LabDuino: An open source tool for science education

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Abstract— **Research shows that the poor quality of science education and related areas in the Brazilian basic education has been negatively affecting professionals training in research and scientific development, also contributes to high rates of evasion of STEM graduation courses. Also, scientific illiteracy are harmful to society, once it's members losses analytical judgment capability and by that are more influenceable. Therefore, it is necessary to obtain ways to reverse this situation. Inspired by Seymour Papert ideas on constructionism and the maker movement, this paper proposes an open source embedded tool for science experimentation on K-12 classes. Created over Arduino development board and mounted on a custom circuit board, designed on an open source tool, and embedded on a laser cut box, this tool, called LabDuino, works like an experiment repository, where the student can choose the subject to be explored, then an experiment and run it following instructions, (sensors setup, initial data and so on), presented on the tool's display. The LabDuino is capable to gathering, process, show and optionally store on SD card, up to eight sensors data, promoting a hands-on experience from setting up to experiment execution in a seamless way. It was tested on a Brazilian seventh grade class, where was taught gravity force and it's effects by doing a dropping test, inspired on egg drop experiment. Was observed an increase of 14% on the experiment class grades and a more engaged students by running the experiments.**

Keywords—LabDuino; Arduino; Embedded Software; Educational Technology; Scientific Education; STEM; Constructionism;

I. INTRODUCTION

The training of professionals in scientific fields is strategic for the technological / scientific development of any country, so the poor quality or lack of such professionals in various fields, increases the external technological dependence, in addition to having to import professionals to work in oil and gas industry, aerospace, civil, chemical, etc.

According to research conducted by the CNI (National Confederation of Industry) in the last decade only 44% of students in engineering courses in Brazil, completed their courses [1] and also the Lobo Institute for Development of Education, Science and Technology points out as the main cause of this result, the deficiency in basic education in mathematics and science [2].

Given such a scenario, it is clear the need, from the early years of elementary education, scientific literacy. According to Professor Luiz Caldeira, Department of Teaching Methodology of the Federal University of Education Center of Santa Maria (UFSM), the lack of presence of scientific methodology in Brazilian classrooms may be related to the low interest of the country's students by science.

The Programme for International Student Assessment [13], puts Brazil ranked 59th among 65 countries evaluated in the category science. The first edition of Scientific Literacy Index - SLI [14], published in July 2014, confirms the alarming PISA assessment: 64% of respondents do not have, or have rudimentary scientific literacy, 31% basic literacy and 5% they are proficient in science.

Still according to this study, the participants recognize the importance of science to everyday life. Ricardo Garcia Uzal President of Abramundo Institute, "is an important clue that there is something wrong in forming the students" [15]. Despite these results, Brazil was the country that registered the highest growth over the averages obtained in the study of PISA, between 2003 and 2012.

Teaching science requires to introduce the student in the ideas and practices of the scientific community and work for students to take ownership of these ideas, or they can internalize the scientific discourse [3], should be create a scientific culture in students. For this is not enough to teach formulas, methods, should correlate this theory with everyday facts [4], instigating curiosity, bring models and practices into the educational environment, students learn more efficiently when they experiment and create your vision of what is being learned [5]. Therefore, it is necessary to access the tools and teaching methods to put into practice such approach.

With the availability and relative ease of access to equipment and technology, anyone with an interest can learn and begin to create innovative solutions to day problems, day. This is the Maker movement, said Mark Hatch [6].

Take this movement to the classroom, giving students the ability to create their solutions to problems of physics, chemistry, mathematics, (STEM subjects), is object of research in science education in institutes like Exploratorium US, Worldfund in Latin America, and Abramundo STEM Brazil (Worldfund arm in Brazil), which enable teachers to implement these teaching techniques in their classes.

There are tools and equipment designed for the teaching of STEM subjects, but for Brazilian reality, especially in the public school setting, the cost of acquisition of equipment and components is high and added to this, much of the software available do not have translation the Portuguese.

The main objective of this work is to develop a low-cost platform, based on Arduino, to assist in conducting experiments in science subjects, collecting, processing and displaying data collected by sensors, applied to classes of elementary school, to facilitate dialogue between student and teacher during the presentation of the matter.

II. MAKER MOVEMENT

According to Mark Hatch, "Making is fundamental to what it means to be human. We must make, create, and express ourselves to feel whole” [6]. Being maker is intrinsically part of human beings, we change our environment, we builded tools and with them, solve problems to suit our needs. This capability has brought us to the current stage of development and differentiates us from other species [7].

Nowadays, is perceptive a great movement around DIY. Creating solutions for everyday problems, with the Arduino, single board PC’s, 3D printers, CNC machines, laser cutters, is accessible for ordinary people. This movement has as keystone sharing knowledge. In the Maker Movement Manifesto [6], Mark Hatch points out the fundamentals principles: (1) Make ; (2) Share; (3) Give; (4) Learn; (5) Play; (6) Participate; (7) Support; (8) Change;

The similarities of these principles with those espoused by Piaget, Papert and others, as will be shown, leads us to think of merging makers practices with teaching STEM subjects.

III. STEM EDUCATION

Pestalozzi, pedagogue who lived between the 18th and 19th centuries and creator of models for kindergarten, believed that learning was naturally achieved the balance between heart (feelings), head (thinking) and hands (do try). Piaget, strongly influenced by Pestalozzi and other ideas, proposed the theory, now known as constructivism, which preaches "... every new truth to be learned must be rediscovered or at least rebuilt for the student, and not simply imported into he” [8] .

Seymour Papert, South African researcher, was based on the constructivism of Piaget and expanded, explaining that students learn more efficiently when this experiment and create your vision of what is being learned [5].

In traditional models of class usually do not put students in direct contact with the object of knowledge. For example, in a typical class, the subject is presented in expository form, and after that are performed a series of exercises to test whether the content has been assimilated. This model gives rise to the student only decorate and repeat the foregoing.

The use of technology in education has always been questioned of how to use it productively. So it was with the radio, TV, computers, Internet, etc. But what is seen in most solutions using these tools, is a disguise for old teaching methods. Still in 1972, Papert warning to this [9]. What is observed is the misuse of technological resources and classes not prepared to use these.

The Papert’s constructionism methodology, put the focus on the interactions student-content, materializing what is being studied, allowing manipulation by the student, allowed an active construction of knowledge.

As seen on the book Invent to Learn by Martinez and Stager, they suggest eight elements for a good project on STEM education, as follow [10]:

- Purpose and relevance: DO project arouses enough apprentice for him to invest their time and effort in its development ?;
- Time: One should be enough time for the student to think, plan, execute, debug, change and expand;
- Complexity: Combination of multiple areas of knowledge and explore the qualities and expertise of each student;
- Intensity: Children have a lot of intensity, which is not used in the traditional school curriculum. The project should be able to exploit it;
- Connection: Students should connect with each other. Lessons learned from interpersonal connections in collaborative projects last a lifetime;
- Access: The student must have access to all kinds of material, whether concrete or digital;
- Shareability: Students must do something that is shareable with others .;
- Innovation: Each student can reach the same goal by different paths;

Keeping in mind these principles and the maker movement basis we see that one complements the other.

IV. STEM EDUCATION AND MAKER MOVEMENT

As noted previously, the maker movement principles to understand the problem, study the solutions, build the solution and share this result. Once constructionism has intercessory points with the maker principles, bring it to classroom, it would be the step to be followed, giving the student the power to use instruments and tools to assist in building solutions, allowing content to be assimilated further. Therefore, the flow of the class should include moments where the student has freedom to explore and create your vision of the solution.

The use of Maker mindset as a facilitator, included in the learning process, allows to explore the creative potential of the child, through programming, design, use of tools and materials, thoughts and sharing projects, etc. Even use of the digital fabrication, that consists in the use of 3D printers, laser cutters, CNC machines, etc. When we add this to proposing the maker movement and the eight points seen previously, it comes perhaps an ideal class model in STEM that empowers everyone involved.

The proposal in this paper is a platform designed to help teachers and students in the knowledge construction on STEM related classes. This platform allows to collect, store and display data from scientific experiment. This solution, along to a class template guided by Papert's constructionism ideas, brings to students a more engaging and meaningful classes.

V. EXISTING SOLUTIONS

For this topic, we searched some projects and products, free or not, for the teaching of subjects related to STEM. For the purposes of this study, it was analyzed the following characteristics: Is the solution open source? Is an affordable/ available on Brazil ? On which platform it was built ? Most common usage on classes.

- Ardusat, design to execute science experiments. Already have several built-in sensors, you can monitor the sensors through a web application. It uses Arduino as a platform. Although claiming to be an open source platform, gathering all materials and components is hard. They sells it in a kit form factor, but it's pricy to import to Brazil

- LittleBits, used for teaching programming, electronic principles / Robotics, but can be use to perform science experiments. The product has several modules that snaps magnetically. The modules are categorized into power, input, output, "wire" and logic. Joining the modules, you can create several things. Can communicate with the network CloudBit module. As the project is open source, you can create a Bluetooth communication module and adapt it to the proposed use in this work. It uses Arduino as a platform. But it's too expensive.

- Mindstorm, used for teaching programming, engineering principles. As LittleBits, can be use to perform science experiments, using Lego blocks. Lego uses a Proprietary platfor. It is not open source, very expensive in Brazil. Despite this, there are several institutions that use it in robotics classes.

- Einstein World, a platform for science education. The company offers a number of integrated features (mobile apps / desktop / sensors). Applications communicate with the sensor platform, called LabMate, and makes the data gathering. Applications help in interpreting the data, the interface and depth of content is tailored to the age of the student group. Teachers can create activities. There is it own Android Tablet / iOS and Android App. Not available in Brazil, pricy to import;

VI. LABDUINO

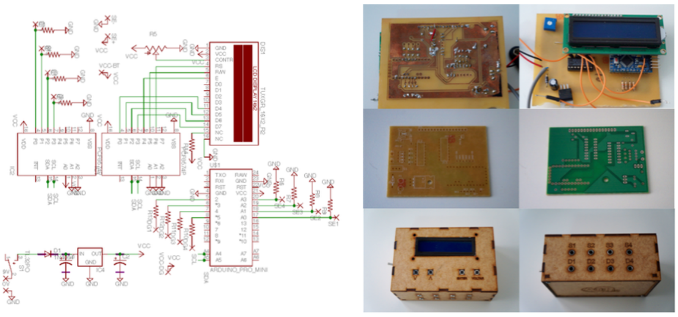
The proposed platform, called LabDuino (Lab + Arduino), is built over, as the name indicates, the Arduino, more specifically, the Pro Mini ATMEGA328P form factor , due to its reduced size and cost.

The choice of this platform was made by it have a wide community of developers, having availability throughout the country, as well the sensors and compatible modules. Besides that, the use of this platform has become popular in both private and public schools across the country, in programming classes and in some cases, educational robotics.

THE HARDWARE

To reach the final hardware version, the LabDuino passed the following stages: Prototyping, using a breadboard, which allows you to quickly add or remove components and do integration testing; Project was created the schematic hardware; Design Board drawing of the printed circuit board and Assembly fase.

In the prototyping stage, it was where the software and hardware have been refined. An example of this was the choice of display type. At first, the Nokia 5110 display that is 84x84 pixels would be used, but it required too many doors to be used, and without possibility of using the I2C protocol, and besides that, the library needed to use it consumed too much memory.



PCB Evolution - The First and the Final Versions

One problem encountered during the hardware design was the number of ports used by the display and buttons (for UI), which left few doors for use in the experiments. The solution to this problem was to use the I2C (Inter-Integrated Circuit) available in Arduino, developed by Phillips in the 80 this bus was specified to connect peripheral devices to low-speed microcontrollers [11]. Using two PCF8574P IC, which implements the I2C protocol, as slaves, one for display and one for the interface buttons, clearing room for use in experiments thus solving this problem. On Arduino, this protocol is implemented in the standard library WIRE.

THE SOFTWARE

To ensure quality of embedded systems, it is common to use state diagrams in their design, according to Wilson Filho, "*state diagrams are used to describe complex logic of complex flows or many details*" [12], being an efficient way to describe systems that are event driven, which is the case of such systems. Therefore, to guide the development of this project the following state diagram was created.

There is three main states as follow, OnMainMenu where a menu is presented in order to choose the subject, OnSubjectExperimentsMenu, where is chosen the experiment and OnExeperiment, where the experiment is executed

The OnMainMenu state is the initial state, where the user makes the choice of knowledge area, for example, the student may choose physics experiments, chemistry, biology and mathematics. Once selected the field or area of knowledge, another menu appears with experiments options on the chosen area, represented by OnSubjectExperimentsMenu state.

After selecting the experiment, you enter the OnExperiment state and are initially displayed relevant information to start this experiment, for example, sensors to be used, which port they should be connected, etc. Then the user are asked to enter LabDuino the initial data of the experiment, if any. For instance, the total track length for average speed experiment.

Finally, after all initial data are informed, the program will obtain the data by reading from the sensors until the end condition is satisfied in the experiment, in the case of the average speed, the object after passing through the initial and final sensor. All code and PCB design is available in a public repository at GitHub (https://goo.gl/22jYS4).

Study Case

The LabDuino was used by students of both gender, aged between 12 and 13, belonging to the same seventh-grade class in a private school in the city of Recife-PE, Brazil.

The subject explored was Math / Physics, more specifically, the free fall and drag (air resistance) taught in the in a class entitled math lab. On this class, students are introduced to some physical concepts to illustrate the mathematics content studied in class.

Students in this class at the beginning of the scholar year, were randomly divided into two sub-classes by the academic board. Each sub-class has it's own teacher. Each class occurs once in a 2 week period alternately. Sub-class A.1 in a week, and A.2 sub-class in the next week.

For test purposes with LabDuino, it was agreed that during the trial period, the same teacher ministered classes for both sub-classes, to have the same educational standard. The class where was held the trials, was not the teacher's original sub-class.

Participants had never studied the physics concepts covered by formal means, (this physics subject is only part of the curriculum in the 9th grade). Within these two groups, the class A.1 for now on call control group, with 18 students, the didacticism to this class remained the same planned by the teacher, that is, applying expository techniques, making use of the blackboard. In the other hand, the class A.2 class, from now on called experiment class, with 19 students, was planned for use of Labduino, making free-fall experiments and aerodynamic drag.

Experiment Execution

In the experiment group, there were two moments, the first occurred during the first class, with basic explanations about the math involved, since it is the ultimate goal of this class. In the second class, it was dedicated to the preparation, execution and analysis of free-fall - aerodynamic drag experiments.

Previously, together with the teacher, was included in LabDuino the free fall experiment, that used a three-axis accelerometer, in order to store the fall data, a memory card module was added to LabDuino. Those datas was used during analysis moment at class, yielding a plot of acceleration over time.

The experimentation was based on egg drop experiment. The LabDuino and eggs was dropped from a height of 4 to 5 meters with and without a kind of parachute. Not to destroy the equipment and also protect the eggs during the trial, there was a maker moment in the classroom to build a sort of protective shell. After this stage, the students went to the school courtyard and climbed to the first floor of the building, in order to carry out the launches.

After the trials, returning to the room, the plot of accelerometer data was made and the results were discussed, many questions were asked. Was notorious the engagement of students throughout the process, with very pertinent questions to the subject and the excitement and curiosity.

Exam Results

In the week after the students worked with LabDuino, the whole class (Control and Experiment), was submitted to regular exam, in which happens every month, with the subject given in class.

In this particular exam contained three questions, two of them about free fall and another about air resistance, as follow : (1)Knowing that the object takes 3 seconds to reach the ground. Determine the height of the building; (2)Who first fell an elephant or an ant? Considering both vacum and non-vacum environment. Justify your answer; (3)For an action movie scene, a car was released from the top of a ravine, 245 meters height. Determine how long the car took to reach the ground. Given $g = 10\ m/s$

The control class reached a score of 46 of 100 and the experiment class reached 60 of 100, a 14 % improvement.

Even though the choice of students for each class have been random, there is the possibility that the experiment group has had a concentration of students with a history of better school performance. To refute such condition, is needed a longer observation, and class interchange, control to experiment and vice versa.

VII. Conclusions

As seen in the previous session, the experiment group obtained 14% better score. But to confirm this fact, we must do a study with a larger number of participants in public and private schools and for a longer period of time, and observe if the income between the control groups and experimental remain favorable to experiment group and also by exchanging the roles between classes (which was control, be experiment and vice versa). This way you can reach a more conclusive result. But from what was observed during the trial, the students engaging in the activity,as well the curiosity expressed to understand the phenomenon, voiced by the questions asked throughout the process, associate this to the difference obtained in yield examination indicate that, even if true the hypothesis of non-homogeneous classes, it is expected that classes with constructionist practices / Maker with application technology, helps communication between teacher and students, and in fact, improves the assimilation of the content of STEM subjects.

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