Reverse Problem-Based Learning

A Case Study with a Braille Machine

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***Abstract*—Engineering Education includes not only teaching theoretical fundamental concepts but also its verification during practical lessons in laboratories. The usual strategies to carry out this action are frequently based on Problem Based Learning, starting from a given state and proceeding forward to a target state. The possibility or the effectiveness of this procedure depends on previous states and if the present state was caused or resulted from earlier ones. This often happens in engineering education when the achieved results do not match the desired ones, e.g. when programming code is being developed or when the cause of the wrong behavior of an electronic circuit is being identified. It is thus important to also prepare students to proceed in the reverse way, i.e. given a start state generate the explanation or even the principles that underlie it. Later on, this sort of skills will be important. For instance, to a doctor making a patient's story or to an engineer discovering the source of a malfunction. This learning methodology presents pedagogical advantages besides the enhanced preparation of students to their future work.
The work presented on his document describes an automation project developed by a group of students in an engineering polytechnic school laboratory. The main objective was to improve the performance of a Braille machine. However, in a scenario of Reverse Problem-Based learning, students had first to discover and characterize the entire machine's function before being allowed (and being able) to propose a solution for the existing problem.**

***Index Terms*—Engineering education, problem based learning, reverse problem based learning, reverse engineering.**

I. INTRODUCTION

The function of the engineering profession is to manipulate materials, energy and information [1]. Teaching the several subjects includes information about theory that must be complemented by experimentation, in order to construct the knowledge. This complementarity can be achieved by a demonstration of learned concepts or by verifying if some experiment meets the specifications. Furthermore, it is necessary to allow for independent and non-specific laboratories, with some autonomy to support work in unusual areas. Thus we can identify several kinds of laboratories that are usually linked with the student autonomy level. The way how the laboratories can be accessed is also changing, taking advantage of the recent Information and Communication Technologies (ICT) advances. In the past, the traditional labs were physical locations where the teachers and students cooperated. Then the virtual experimentation appeared, allowing the student to perform experimentations alone. More recently we see the promotion of remote experimentation labs that allow the student to execute a real experiment, but one that takes place elsewhere [2]. All of these labs have their own relative advantages at several levels such as social interaction, cost, autonomy, educational means, behavior training, etc. Some are less expensive but the experiments are developed independently and so the student social skills are not considered. Others are more costly but have the advantage of the presence of others students and tutors.

Today's universities are changing education methodologies, largely driven by economic reasons. In just a few years the education processes evolved from an empiric model to a complex and efficient one. In the engineering field, degrees tend to be shorter and focused on a very specific knowledge area. To illustrate several subject parts, some problems are proposed in a very artificial way. Training questions have a tendency to include a set of very well defined start conditions and a desired state. This kind of exercise only allows students to put into practice they own subject skills. Among several advantages this methodology presents also some limitations, as in the real world the posed questions aren't always completely defined. In fact, an important part of the engineer job consists exactly of unexpected behavior detection and the subsequent system diagnosis and correction. The work described in this document presents an experiment based on the automation of a stereotype Braille machine. The specific project objective was the conversion of a manual equipment into an automatic one. Unlike others projects, developers first needed to autonomously understand the equipment before proposing any kind of solution.

II. THE EDUCATIONAL MODEL

Each school has its own principles, although frequently based on a common model [3] and so it happens with the associated learning strategies. However, these can no longer be static and are becoming increasingly dynamic in order to take advantage of recent technological or social advances, being a constant challenge for the educators. Good teaching should include a balanced distribution of the mentioned advantages to achieve the fundamental goals that are listed on the schools principles. The education model is rising in efficiency but also in complexity. The traditional education model has been upgraded by adding information collectors, outcomes and set points. The traditional open loop education model gave room to new ones, frequently based on closed loop approaches, with various set points and feedback information. One motivation for this originates from prospective employers and is related with the manner how graduated students react in the presence of partially solved problems. In the real world, sometimes it is necessary to propose a solution for a given problem that was earlier addressed by somebody else. In most of these cases we have only a few pieces of information and, sometimes, no information about the main guidelines that drove the project. In these cases, recently graduated employees tend to be confused and are hardly able to propose any solution. One reason can be found in the way how student's exercises are proposed and solved. Electronic engineering degree includes several subjects ranging from the usual introductory courses progressively to higher level subjects as Electronics or Design for Debug and Test [4,5]. The main reason for this particular course is that every electronic circuit should be planned with an underlying test strategy. Nowadays we use several programmable and configurable devices (e.g. microcontrollers and FPGAs) that are increasingly used in the real world. Nevertheless, experience has shown that is very rare to develop a correct program at the very first attempt. The common practice consists of detecting the circuit error (i.e. different from the expected), diagnosis it (i.e. identify why), and remove the error (i.e. correct the code/design). All these tasks are critical and a good student should develop adequate skills to face all sorts of inevitable issues when developing a project. The training is usually performed by executing a set of proposed exercises.

In summary, teaching strategies that include Problem-Based Learning (PBL) have proven to be useful as they help to incorporate several students' learning styles as well as making the interaction between all the intervenient on the classroom easier. PBL allows the integration of several students with different learning styles to produce different solutions, eventually using brainstorming. The traditional PBL is used when a student faces a problem with incomplete data and intends to achieve a solution based on his own knowledge. In this approach it is very important to define a clear objective, propose solution strategies and elect one. Basically the student has a start point (Start state) and needs to know how to go to the desired goal (End state). Figure 1 depicts this methodology.

Another important issue, however, is to also have a mind trained for the reverse operation, i.e. given a start point the student needs to develop a set of motives that explain why we are in present state. That means the start state is itself an unexplained consequence of one previous state which needs characterization. Figure 2 depicts this methodology.

In medical school, for instance, the PBL starts from facts and the student is required to use his background knowledge to perform an elaborated diagnosis. The reverse process can be called Reverse Problem Based Learning (R-PBL) and is when the student generates the case history [6]. In engineering these skills are also important, even if not always taught in a structured way, and can be included into the so called Reverse Engineering. In the specific case of electronic circuits, several approaches have been developed to support debug operations in digital and mixed-circuits [7,8], that intend to locate, diagnose and remove malfunction causes. More often the development of R-PBL skills takes place indirectly, during a PBL approach when the student finds out that a solution does not match the desired behavior. He will eventually discover what is wrong and, during a very important little time, understand that the obtained and the expected results were different and even so, coherent with an involuntary mistake. Usually this kind of circumstances takes place during the laboratorial classes of electricity, electronics or even when developing program code.

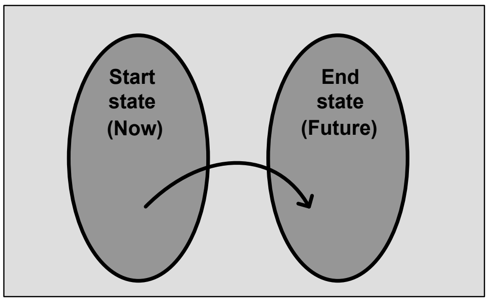

Figure 1. The traditional PBL methodology.

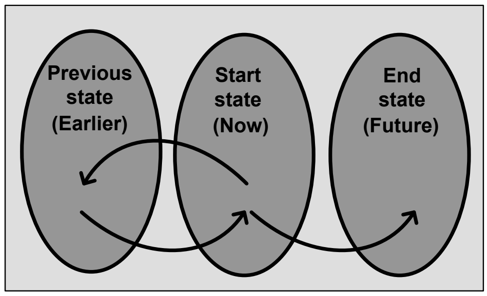

Figure 2. The traditional PBL methodology.

Improving the R-PBL skills is important because later on a significant number of students will need it for diagnosis during the debug phase in electric or electronic circuits or, more often, when coding programmable or configurable circuits. More important, when used as a teaching methodology it has been reported that this type of leaning increases the mastery of concepts [9] and improves course scores [10].

In the next section we describe an experience that took place in a polytechnic engineering school, in order to illustrate the discussed concepts. The lab involved was not a typical class laboratory but one associated with a research group. Teachers were near and available but not always present. The assignment consisted of reusing an old electro-mechanical machine and converting it into another with better performance, using modern digital technologies. The work included an initial phase where the students should completely understand the equipment, based on the incomplete information available. Students relied on the knowledge from several already studied subjects, such as electrical machines, electronics, informatics and microcontrollers. Furthermore this work was inserted in the school objectives framework, namely the development of significant activities for the surrounding community. Despite the several issues involved in this project, namely educational, training, multidisciplinary integration and R-PBL engineering training, this document is focused mainly on the technical difficulties and the advances achieved by the student workgroup.

III. THE TARGET

The proposed target was a stereotype Braille machine provided by an institution dedicated to blind individuals' support [11] located into the same conurbation of the school of engineering. The Braille alphabet consists of a series of characters resulting from the combination of six dots. Figure 3 presents the generic Braille matrix and the first three letters of the alphabet.

Printing on Braille, in the present context, consists of changing a flat surface of paper sheet into a wrinkled one, thus forming the Braille characters. The used Braille printing process depends upon the number of identical copies that are required. For only one or a small number of copies a direct printer machine is usually used, which uses a matrix of six needles that directly prints the paper characters one by one, forming the text. This procedure is very practical for traditional books or publications and is performed using a special printer directly connected to a PC. However, this process is very slow, being only used to address small requirements, as in order to produce a single book the printer must be working for a long time, e.g. 8, 12 or more hours. An alternative for large scale publication, such as daily or weekly newspapers or magazines, is another process based on the stereotypy press that allows printing several (two, three or more) full pages per second. This process includes two steps as represented in the Figure 4: the plate production and the high speed Braille printing.

The first process, the plate production, starts with a pair of flat aluminum sheets we call the Upper Aluminum Plate (UAP) and the Lower Aluminum Plate (LAP), which are directly printed (Figure 4a). At the end of this process, we obtain the formed UAP and LAP (Figure 4b). After that, these two plates are transferred to another machine for the second part of the process where plates have now the function of master printer plates. A sheet of paper is then introduced between the two plates and pressed (Figure 4c), originating a fully Braille pressed paper.

Our proposed work concerns only the first process. At present it is entirely performed by a worker using a stereotype machine, where each character is introduced manually one by one. Figure 5 a presents a common stereotype machine, e.g. a plate printer, being operated by a specialized operator.

This process includes several steps as follows: (1) the operator reads the target text, he (2) mentally executes the translation for Braille and, (3) for each printed character he presses the correspondent set of six keys to obtain the Braille character. Obviously, this procedure is very slow and fastidious.

The objective of the proposed work was to automate the stereotype plates' production machine. In the end the operator should only be required to send simpler and high level task orders such as "load a text" or "print the text", during the entire plates execution.

IV. THE STRATEGY

The proposed work methodology was basically divided into two main tasks. The first was to completely understand how the actual machine works and the second was to propose and implement a solution according to some externally defined requisites.

The first task was a basically different problem from the usually proposed to the students during their education in engineering because, instead of starting from a known state and being directed where to go, they were proposed to execute reverse engineering tasks in order to understand how the machine worked and what were the principles related to it. This task can be viewed as an R-PBL problem, as the students must understand the original underlying machine project principles. This was the most important and challenging part of the proposed work for several reasons. The first one was the lack of information about the machine, as it was a very old model built in the late sixties. Another was the multi-disciplinarily actions required as the machine had several different parts, both mechanical and electrical (or both) and the final solution also required considerable electronics and informatics knowledge.

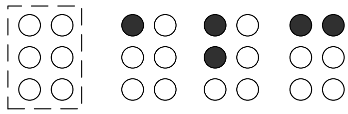

Figure 3. The Braille matrix and the A, B and C characters.

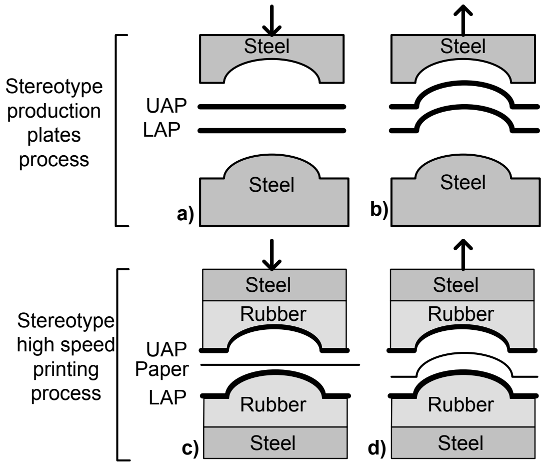

Figure 4. The stereotype production scheme.

Figure 5. The stereotype machine used for plates' production being operated by a specialized operator.

The second task was the design and implementation of a solution that generically required the installation of a microcontroller into the machine to communicate with an external PC. Note that the solution can only be implemented after and as a consequence of the first task, i.e. the two tasks cannot be developed in parallel as classically defined in a PBL approach.

The institution where this process is currently being used has two stereotype machines, where the number one is in use and the number two (the cannibalized machine) is currently used to provide spare parts to the number one machine when something breaks. The work was executed in the machine number two but it should be later extended to machine number one. This objective imposes some constrains, as the proposed solution must be easy to extend from machine number two to machine number one, thus requiring modifications to be minimized. This condition must be in the top of the generic specifications when they are later listed.

V. THE RESULTS

This project was elected by a workgroup of three students that found it particularly interesting and challenging. During the work they periodically presented their reports with preliminary results, first about their own understanding of the machine and components and later about the proposed solution. Their findings are briefly described in this section.

The machine can be considered as a XYZ motion device as represented in Figure 6.

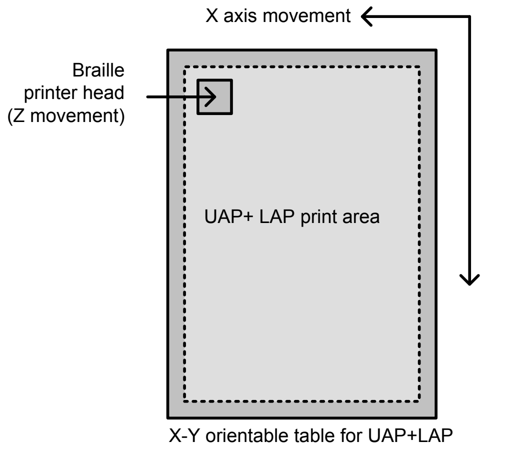

Figure 6. The principle of the XYZ table from the stereotype machine.

The entire motion resembles an old regular paper typewriter machine. The UAP and the LAP form a set of twin plates which can be moved in the X-Y directions. Every time the operator press a set of keys corresponding to a Braille character the printer head goes down (Z+) and then up (Z-). After this, the machine increments the X step, going to a new position and waits for the next character. Note that in the traditional inkjet printers the paper is static for X and it is the printer head that moves, starting in the right side. In the stereotype machine this is reversed, i.e. the printer head only has Z movement and it is the twin plates that have X-Y movement. After several characters are printed the end of line is reached and so the operator must press the Carriage-Return key, resulting on the twin plates moving to the X=0 and Y=1 matrix position, e.g. the beginning of a new line. At the end, when all the twin plates are printed, the operator changes them for a new pair of twin plates.

The Y movement is provided by a common 24V DC motor as shown in figure 7.

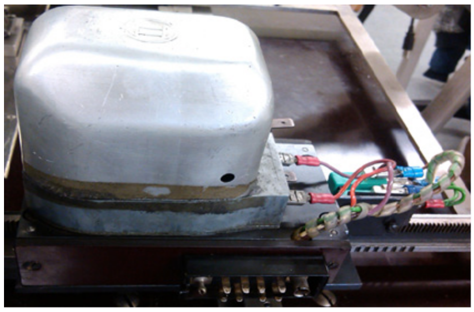

Figure 7. The Y axis DC motor.

Its control is based on three traditional states: motion Y+ state, motion Y- state and standstill state. The use of one permanent magnet DC motor was interesting because it is a real use of a machine already studied. Later on, the students were faced with the problem of how to increase its speed to obtain a better printer performance. The increment of the applied voltage resulted in higher speed but also in poorer position precision. They finally adopted a scheme were the motor was shorted-circuited during the standstill state. This kind of motor is a reversible motor-generator machine. During the Y+ or Y- motions the machine is working as a motor, converting electric energy into rotational kinetic energy. During the standstill state the machine switches to generator and its kinetic energy is transformed into electric energy that is quickly transformed into heat, which allows the motor to stop faster, thus improving the position precision. In fact this scheme is frequently used on cars' windshield wipers movement.

The X movement is provided by a special torque motor shown in Figure 8.

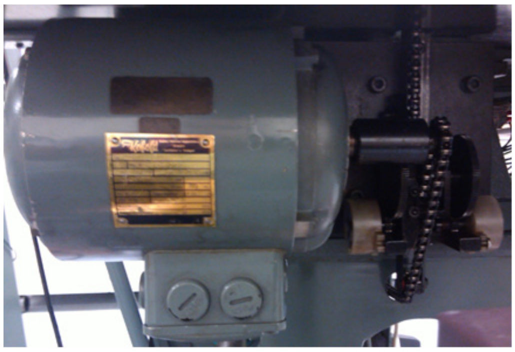

Figure 8. The X axis motor

Unlike others motors this one does not have speed as the output variable but torque instead. In this application the motor has only two states: X torque+ state and X torque– state. That means the X-Y table is generally tensioned on the X+ direction. Every time a Braille character is printed the Z-movement mechanically releases the X for one step only. This fact was very interesting to the students as they had never studied this type of motor before.

The printer head principle is presented in Figure 9.

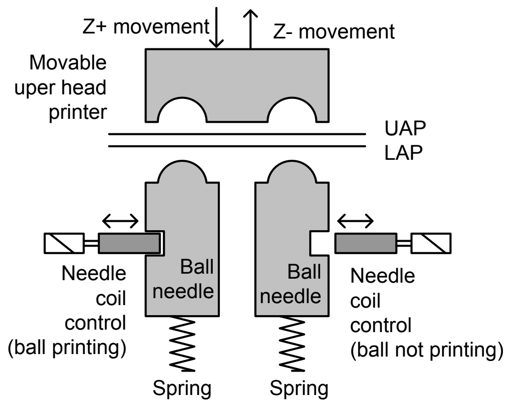

Figure 9. The printer head.

The printer head is basically a matrix where the Braille characters are printed in the twin plates and can be divided in two parts. The upper part has movement Z+ (down) and Z- (up). The lower part is static and includes the 2x3 ball-needles matrix for printing the twin plates. Each ball-needle is controlled by a control- needle that is activated by a coil. Each coil is directly connected to the operator keyboard. When the operator presses a combination of keys, the activated coils introduce the control-needles into the respective ball-needles. This prevents some ball-needles to retreat and then, when the upper part of the head goes down, the respective ball is pressed into the plates. The other ball needles are only compressed against the spring and retreat and so they do not print a ball in the matrix character.

The Z axis movement is provided by a three-phase motor, together with a set of mechanical and electromechanical components as depicted in Figure 10.

The system includes a motor Mz, an electro-clutch, a camshaft and finally a mechanical linkage to the upper part of the printer head. The electro-clutch is controlled by two coils where one of them is always activated. When coil 2 is active no movement is transmitted forward. When coil1 is active, the motor axis is directly connected to the camshaft where the rotational movement is transformed into a linear up-down movement. This last component is mechanically linked to the upper part of the printer head.

The system includes two control boxes, the electric one and a relay control one, the last later replaced by an electronic box. This includes a motherboard with six Printed Circuit Boards (PCBs), each having only one connection to the mother board.

In the end of the first part the entire system was completely studied and documented, resulting on 45 electric schematics. This work was important because it allowed to completely characterize the entire system. At this point we had a lot of information that explained how the machine works. So we were in an excellent position to move on to the next state that was the proposal of a solution for the initial problem.

The proposed solution should accomplish the previous referred requirements to minimize the overall changes into the machine. Thus the students designed and implemented a new set of PCBs to replace the all original ones. The overall solution is presented in Figure 11. Instead of using a set of PCBs with only one connection to the motherboard, in this new solution each PCB was specifically designed to monitor or control signals pins from the motherboard.

To achieve the required objectives we now had several connections between the new PCBs. These consist of an input signal board, an output signal board and a microcontroller board from ARDUINO. Some PCBs are dummies, i.e. they do not have any components but only electrical connections to provide signals to the input board or distribute signals from the output board. Figure 12 shows the input and output PCBs installed into the electronic box.

The microcontroller PCB is connected to the PC via a USB connection. An applet in C# was developed on the PC side of the application in order to allow the operator to load a text and send it to the Braille machine. Additionally, the applet allows monitoring several parameters and the input/output state variables.

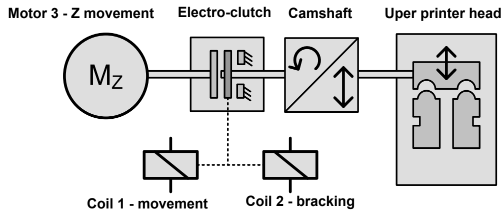

Figure 10. The Z movement generation.

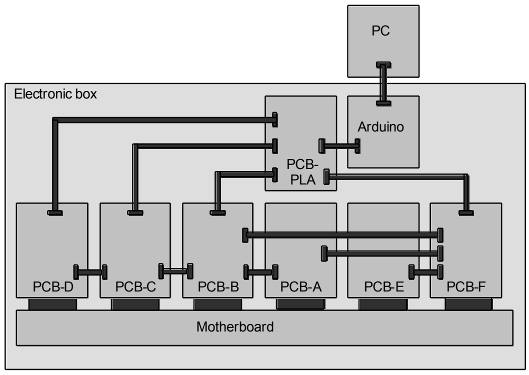

Figure 11. The new PCBs scheme on the electronic box and the PC connection.

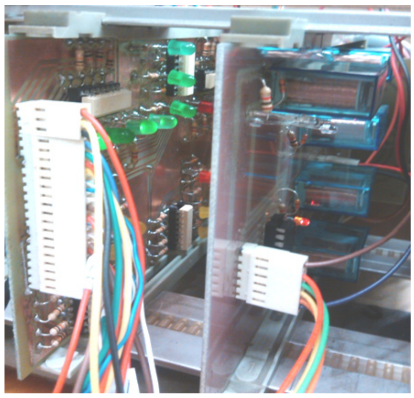

Figure 12. The electronic box with the new PCBs installed.

VI. CONCLUSIONS

This document describes a project which deals with engineering education in laboratory and was proposed for a students' group. Unlike other similar projects, this one clearly imposes a methodology that is both unfamiliar and difficult to students but also challenging. The former aspect emerged as essential during the project selection phase.

The proposed work involved PBL and R-PBL methodologies. This last methodology revealed itself much more complicated than expected. In fact, students were quite familiar with PBL but they were more adverse to R-PBL. PBL methodologies are so effective and straightforward that cause some feeling of a waste of time when trying to understand what underlies the current state. In the described project, several times the students proposed to completely disassemble the machine in order to build a new one from scratch, i.e. to eliminate the R-PBL part and develop the PBL part only. However, in the end they were able to understand the importance and real-world purpose of the proposed work, as a way to develop a simple, yet effective solution for improving the performance of an old Braille machine.

REFERENCES

[1] L. D. Feisel and A. J. Rosa, "The role of the laboratory in undergraduate engineering education," *Journal of Engineering Education*, vol. 94, issue 1, pp. 121-130, January 2005. http://dx.doi.org/10.1002/j.2168-9830.2005.tb00833.x

[2] Carlos Manuel Paiva, Pedro Nogueira, Gustavo R. Alves, Arcelina Marques, Pedro Guimarães and Rubem Couto, "Flexible Online Apparatus for Projectile Launch Experiments", *International Journal of Online Engineering (iJOE)* [Online], Volume 9, Special Issue 1: "REV2012 Exhibition", pp. 35-36, 2013

[3] L. D. Feisel and G. D. Peterson, "A colloquy on learning objectives for engineering educational laboratories," *ASEE Annual Conference and Exposition*, June 2002.

[4] Manuel C. Felgueiras, Gustavo R. Alves and J. M. Martins Ferreira , "A built-in debugger for 1149.4 circuits, *Proceedings of 13th International Mixed Signals Testing Workshop and 3rd GHz/Gbps Test Workshop (IMSTW / GTW 2007)*, pp. 93-98, 2007

[5] André V. Fidalgo, Ricardo J. Costa, José M. Ferreira and Gustavo R. Alves, "Experimenting the 1149.1 and 1149.4 test infrastructures in a Web-accessible remote Lab (without Plug-ins!)", *XVI Conference on Design of Circuits and Integrated Systems (DCIS'01),* Porto, Portugal, November 2001.

[6] D. E. Hesse and A.E. Hentzen, "Reverse problem based learning," *Laboratory Medicine*, number 3, volume 33, March 2002.

[7] G. R. Alves and J. M. M. Ferreira, "From design for test to design for debug and test: analysis of requirements and limitations for 1149.1," *17th IEEE VLSY Test Symposium*, IEEE Computer Society Press, pp. 473-480, April 1999.

[8] M. C. Felgueiras, G. C. Alves and J. M. M. Ferreira, "A built-in debugger for 1149.4 extensions," *Proc. of the International Mixed-signal Testing Workshop*, pp. 93-98, 2007.

[9] K.M. Edmondson, "Concept maps and the development of cases for problem-based learning", *Acad med*. Volume 69, issue 2, pp.108-110, 1994. http://dx.doi.org/10.1097/00001888-199402000-00004

[10] H. Burford, "Development and evaluation of patient-oriented problem-solving materials in pharmacology", *Acad med*, Volume 65, issue 11, pp. 689-693, 1990 http://dx.doi.org/10.1097/00001888-199011000-00011

[11] http://www.scmp.pt/, visited on June 2013

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