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A framework for K-12 engineering education at low budget institutions

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ABSTRACT

Peruvian students demonstrate poor performance results in math, science and reading. Critical thinking and significative learning is avoided or rarely infused in the classroom. Teachers are content-oriented, and it is pretended that all students learn the same material at the same time, ignoring individual interest and motivations. Also, the national curriculum ignores cultural diversity and particular necessities in each town and city. Moreover, there is a strong rivalry among schools and low cooperation among teachers of the same school. The Internet features plenty of resources for engineering education. Also, there is low-cost hardware and free software for a variety of engineering projects in the K-12 level.

This paper describes a framework for an integrated science, technology, engineering, and mathematics education approach considering the current context in the Peruvian education system. An ad-hoc methodology was used to promote students interest in engineering by developing extracurricular workshops with an emphasis in electronic engineering, computer science, and physics experiments. We described some engineering workshops and computer programs developed along many years, including a simulator that is being used around the world for logic circuit design. In our experience, building interests in science and engineering can be addressed with extracurricular workshops in an informal setting. We think we must persist in STEM education by reaching all interested teachers and students.

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1. INTRODUCTION

According to PISA international evaluations, Peruvian students demonstrate poor performance results in math, science and reading.[1] This situation limits prosperity and the ability of Peru to compete globally. Many Peruvian schools are equipped with computers, and many people have Internet access, but lecturing still is the teaching style while the learning style is passive and memoristic. Evaluations measure how well students are able to remember facts and follow procedures. Critical thinking and significative learning is avoided or rarely infused in the classroom. Teachers are content-oriented, and it is pretended that all students learn the same material at the same time, ignoring individual interest and motivations. Also, the national curriculum ignores cultural diversity and particular necessities in each town and city. Moreover, all teachers have a low-paid job, and many of them work in problematic places, and also there is a strong rivalry among schools and low cooperation among teachers of the same school.

An integrated science, technology, engineering, and mathematics (STEM) education to achieve significative learning and practical skills is necessary for a competitive and rapidly changing world. Standards, books and reports for STEM education can be downloaded from the National Academies Press.[2–6] Top-ranked universities, like MIT, Stanford, and Berkeley, provide materials for K-12 education.[7–9] NASA Education, Intel Education, Edutopia, and Science-Buddies are supporting science and engineering projects by providing high-quality curriculums and lesson plans. MOOC courses from edX, Coursera, Udacity, and Novoed address a number of STEM disciplines. TV programs and videos from Redes, Euronews Learning World, and Teaching Channel show examples of education issues on different settings and contexts around the world.

With respect to technology access, low-cost hardware (sensors, motors, microcontrollers, programmable logic devices) for a variety of engineering projects in the K-12 level are available directly from local and international distributors. Software for computer-assisted design and simulators (electrical circuits, physical structures, industrial processes, scientific experiments, etc.) and programming environments can be freely downloaded from the Internet. However, in many Peruvian schools, cheap still means expensive while easy access to information does not imply understanding.

In this context, how can low-budget and low-performing schools provide a high-quality global education? Next section describes a framework for engineering education that addresses local concerns, problems and necessities by looking for practical solutions under an integrated STEM approach. Section 3 describes some tools developed and how this approach has been applied in a couple of school workshops. Section 4 presents the overall results with this methodology that are discussed later in section 5. Finally, conclusions are stated with a mention to future work.

2. A FRAMEWORK FOR K-12 ENGINEERING EDUCATION

This framework has been designed following pedagogical recommendations[10] and considering the current Peruvian education system. Given the limited technology and academic resources in Peruvian schools, the initial objective for this framework is building science labs and engineering design workshops from scratch. This way, it can help to foster constructive and autonomous learning by providing multiple low-cost but practical resources as well as many analysis and design opportunities for real-world problems and necessities. For instance, mockups and prototypes can use recycled objects found in schools, homes, stores, etc. After the experience gained from a number of extracurricular engineering workshops freely developed at a public school, we have found two critical issues: 1) building and promoting a culture of cooperation and team work among schools, communities, and local governments for a significative and productive learning, and 2) using, adapting and creating tools according to students' learning styles for a personalized education.

Figure 1 illustrates an approach to address these issues. Instructional objectives are selected to promote higher levels of thinking according to Bloom's taxonomy. Activities for students are aligned with the 5E instructional methods and are closely related with the project-based learning and the inquiry-based learning to develop understanding, abilities and skills in engineering design and scientific inquiry. Fostering mathematical reasoning and technological creativity provides an integrated STEM education. Formative assessment is applied along the entire course period. Instruction begins with the teacher presenting a variety of applications and mechanism and ends with the students demonstrating their investigation results and designed prototypes. Over time, the instruction responsibility goes from the teacher to the team of teachers and students. This way, teachers and students can build concepts, tools, designs, and prototypes. They talk to the community frequently to

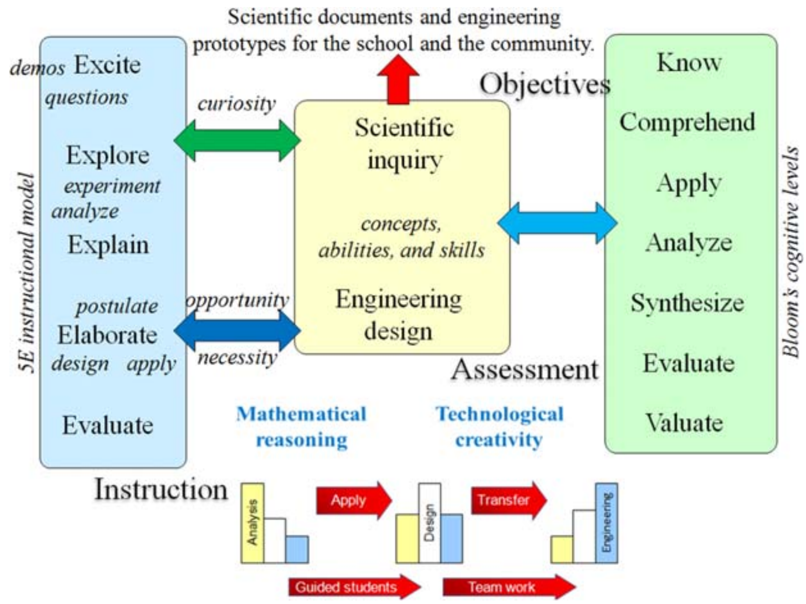

Figure 1. A framework for engineering education integrated with STEM.

know, specify, and develop solutions by applying what is learned in school. Also, teachers gain time to develop custom learning styles and tools for each student in order to achieve their full potential and become autonomous learners.

3. APPLICATIONS

An ad-hoc methodology was used to promote students interest in engineering by developing extracurricular workshops with an emphasis in electronic engineering, computer science, and physics experiments. We provide computer tools and design opportunities so students can gain familiarity with different representations and analysis of information by playing with a variety of technologies for a number of useful applications.

Electronics: Logic circuit design

Figure 2 shows some practical circuits with different abstraction levels for logical digital design. The program used helps students to learn and reinforce their logic design concepts and methods from several perspectives.[11] In an introductory class, students are first **engaged** with alarm and control systems based on mechanical switches, movement sensors, laser rays, temperature sensors, DC motor controllers, water supply systems, and traffic controllers—among others circuits—both in real and virtual versions. Then they **explore** how a NAND circuit works by building the circuit in the computer and on the breadboard, and later they build and analyze the truth table looking for patterns. Also they write pseudo-codes to describe and **explain** the logic functions. Working in groups, students analyze other basic circuits (NOR, AND, OR). With teacher's support, they **elaborate** more complicated circuits such as full-adders, comparators, latches, flip-flops, and counters, and then use them to design practical solutions to real problems. Finally, students compare their initial understanding about logic circuits with their current achievements, and then they make plans for new designs.

At the end of this lesson, students are able to **know** many circuit descriptions, **understand** how to build different circuits to do the same functions, **apply** logic concepts to discover more functions, **analyze** schematic circuits, identify circuits on schematic diagrams and on breadboards, **design** a variety of circuits for practical applications, **evaluate** and communicate their results to gain feedback, and **appreciate** their work and learning process. The entire course follows a hardware-software co-design approach. Students are animated to build their own microprocessor (hardware) and to design their own instruction set and programming language (software) so they will have a close encounter with the fundamentals of electrical engineering and computer science.

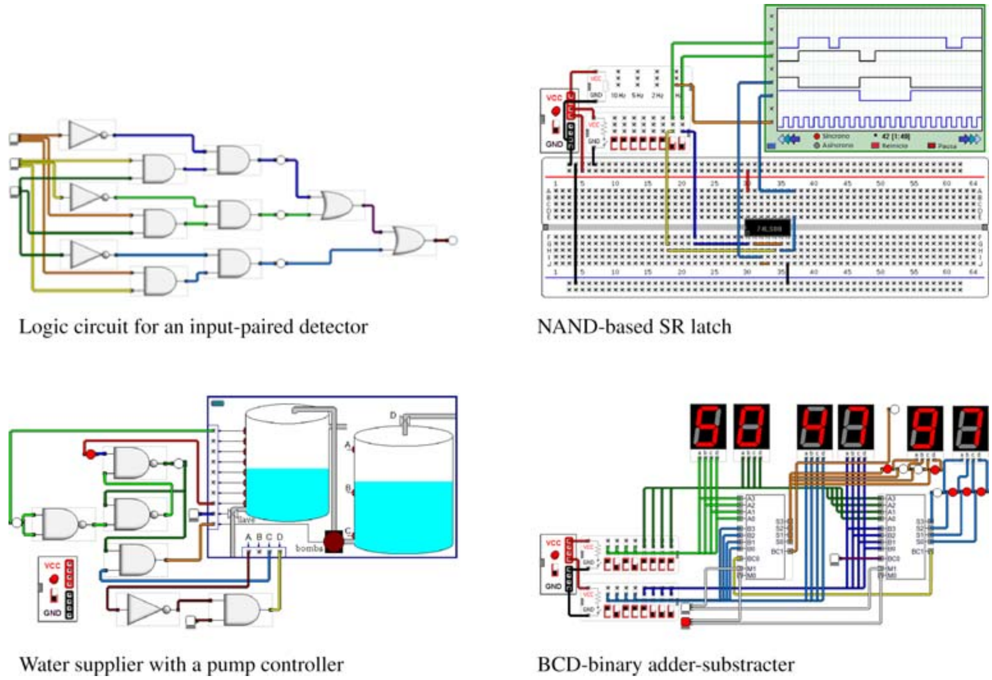

Figure 2. Some circuits used in an introductory class to logic design.

Mathematics: Triangles and circles

Many concepts in mathematics are too abstract for students. Relating abstractions with real world applications can help students to grasp difficult concepts. For instance, an odometer can be designed to measure perimeters or long distances by using electrical and mechanical components attached to a wheel and by applying the rate between the circumference and diameter of the wheel. This relation can be found through measuring the diameter and circumference of various disk-shaped objects. In the same way, students can discover relations between angles and sides of different-sized triangles and then apply their findings to calculate the height of trees and buildings. Then the teacher can introduce the trigonometry functions. Further, students can develop a design to read the height automatically by using an LCD display, accelerometers, microcontrollers, potentiometers, and other electronic circuits.

Physics: Electricity and kinematics

Figure 3 shows some computer programs for teaching and learning fundamental concepts in electricity and kinematics. These programs help students to discover Coulomb's law and superposition principle by moving virtual-charged particles, and found electrical properties (Ohm's law, Kirchhoff's laws, Thévenin's theorem, Norton's theorem) by changing the circuit operation conditions. Students can obtain data by reading virtual instruments, and they can build tables and analyze response curves in order to find mathematical relations. In the same way, students can analyze virtual experiments to learn how gravity acts on falling bodies. They deduce free-falling and compound movement laws and can design experiments to calculate local gravity acceleration by using electronic counters. Guided by their teacher, students learn how to choose components such as integrated circuits, resistors, oscillators, and sensors. Next, students analyze the trajectory of projectiles. This experience incorporates **science** (scientific method), **math** (functions, calculus), **technology** (electronics, computing), and **engineering** (design of experiments and tools to capture reliable data).

4. RESULTS

For over ten years, we had developed many short-time workshops for engineering design with different results. The programs described above have been developed along those years. In the last years we invited others high schools in the Peruvian coast to participate in these workshops, but there was no interest over the long term.

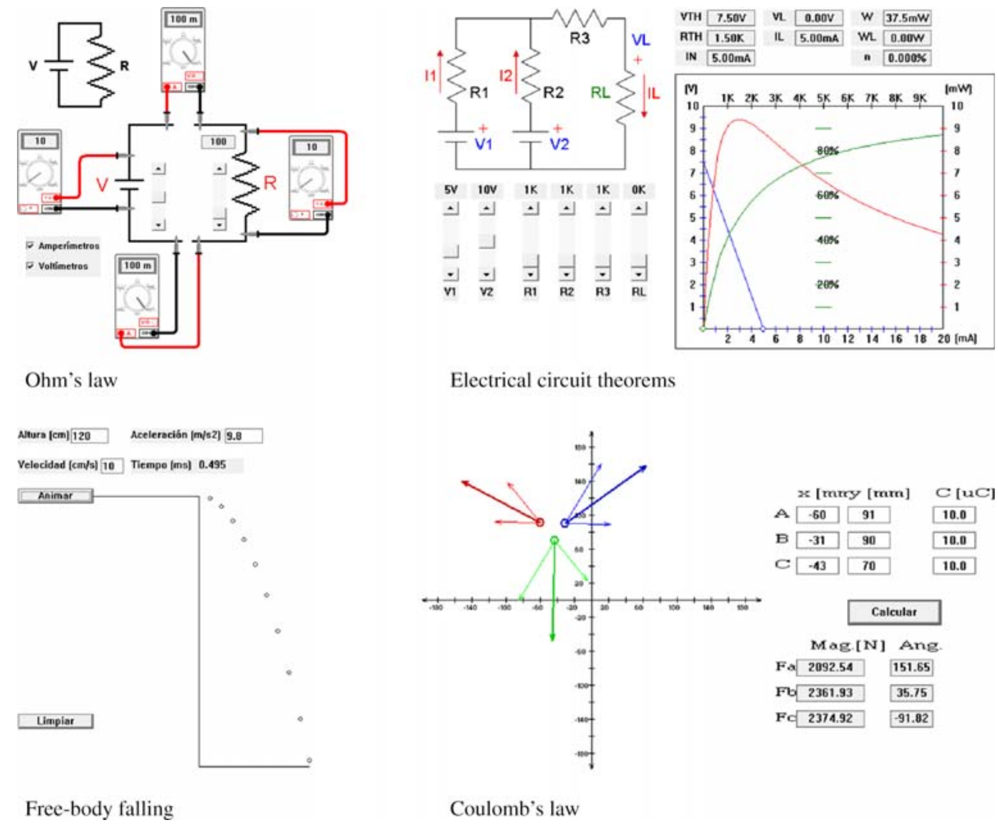

Figure 3. Computer programs for physics virtual experiments.

A number of extracurricular workshops have been developed at public high school José Pardo y Barreda, Chincha-Peru. Some results were positive. Once, one team won a third place in a national electronic engineering contest. Two years later another team won this contest and an opportunity to participate in an international science fair. Up to today, three students of the first workshops are pursuing or have obtained electronic engineering degrees. Of course, we have learned from many mistakes. In weekend workshops we have few students when compared to daily sessions. Weekend sessions carried more problems because of inertial issues raised along the previous week. It was more difficult to maintain a work dynamics. However, after working on a daily basis, we returned to the school one month later and the students behaved as the first day: all silent. Indeed, culture wins.

Recently, we had the opportunity to work with students in the K-8 grades. They built some simple electrical circuits and mechanical devices. The kids were happy but time was too short and the number of them was too high for developing advanced concepts and abilities. This experience makes us believe that there is hope for developing more science and engineering workshops in Peru.

5. DISCUSSION

Based on our experience, an integral combination of project-based learning and inquiry-based learning seems to be the best methodology to reach most students in the classroom, together with a close attention to the learning style of all students. Since students love sounds, automatic movements and lights, robotic projects seem to be an optimal start to attract them to the fields of science and engineering. On the other hand, we need to learn new forms and be more creative to convince teachers for team work. We believe understanding how students learn will help us to improve the education system. Also, we need to pay more attention to assessment techniques and tools.

6. CONCLUSION AND FUTURE WORK

Building strong science and math foundation for student success, and interests in science and engineering is a tough mission in the current Peruvian education system. In our experience, building interests in science and engineering can be addressed with extracurricular workshops in an informal setting. Without establishing clear and sound connections to technology and engineering, science and mathematics will mean just formulas and equations to most students. Seizing global opportunities and facing local challenges can be reached only with organized teamwork, but current pressures on standardized curriculum impose serious limitations to this objective. However, we think we must persist in STEM education by reaching all interested teachers and students. For instance, a science and engineering club seems to be an optimal start, although a main issue is how to convince teachers and administrators to favor and support cooperation over competition.

Currently, a 4-year curriculum for high-school students is being developed under the framework described above with an emphasis on digital electronics and computer programming. It includes industrial-class microcontrollers and programmable logic devices, VHDL and Verilog hardware description languages, and C++ and Python programming languages. On the way, students will learn how to create digital systems like microprocessors and memory units, and specify and build their own computer languages and compilers. Also, we are interested in more modular designs that allow easy reusing of components so we will work in remote access laboratories to facilitate sharing of designs and experiments.

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