The approach related to this article is the second one.

III. BUILDING THE DIDACTRONIC

The Bluetooth protocol has being used for connecting Arduino to smart devices recently[26][27]. So the wireless way to connect the Arduino chosen was through the bluetooth module, which is very popular and cheap. In order to attend to the specifications proposed above, a firmware was developed and a circuitry projected to achieve the goals proposed in this paper. The firmware coded in this project can be run in any simple Arduino UNO-like board. The hardware is fit to allow the student to a plug-and-play use to measure signals, to export different kinds of voltage sources or to prototype electronics projects and circuitry. A free app called "Bluetooth Electronics" was used- an environment which permits the creation of virtual interfaces in a smartphone or tablet, and also the Arduino with the smart device through the Bluetooth module lately. The use of a smart device has being researched[19] as a tool to improve education. In this app we created some screens: the DidacTscope, the Voltmeter and the Ohmmeter, where the user can check the waveforms and the voltage and resistance values, respectively.

A. The Firmware

The "brain" of the development kit DidacTronic is the Atmega328, the microcontroller Arduino platform is based on. The IDE (Integrated Development Environment) the firmware was built is also free. The firmware coded can be divided in three modules: The oscilloscope (In an alternative way of [6], the multimeter and the function generator. There is a main function which reads the inputs from the smart device and calls each function from the firmware to let the user achieve what it's intended, such as turn on or turn off an output (that could be a LED, for example), or activate a module (a motor, for example).

The multimeter is divided in two codes: a voltmeter and an ohmmeter. They have some similarities: They read an analog input using the microcontroller's 10-bit ADC (Analog to Digital Converter), which transforms your continuous input in a discrete number in a range of 0 to 1023. It's calibrated to each function to represent a value representing the voltage (to the voltmeter) and the resistance (to the ohmmeter). Finally the corresponding value is sent to the device, so that the user can see the measure.

The oscilloscope also measures an analog input and calibrates it. The input waveform can be seen in the screen of the smart device, in a real-time way, because in a small amount of time the input voltage is read and converted, calibrated and sent to the app. This is useful to see temporal dynamic voltage waveforms to analyze the behavior of the system the student is measuring.[6].

To deliver to the user some usual input waveforms, it was developed a function generator, which works as a voltage source. The signals generated in this module supply the user with square, sine, triangular and ramp waveforms, which are some of the most used waveforms in electronics. They are created using the PWM (Pulse width modulation) technique, which sends to a digital output mean values corresponding to the range of 0 to 5 volts. It works by sending a squared wave with a variable duty cycle, that results in a variable mean value in the Arduino's output pin. Each wave has a pattern- so each wave is dealt with in different ways. The sine generator gets a value of a vector created in a range of 0 to 255- representing the 5 Volts range- in a sinusoidal sequence, from -1 (0) to 1 (255), passing through 0 (127). The ramp is an accumulator that is reset when the maximum value (255) is achieved. The output voltage of the selected waveform is the present value of the sequence (in the sine wave generator) or the value of the accumulator (in the triangular and ramp wave generator). The square wave is a bit different: it is on in the half period of time and off in the other (a duty cycle of 50 percent). In other words, At the end of the first half period of time, the state of the digital output is changed, and so is in the second half. If these tools are explored together, with the right assistance to do so, the student who uses the resources in the kit is able to have a complete low-cost laboratory.

B. Hooking up the system

The construction of the hardware must allow the user to use the functions properly and safely. The kit comes with a guide that leads with measurements, breadboard wiring and electronic components configuration. If an unaware student short circuits while measuring or prototyping, this mistake wouldn't damage the mobile device, just a low-cost component. The voltmeter and the ohmmeter are basically a probe which interconnects the Arduino system and the measure to be made. The probe is a voltage divider between resistors with two different resistance. In the voltmeter, there are an electric circuit to protect against overvoltage: the voltage measured is the voltage in a 1 kΩ resistor. The voltage that the user chooses to measure is put in a terminal of a 10 kΩ resistor. So the voltage read is the difference of the analog port which read and the GND (in other words, the voltage in the 1 kΩ resistor). The ohmmeter's operation is very similar to the voltmeter. The difference is that we have a voltage divider between a standard resistor value (1 kΩ) and the load. The load is automatically connected to VCC and to the 1K resistor, which is connected to the GND (closing the loop). The value read through the analog input is the voltage in the fixed resistor. Through an arithmetical relation in the firmware, it is exported to the screen of the user's device the value of resistance of his/her load (It can be a resistor, capacitors, LEDs,- paying attention to the polarity of the two last components, because they must be working to be measured).

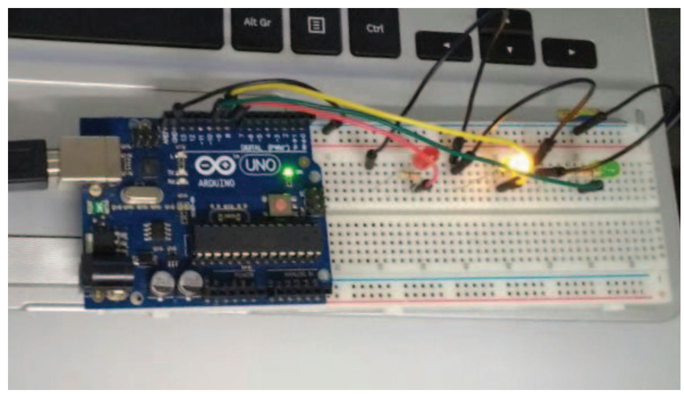

Fig. 3. Electrical connection of the traffic light circuit, with three LEDs (red, yellow, green)- each one connected to a 330 Ω resistor, a breadboard and some wires connected to an Arduino Uno board.

During the classes the students used a breadboard to interconnect the circuits of the proposed projects. The first one, a single traffic light, using three LEDs (one red, yellow and one green). (It can be seen in the Fig. 3). The resistor value was chosen by showing them the circuit loop that is formed among the components and the Arduino board's source (Vcc and GND). The voltage drop of the LED were measured using the DidacTronic's ohmeter and they were shown how to calculate the minimum value of the resistor so that the LED wouldn't be burnt (by the electrical current; the students were also taught that one of the resistor's uses is to give a limit to the current, that can burn electric-electronic components). The students were instructed about the connection of the resistor and the LED in series, in order to make a single LED blink. They adjusted the template code from the Arduino IDE to let the red LED be turned on for 7 seconds, the yellow for three seconds and the green one for 10 seconds, all the instructions in a loop, so it would be repeated whilst the system is turned on (let's call it "the daily sequence"). Later the freshmen started using a LDR- Light Dependent Resistor, a resistor that varies it's value of its resistance according to the brightness. This second project proposed, which is based on a voltage divider between a fixed resistor (1K Ω, for instance) and the LDR. The project is about reading the value of the resistance of the LDR and, depending to the level of voltage (related to the light) on it, turns on or off a LED or turns off. The students were informed about the industrial and commercial use of this system, for example, in the public lighting lamps. As can be seen in the Fig. 4, the blue wire measures the voltage level of the LDR, as the LDR's right terminal is grounded.

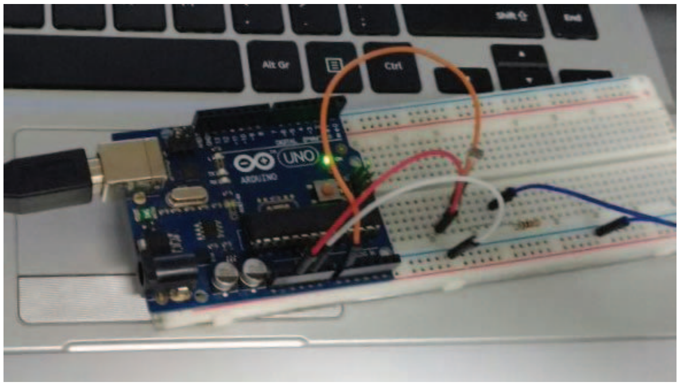

Fig. 4. Electrical connection of the light sensor circuit, with a LDR, a resistor, an Arduino Uno board and some wires.

As a third experiment, the students had to project a traffic light which works in the way it was shown in the ”day” and during the ”night”, it works blinking ”the daily sequence”. We did it because at night the traffic is more dangerous than in daylight, so, for safety (the driver's attention is called by the blinking traffic light) the LDR was used- to discover if it's day or night. The Fig. 5 shows the complete work: the traffic light and the light sensor circuit.

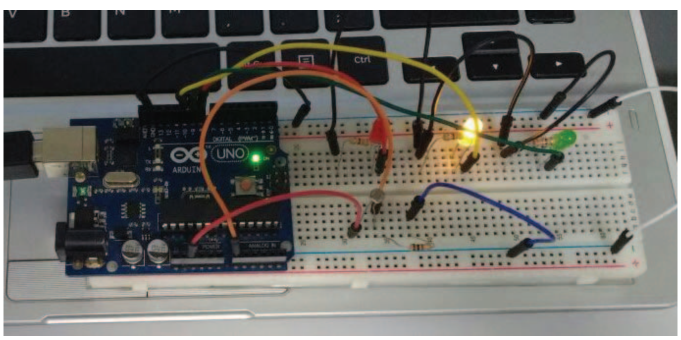

Fig. 5. The complete electrical connection of entire project's hardware

IV. THE KIT

The meaning of ”kits” here is a group of electronic components and devices which are gathered to give to its user a flexible electronic laboratory. As it is low-cost, the student can choose one of the three possible kits we developed, according to their need (Fig. 6). If this person is beginning his/her studies, and only want to have a material to a better comprehension of electricity and/or electronic, he/she may prefer to buy the basic or the ”starter” kit, with fewer components and resources (only the ones a beginner in electronics really needs). For people who are fully engaged in the worldof electronics and technology, it's recommended the advanced kit, which is modular and covers more electronic engineering contents. The modularity allows an evolution in the user's Project, as in [28]. Depending on the area of engineering preferred by the user, the kit comes with a specific component, such as a step motor for people who like mechatronic projects, or more sensors to control and system applications. An intermediate kit is also available if the the students want something more than the starter kit. As the kits are modular, the students can easily migrate from one kit to another, just getting the components that aren't in their kit. The resources inside each kit were set thinking on the kind of projects the user may be working in the class or by himself. As they are low-cost kits, the final price is affordable to most of the students, as they will have in their hands a digital oscilloscope (what we call here DidacTscope), a multimeter, a signal generator and an environment to prototype electronic projects using an Arduino board (what can be seen in the Fig. 7 and Fig. 8, respectively, the basic and advanced kits' components and price). The intermediate kit is similar the advanced one, it costs less than R$90,00 (less than US$30.00).

Fig. 6. The three available kits: DidacTronic basic, intermediate and advanced.

V. POSSIBLE PROJECTS WITH KITS

As already said, DidacTronic offers resources to develop different kinds of projects. Some projects were implemented by freshmen students. They are examples of didactic development that can be used by undergraduate students from electronic engineering, from the beginning to the course's end.

A. Bluetooth Communication

Every kit has a Bluetooth module. It's used to communicate the Arduino board with the user's smart phone or tablet. It's a joint of the real and normally used objects from the student's environment with electronics, sounding more natural to them. That models a wireless and low-energy consumer communication module, which can be used in many kinds of projects. The student can combine a large variety of projects, using a cell phone. As an example it can be implemented a digital watch based on Arduino timer interrupt to assign the time transition and the module to connect the hardware to the user's device. In this case the cell phone is the interface we can check the time, but we can also use it as an input interface to set some parameters in the hardware. A simple digital keyboard (music instrument) can be used using only a buzzer and a resistor, and the Bluetooth module. By pressing a key or a button in the cell phone, it sends a string value to the Arduino hardware which identifies the tone and will give the right frequency to the buzzer. The number of applications is unlimited, depending on the user's creativity, intention and components.

BASIC KIT

Components	Quantity	Price (R$)
Yellow LED	1	0,15
Green LED	1	0,47
Red LED	1	0,12
7 segments Display	1	1,80
CI for 7 segments Display	1	1,60
Potenciometer	1	2,00
Push-buttons	2	0,80
Keys	4vias	1,50
LDR	1	0,60
Resistors	10	1,00
PROTOBOARD	400furos	12,00
bluetooth Module	1	25,00
Arduino	1	15,00
Jumpers	10	3,60
	TOTAL:	65,64

LEGENDS:

(yellow)	Outputs
(light green)	Inputs
(blue)	Electronic devices
(dark green)	Essencial

Fig. 7. The list of the Basic Kit components and their price.

B. Traffic Light using Arduino

This is a beginning application that can be implemented using digital electronics' contents. Developing different levels of difficulty may stimulate undergraduate students in digital logic in an alternate way to digital design. It can be assigned with 3 or 6 LEDs (green, yellow and red- 6 to represent a crossroad), resistors, a breadboard, an Arduino board and, to enhance the student's performance, an LDR, a piezo-buzzer and a push-button.

As the LEDs are a kind of diode, this practice introduces the diode theory to the students, and also the electrical circuit laws. It is explained to them that diodes work as a switch: if the voltage given to it is lower than it's threshold (minimum value to start working), it is OFF, with a high resistance. If a higher voltage is provided to it, it turns ON, the current flows to the entire circuit and the diode has a finite value of resistance. The students are stimulated to calculate the resistor's value according to the voltage drop in the LED, and also realize that each color of LED has a specific drop- all by experimental tests. As the resistor used to limit the current is connected in series with the diode, it created a voltage divider between the diode and the resistor. At last, it is introduced to the students how to discover the value of the resistor through it's color code. The tools used are the ohmmeter and the voltmeter, which are inside of the kit.

ADVANCED KIT

Components	Quantity	Price (R$)
Yellow LEDs	2	0,30
Blue LEDs	2	0,90
Green LEDs	2	0,94
Red LEDs	2	0,24
RGB LED	1	0,90
7 segments display	4	7,20
CI for 7 segments display	2	3,20
Buzzer	1	2,00
Potenciometer	2	4,00
Push-buttons	8	3,20
Keys	8vias	1,60
LDRs	3	1,80
Temperature/Umidity sensor	1	6,25
Resistores	23	2,30
Diodo	2	0,30
Transistor NPN	2	0,50
Capacitores	2	1,70
Amplificador Operacional	1	2,00
CI555	1	0,70
PROTOBOARD	800furos	15,00
Modulo bluetooth	1	20,00
Arduino	1	15,00
Jumpers	50	18,00
	TOTAL:	108,03

Fig. 8. The list of the Advanced Kit components and their price. (1US$ = R$3.25)

C. Bargraph

The bar graph is a serial combination of LEDs. It transmits a visual information about a variable, to quantify is its level. It is used in many application in the real world: from acoustic applications to see the voltage level of a signal, to elevators, to check the total weight inside of it.

This project continues to teach the students diodes and circuit theory, as they can see the voltage drop both with the voltmeter and with the bar graph. It's more tactile, tangible and physical, so the user is more likely to induce the physical laws based on visual experiments.

D. Home Automation

Some components inside DidacTronic like sensors and actuators permit the user to have a big variety of projects in this field. As an example, in the workshop given to the students, they were able to see in action the Light Dependent Resistor- LDR- which works as a variable resistor. They calibrated a system to turn on a LED if the environment is dark and off if it's bright, also using the tools from DidacTronic (ohmmeter). They checked the value of the LDR's resistance when it was covered with a hand and when it was not. Using this circuit to teach the Kirchhoff's Voltage Law show the importance of learning physical concepts so that they can project valuable applications.

VI. TECHNICAL AND PEDAGOGICAL RESULTS

The oscilloscope shows sinusoidal waves in a nice visual result for a maximum frequency of 4 kHz. Square waves in a maximum frequency of 1 kHz. The sample rate of the oscilloscope is around 10 kHz. The Fig. 9 represents the measurement of sine wave generator with the frequency of 400 Hz, with 5V of amplitude. The amplitude of input signals must be in a range between 0-50V, as explained in the hooking up the system section, to the voltmeter, and to the oscilloscope until 5V (because the variation or the dynamical behavior of the voltage level is normally wanted to be measured, not the amplitude value itself). As the range of frequencies is limited by the microcontroller's timer set up, the range of the signal generator is also fixed, resulting in a lab which can generate and visualize (throughout the DidacTscope) frequencies until 4 kHz. The voltmeter shows precision until the second decimal place, while compared with a traditional digital multimeter. The ohmmeter also shows a nice result, while compared with traditional multimeter: the error is in the second decimal place. The Fig. 10 shows the response of a square wave of 5kHz as an input in a RC circuit, and the voltage on the resistor was measured. It is loyal to the response model of a RC circuit to a DC voltage, an exponential decay. In the left scope screen it is possible to see the signal zoomed, improving the signal visualization.

After the practical classes, most of the students showed enthusiasm and motivation to continue developing projects on Arduino and on electronic in general. A survey was made in the class, using the free website SurveyMonkey, and the students answered some questions. In a compact way, the results show that:

- Half of the class had already developed electronic projects before starting college;
- 58 % of students had never used the Arduino board, and the rest used in small personal projects;
- 50 percent of the students declared to have no or a basic knowledge in electronics, the other half declared to have regular or a good one;
- 92 percent declared to own and use a smart device such as Tablets or Smart phones, and the rest declared to have access to one, not using frequently;
- Only 25 % of students use cell phone or tablets as a tool for developing projects in engineering;
- 83 percent said to be fully interested in electronic projects after meeting Arduino, and the other part is highly motivated, as Fig. 11 informs.

The survey was answered by twelve students, from May to June 2016. Most of them really desire another workshops in the future, dealing with industrial applications. Some asked if it would be possible to have a free course, to learn electronic concepts in a more profound way.

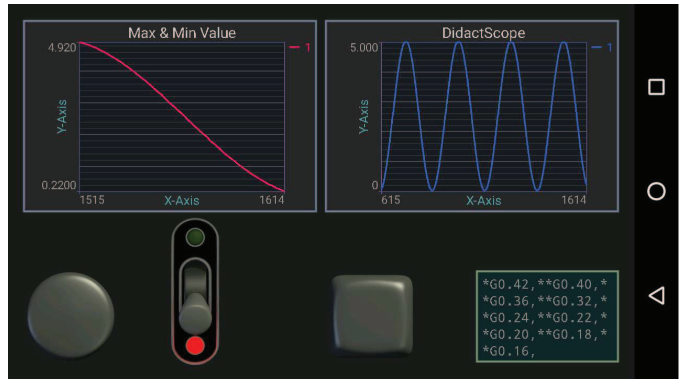

Fig. 9. The screen of the DidacTscope showing a sinusoidal signal

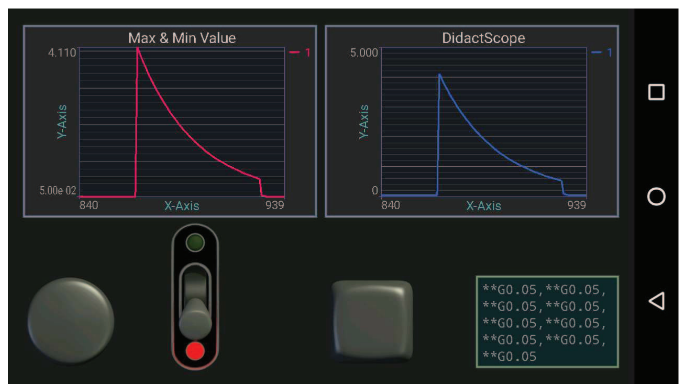

Fig. 10. The screen of the DidacTscope showing the voltage signal on the resistor.

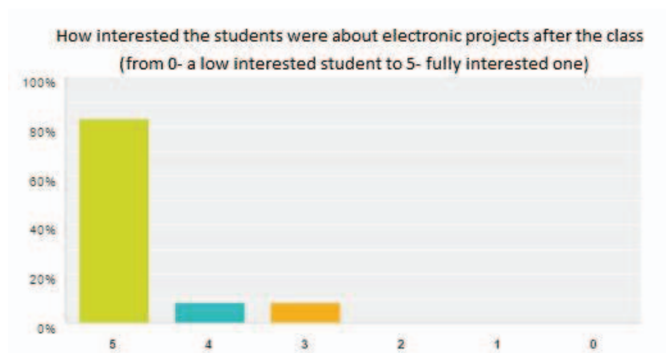

Fig. 11. One of the questions from the survey made with the students.

VII. CONCLUSIONS AND THE FUTURE WORK

The work presented and also the tools developed show the usefulness of the lab and how it operates: a low frequency digital oscilloscope (DidacTscope), a function generation up to 10kHz, both capable to work in the audio frequency range (which is enough for most of electronic prototyping ideas and projects). The voltmeter showed precision until the third decimal and can read voltages in the usual range of values in basic electronic projects, with a large protection level (it is yet larger than the usual voltage levels in electronic projects, up to 15 V). As future work we intend to take part in an university extension project that aims to teach math and science to high school students from a local public school were students are socially challenged. We are going to continue giving workshops and courses to electronic engineering freshmen. We will also continue to develop the hardware, expanding the range of frequency read by the DidacTscope and the signal generator. As the kits are flexible, there is a very large number of teaching activities possible for high school and undergraduate level. Furthermore we intend to create a booklet with the basic principles of electromagnetism and electronic to high school users and a pedagogical guide to engineering students. The lab isn't limited to beginners, so we want to apply advanced concepts of electrical machines, control, telecommunication and hardware/software development to use the lab at its fullest.

REFERENCES

[1] K. Zachariadou, K. Yiasemides, and N. Trougkakos," A low-cost computer-controlled Arduino-based educational laboratory system for teaching the fundamentals of photovoltaic cells", in European Journal of Physics, vol. 33, no. 8, pp. 1599-1610, Nov. 2012

[2] S. V. Shidlovskiy, O. M. Ravodin and V. S. Shidlovskiy, "Virtual laboratory in new educational technologies, "Virtual laboratory in new educational technologies" , in Modern Proceedings of the 9th International Scientific and Practical Conference of Students, Post-graduates and Young Scientists, pp. 246 - 247, Apr. 2003.

[3] E.K. Takahashi, D.C. Cardoso, H.G.F. Neri, R.M. Moura, R.Gedraite,A.C. Dantas, M.J.P. Pacheco and P.H. Borges, "A Virtual Learning Environment for the Study of the Discovery of the Electron" in Ieee Revista Iberoamericana De Tecnologias Del Aprendizaje-ieee Rita, pp. 186–194, vol. 10, no. 3, Aug. 2015

[4] C. H. Crouch, A. P. Fagen, J. P. Callan, and E. Mazur , "Classroom demonstrations: Learning tools or entertainment?", American Journal of Physics, vol. 72, no 6, pp. 835-838, Jun 2004

[5] S. Lopez, A. Carpeno, and J. Arriaga, "Remote Laboratory eLab3D: A Complementary Resource in Engineering Education" in Ieee Revista Iberoamericana De Tecnologias Del Aprendizaje-ieee Rita, pp. 160 - 167, vol. 10, Issue 3, Aug. 2015.

[6] I. A. Karim, "A Low Cost Portable Oscilloscope Based on Arduino and GLCD", 2014 International Conference on Informatics, Electronics & Vision (iciev), pp. 1-4, May 2014,

[7] V. Georgitzikis, O. Akribopoulos, and I. Chatzigiannakis, "Controlling Physical Objects via the Internet using the Arduino Platform over 802.15.4 Networks", Ieee Latin America Transactions, vol. 10, no. 3, pp. 1686-1689, Apr 2012.

[8] F.M. Lopez- Rodrigues and F. Cuesta, "Andruino-A1: Low-Cost Educational Mobile Robot Based on Android and Arduino", in Journal of Intelligent & Robotic Systems, pp. 63–76, vol. 81, no. 1, Jan. 2016.

[9] R. M. de Melo, I .J. de Melo, F.D.D Feliciano, and R. S. Carvalho, "Using Arduino as Pedagogical Strategy in Learning Logic Programming,", Proceedings of the 2014 9th Iberian Conference on Information Systems and Technologies (cisti 2014), pp. 1-5, Jun. 2014.

[10] M.A. Rubio, C.M. Hierro, and A.P.D.Y. Pablo. "Using Arduino to Enhance Computer Programming Courses in Science and Engineering, " Edulearn13: 5th International Conference on Education and New Learning Technologies, pp. 338, Jul. 2013.

[11] P.L.Urban, "Universal electronics for miniature and automated chemical assays", in New Review of Hypermedia and Multimedia, pp. 963- 975, vol. 140, no. 4, 2015.

[12] G.A. Mabbott, "Teaching Electronics and Laboratory Automation Using Microcontroller Boards" in Journal of Chemical Education, pp. 1458–1463, vol. 91, no. 9, Sep. 2014.

[13] A. DAusilio, "Arduino: A low-cost multipurpose lab equipment", vol. 44, Issue 2, pp. 305313

[14] O. Pineno, "ArduiPod Box: A low-cost and open-source Skinner box using an iPod Touch and an Arduino microcontroller," Behavior Research Methods, vol. 46, no. 1, pp. 196-205, Mar. 2014.

[15] N. Lasry and P.O. Christin, "Engineering Magical Learning Environments", in International Journal of Engineering Education, pp. 580– 584, vol. 27, no. 3, 2011.

[16] O.C. Santos, M. Saneiro, J.G. Boticario,. and M. C. Rodriguez- Sanchez, "Toward interactive context-aware affective educational recommendations in computer-assisted language learning", in New Review of Hypermedia and Multimedia, pp. 27-57, vol. 22, no. 1-2, Jan. 2016

[17] F.P. Barbeito, I.G. Castao, F.P. Cambeiro and M.F. Bolivar, "Educational experience in the employment of virtual platforms and new technologies in the classroom", in Global Engineering Education Conference (EDUCON), pp. 1 - 6, Apr. 2012.

[18] A.M. Brandt and M.B. Colton, "Toys in the Classroom: LEGO Mind Storms as an Educational Haptics Platform", in 2008 Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pp. 389 - 395, Mar. 2008

[19] L. Petropoulakis and F. Flood, Interactive student engagement using wireless handheld devices, in International Journal of Engineering Education, pp. 46–55, vol. 24, no. 1, Dec. 2007

[20] A. Valera, A. Soriano, and M. Valles, "Low-Cost Platforms for Realization of Mechatronics and Robotics Practical Works,", Revista Iberoamericana De Automatica E Informatica Industrial, vol. 11, no. 4, pp. 363-376, Oct. 2014.

[21] N. Gupta, N. Tejovanth, and P. Murthy, "Learning by creating: Interactive Programming for Indian High Schools," in 2012 Ieee International Conference on Technology Enhanced Education (ictee 2012) pp. 1-3, Jan. 2012.

[22] J. K. Author, M. Xavier and J.Alcarez, "Integrated Training in Digital Applications and Teaching Electronics (it Date): Designing a More Effective Way to Teach Computer Programming and Embedded Systems in Philippine Secondary Schools" in 7th International Technology, Education and Development Conference EOLEOL (INTED), Mar, 2013, pp 6297-6304.

[23] Slany W., "A Mobile Visual Programming System for Android Smartphones and Tablets", 2012 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC), pp. 265 - 266, Oct. 2012.

[24] S.S. Kendre, P.V. Mulmule, and S.D. Shirbahadurkar, "Developing Experimental Platforms Using Common Software Tools For Enhancing Technical Skills of Electronics Engineering Students in Microcontrollers", in 2013 Ieee Frontiers in Education Conference, pp. 1450 - 1452, Oct. 2013.

[25] P.L.Urban, "ChemDuino: Adapting Arduino for Low-Cost Chemical Measurements in Lecture and Laboratory", in Journal of Chemical Education, pp. 963-975, vol. 140, no. 4, 2015.

[26] P. Gonzalez-Nalda, I. Etxeberria-Agiriano, and I. Calvo, "Flexible, Modular, Standard, Free and Affordable Model for CPS Control Applied to Mobile Robotics" in Proceedings of the 2015 10th Iberian Conference on Information Systems and Technologies (cisti 2015), pp. 1-6

[27] J. F. M. C. Silva, D. M. S. Santos, V. C. Marques, K. D. Oliveira, and T. O. Rodrigues, R. G. F. Texeira, J. W. M. Menezes, and F. D. Silva, "A Study of Bluetooth Application for Remote Controlling of Mobile Embedded Systems" in 2012 Brazilian Symposium on Computing System Engineering (SBESC), , pp. 116, Nov.2012.