

Digital Systems Laboratory for Visually Impaired Students

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Abstract

This paper describes how the practical sessions of the Digital Systems Laboratory within the Computer Science Degree have been adapted to allow a visually impaired student to take part in the practical sessions. Regular students use a computer-aided design tool (OrCAD) for digital design in their practical assignments. This work shows how the use of special instrumentation allows visually impaired students to work with regular students in the same lab, where the CAD tool is installed. The teaching methodology and the obtained assessments are introduced here. Some specific practical materials have been designed and they are described in this work; the design of a special buzzer is also presented.

1. Introduction

The subject known as Computers Structure and Technology is scheduled for the second semester of the first academic year in the Computer Sciences Degree in the University of Córdoba, Spain. It consists of 45 theoretical hours, 15 hours of exercises, and 30 hours for practicals in labs. Four theoretical hours a week are given, including theory and exercises, while two practical hours a week are given in labs. The course lasts for 15 weeks. This information is all summarized in Table 1.

Table 1. Course description

Lectures (4 h/week)	Week	Laboratory (2 h/week)
1. Introduction. General overview	1	Lab. equipment and safety
2. Information representation	2	CAD tool introduction
3. Boole Algebra. Logic gates	3	Simulating logic gates
4. Logic functions. Minimisation	4	Minimisation
	5	NAND, NOR synthesis
5. Combinational design	6	Combinational I
6. Combinational logic circuits	7	Combinational II
7. Digital arithmetic	8	Adder/Subtractor
	9	Arithmetic Logic Unit
8. Digital arithmetic circuit	10	
9. Sequential systems	11	Counters
	12	
	13	RAM memory
10. Sequential circuits	14	Laboratory examination
	15	

The main objective is to introduce the basic concepts underlying the digital systems, as well as the instruments used to design digital electronic circuits. In the laboratory, the students use the OrCAD tool to design simple combinational, arithmetic, and sequential circuits.

A visual impaired student (VIS) enrolled in this subject. He was not able to perform the lab sessions with the CAD tool due to his impairment. Thus, an alternative method was needed. The goal of this paper is to describe this alternative method.

This particular experience is to be considered as a starting point for teaching Digital Systems to visually impaired students (VISs).

2. Course Description of the Practical Sessions

Below, the proposed practicals are described:

- **1st Week** Laboratory equipment and safety. In this session, the lecturer introduces the practical sessions, shows the lab to the students, explains the safety rules and informs the students about the emergency exits.
- **2nd Week** CAD tool introduction. The second session is used to teach the students some concepts about the operating system (OS), their OS accounts, and to perform an introductory tour about OrCAD, showing the main characteristics of this tool.
- **3rd Week** Simulating logical gates. Students learn how to design a basic circuit using logical gates, input and output ports, and wires. The process to compile, stimulate, and simulate a circuit is also shown. How to understand the graphical simulation is also explained.
- **4th Week** Minimisation. Simple combinational problems are simplified using Karnaugh maps. Afterwards, students implement the solution in OrCAD and simulate it to check its validity.
- **5th Week** NAND and NOR Synthesis. Students apply the universality of the NAND and NOR logic gates.
- **6th Week** Combinational I. To familiarize students with real cases, simple problems are described. Students should first obtain the truth table, perform Karnaugh simplification, obtain the logical equation that represents the solution, turn the equation into a schematic design, compile it, and finally, stimulate and check that the simulation is correct.
- **7th Week** Combinational II. More complex problems are introduced in this session. These problems require the use of buses.
- **8th Week** Adder/Subtractor. In order to introduce the students to binary arithmetic, a 1-bit full adder (FA) is designed. Then, students use this component to design a 4-bit FA. Next, using two's complement, students design a 4-bit subtracter using the adder which was previously designed. Concepts of hierarchical designs are introduced.
- **9th-10th Week** Arithmetic Logic Unit (ALU). A 4-bit ALU capable of performing 8 different operations, is implemented within this practical session.
- **11th-12th Weeks** Counters. The design of a modulo-6 up/down counter is proposed to introduce students into the sequential systems. Synchronous and asynchronous signals are studied.
- **13th-14th Weeks** RAM Memory. Students are asked to design a 4 x 3 RAM memory, with one bidirectional 3-bit data bus. It provides the students with the concepts of memories, bidirectional ports, and tri-state buffers.
- **15th Weeks** Laboratory examination. Students are asked to design, implement, and simulate one exercise based on the previous sessions.

3. A visually impaired Student

University of Córdoba informed the professors a few months before the course started that a student called Rafael (Rafael allowed the use of his name and photographs within the academic scope.) enrolled in the subject described above. He presents a visual impairment that consists in just 12% lateral vision in the right eye, while the left eye is totally blind. He is able to read Braille proficiently. He is able to recognize different colours presented in large lines. However, he needs to approach his face to the drawing very closely. This impairment prevents him from performing the practical sessions with the OrCAD tool. Thus, a different approach was needed. This approach should give Rafael similar knowledge to that acquired by the other students.

First of all, a search in the scientific literature for different strategies for teaching Electronics, Digital Systems, or similar subjects to VISs was carried out. A small amount of works in this field were found. Some of them, which are the most representative ones, are stated below. In (Graham *et al.*, 2007), an initial study on interface design for VISs is presented. In this work from the Computer Science at Ulster and Electronics at York, they obtain one main conclusion: touch is best for orientation in schematics. They also recommended to suppress superfluous information. However, no experimental results are shown in the article. (Bel and Bradburn, 2008) present a basic study about materials and accessibility, based on a questionnaire distributed among teachers. Results suggest that professors show a lack of technical knowledge that prevents them to use the technical material properly. In (Harrison *et al.*, 2008), the authors present a preliminary work to collect information for a future Virtual Learning Environment (VLE) tool. This VLE tool was expected to be an interesting starting point for adapting the practices for Rafael; however, current VLE platform is not available for severe VISs or blind people. (Rodríguez-Ascaso *et al.*, 2008) show a work in progress about personalized support to students with disabilities based on some educational guidelines for higher education. Conclusions are not yet obtained, and thus, those guidelines have been used just as suggestions. All these works in progress about accessibility in education for students with disabilities are theoretical proposals without any experimental results.

Currently, interface design for VISs predominantly includes Tactile User Interfaces (TUIs) or Audio User Interfaces (AUIs) (Benyon *et al.*, 2005). Several authors have stated the importance of the tactile abilities for blind students (Tubiana *et al.*, 1984), (Rogow, 1987), (Rogow, 1990), (Mommers, 1975). Other authors (Fricke and Baehring, 1994), (Huang *al.*, 2004), have made use of different instruments to control systems using audio interfaces. Thus, the proposed solution was to substitute the practical sessions using the CAD tool with other using real lab instrumentation which could be controlled by means of the hearing and touch.

On the other hand, in order to make the integration of Rafael with the rest of the students easier (Stovall and Sedlacek, 1983), the instrumentation to be used is taken to the lab where those students are working. Fig. 1 depicts this situation.



Fig. 1: Rafael and other students at laboratory.

4. Practical Material and Instrumentation

As it has been stated previously, Rafael is able to read Braille. This fact is quite common in most visually impaired students (Gray and Wilkins, 2005), and thus, most of the subjects previously translated to Braille are available for new students. However, in this case, after a deep search helped by ONCE (Spanish National Organisation for the Blind), there were not found any VIS who had attended a Digital Circuit lab within Computer Sciences Degree in Spain. Therefore, the first task was to translate all the written course material into Braille. All the used diagrams were also embossed and coloured.

In the search for methods for the adaptation of the assignments for Rafael, different solutions were considered. Two of them have been frequently used in assisting visually impaired people: Windows Magnifying Glass (Pyy *et al.*, 2007) and JAWS Software (Freedom Scientific, 2009). However, they were not applicable within this scope. Windows Magnifying Glass is useful when the visual impairment is not severe. The method described in this work is designed for seriously impaired people, even for blind people. Therefore, Windows Magnifying Glass was discarded. JAWS Software is useful when the impaired person works with textual information. In this case, the electronic designs are represented using schematics. Thus, JAWS Software has not been a great help for this work. After that, other solutions were investigated. Several attempts using a voice synthesizer software capable to read the screen (Barry, *et al.* 1994) with OrCAD design software were tried. However, this produced unsatisfactory results and thus, it was rejected. Finally, it was decided not to use OrCAD software and to adapt the assignments to be able to implement them using physical circuits. Moreover, the fact that the impaired student could work with real devices, instead of with CAD tools, was considered to be very interesting.

4.1. The Generic Protoboard

VISs use their fingertips to read, to locate elements, etc. They are able to locate chips and to count every pin of them. However, these pins are too close to each other and sometimes they find hard to plug cables attached to those chips. In order to help the tactile guidance of the VIS throughout the chips involved in the implementation of the different assignments, a generic protoboard was used. This protoboard allows the use of different 74LSxxx chips. The chips needed in the design of the solution of the laboratory assignments are plugged in the sockets of this protoboard. Each chip socket has a plastic piece to unplug each chip easily and without damaging its pins. By using this protoboard, pins are guided by wires to separated sockets, much easier to manage by VISs than the standard pins in the chips.

4.2. Embossed Cardboard of the Chip

Several days before each session, a cardboard with a design of every chip is given to Rafael. This cardboard is designed using Braille for the text and embossed and coloured lines for the electrical connections. Different chips are identified by Rafael, and he situates them close to the protoboard in an order that allows him to remember each one and lets him locate and use the documentation translated into Braille of each chip.

4.3. Proposed Practical Material and Instrumentation

Standard lab instruments have been used, but as other authors have done (Fricke and Baehring, 1994), one instrument was specifically designed to perform the proposed assignments (the buzzer) and another was adapted to be used by VIS (small modifications on the protoboard). The proposed instrumentation comprises:

- **A 5V continuous** current power supply used for TTL logical devices.
- **A clock generator** device.
- **A generic protoboard** which allows to discern between the pins of a chip by touch. Small modifications have been carried out on the internal connection lines of this protoboard, as well as on the ground and power lines, which are embossed in order to be easily identifiable. To differentiate between them, power lines are coloured in red, while ground lines are coloured in black. If other students are not able to differentiate between colours, the embossed lines could be modified using different textures.
- **A specially designed buzzer.** It consists of one terminal that can be easily connected to any of the protoboard pins in order to perform voltage measure. The buzzer volume can be easily adjustable due to the variable impedance that has been incorporated. A logical 1 activates the buzzer, while a logical 0 produces no sound. The buzzer design is illustrated in Fig. 2a. The device is shown in Fig. 2b.
- **Cables** with connectors for the protoboard.
- **Some chips** from the TTL 74LSxx family. The student is given special instructions about the encapsulation and how to identify the different pins.

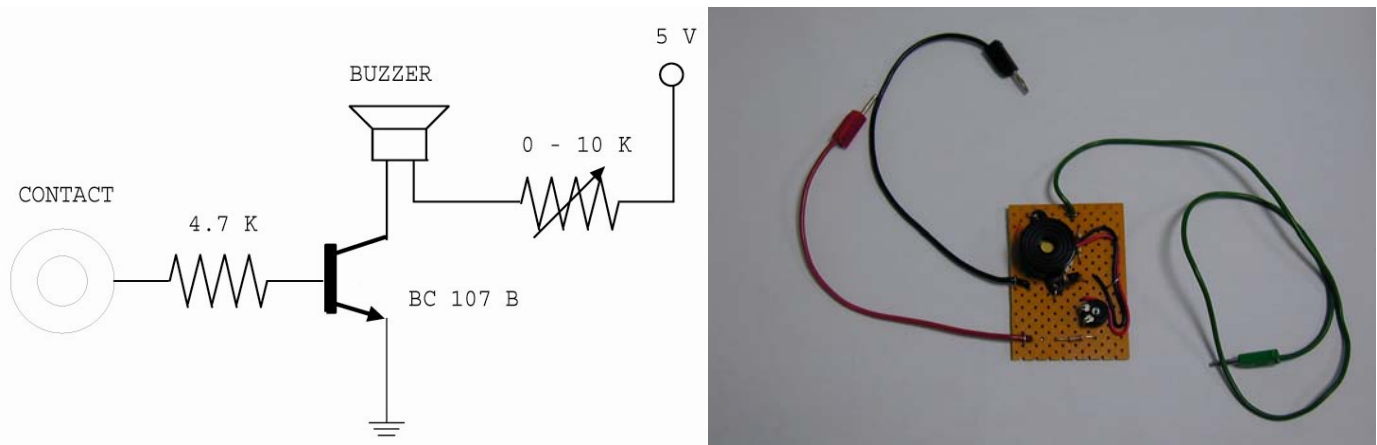


Fig. 2, a): The Buzzer design.

b) The Buzzer

It is to be mentioned that all these practical material and instrumentation have been designed and built in a low-cost basis because no extra funds were given for this project. The only external body which provided some help was ONCE: a printing device able to print in relief, which was used to print Braille texts and schematics.

4.4. Security Issues

With regard to the security issues, they are described to Rafael in the first week of the practical sessions. Rafael's workplace is located close to the exit and out of the way out. Thus, the other students could easily evacuate the classroom in case of emergency. Furthermore, the student situated closer to Rafael would help him in his way out of the lab. The equipment used by Rafael has low voltage and amperage. And therefore, no additional security measures are needed.

5. Description of the Adapted Assignments for Visually Impaired Students

In this section, the different assignments adapted for VISs will be described. They have been designed to be feasible for other visually impaired students. The practical sessions are the following:

- **1st Week** Laboratory equipment and safety. In this session, the lecturer introduces the practical sessions, shows the lab to the students, explains the safety rules and informs the students about the emergency exits. The student with the visual impairment sits in a special table close to the lecturer and to the main exit of the lab. In an emergency case, he should follow the instructions given by the lecturer. Moreover, the student that is closest to the one with the impairment is trained to help him to evacuate the lab if it is needed.
- **2nd Week** Lab instrumentation introduction. The student is instructed about the use of the instrumentation listed in Section 4.
- **3rd - 4th Weeks** Getting used to the instrumentation and logical gates. This session is used to familiarize the student with the instruments. The student verifies the truth table of the several TTL logic gates. He learns how to stimulate logic gates. Different gates are given to the student and he is asked to identify each of the gates, interpreting the truth table obtained using the buzzer.

- **5th Week** NAND and NOR Synthesis. The student applies the universality of the NAND and NOR logic gates simultaneously with his classmates. At the end of the session, he is able to easily identify the logic state of inputs and outputs of the logic gates.
- **6th Week** Combinational I. This session is similar to that performed by the rest of the students using OrCAD. He designs the solution before the practical session, and once in the lab, he implements it and checks it.
- **7th Week** Combinational II. This session is also similar to that performed by the rest of the students. More complex problems than those proposed in the past session are proposed in this assignment. At the end of the session, the student has achieved the same level of knowledge in digital logic design as the other students, except for the information about OrCAD.
- **8th – 9th Weeks** Adder/Subtractor. The student is introduced in the field of digital arithmetic by the implementation of a 1-bit full adder. This task is also scheduled to regular students. After that, a 2-bit full adder is designed, instead of the 4-bit full adder implemented by his classmates. This is due to the higher complexity of the physical designs against simulated designs. However, the knowledge acquired by the student is equivalent. Finally, an adder/subtractor using two's complement is implemented.
- **10th Week** Combinational MSI (Medium Scale Integration) Devices I. The design of an ALU requires a great number of connections and components. Therefore, it is not possible for a VIS to tackle with such a design. Instead, the student is asked to design the Logic Unit only, using a 74LS151 multiplexer and a function generator to test all the possibilities.
- **11th Week** Combinational MSI devices II. The student designs simple combinational circuits using a 74LS138 decoder. The technique to use a decoder as a demultiplexer is also introduced.
- **12th Weeks** Counters. The student works with a 4-bit binary counter (74LS161) and a decade counter (74LS162). Then, he designs an 8-bit decade counter using two 74LS161 modules, applying carry propagation.
- **13th Week** Registers. In this session, the student works with a 4-bit register (74LS194), which allows parallel and serial access, as well as left and right shift. During 12th and 13th sessions, the concepts of synchronous systems, clock edge, and sequential systems are introduced.
- **14th Week** Flip-flops. In order to understand the functionality of memory elements, a JK flip-flop (74LS112) is used. The four possible inputs of the flip-flop are tested. A 2-bit asynchronous counter using a JK flip-flop is also designed.
- **15th Week** Laboratory examination. This session is not necessary, as the student is continuously evaluated.

A comparison between the assignments performed by regular students and those proposed to VISs is given in Table 2. Apart from the practical sessions in weeks 1, 2, and 15, used to get in touch with OrCAD and to examine the students, they must complete eight assignments. In weeks 3 to 8, a VIS solves the same assignments than the other students. In week 9, a VIS implements part of an ALU. Regarding the

counter, a VIS designs an 8-bit decade counter using MSI circuits, instead of using logical gates as his classmates. At the end, a VIS studies the flip-flop as the basic memory element, and uses it to design registers. On the contrary, the rest of the students design a full 4 x 3 RAM memory.

Table 2. Laboratory course comparison

Visually impaired student	Week	Other students
Lab. equipment and safety	1	Lab. equipment and safety
Instrumentation introduction	2	CAD tool introduction
Basic logic gates	3	Simulating logic gates
	4	Minimization
NAND, NOR synthesis	5	NAND, NOR synthesis
Combinational I	6	Combinational I
Combinational II	7	Combinational II
Adder/Subtractor	8	Adder/Subtractor
	9	Arithmetic Logic Unit (ALU)
Combinational MSI I	10	
Combinational MSI II	11	Counters
Counters	12	
Registers	13	RAM memory
Flip-flop	14	
Not used	15	Laboratory examination

While regular students perform 9 assignments (weeks 3 to 14), a VIS completes 10. However, the practical sessions in weeks 10th and 14th are reduced versions of the equivalent assignments for the other students (part of an ALU in week 10th and flip-flops instead of RAM memory in week 14th). Thus, it is expected that a VIS is able to acquire a similar level of knowledge as the rest of the students.

6. Evaluation

After presenting the adapted assignments, the evaluation of Rafael with those assignments is shown. Each practical assignment, previously translated into Braille, was proposed to Rafael at least two weeks in advance. Thus, Rafael prepared the formulas and the resolution of each practical before coming to the lab. The qualification of each practical was obtained using several principles such as attendance to the practical sessions, theoretical development of each practical, implementation (in particular, good organization, cleanness, and tidiness of the design in OrCAD), and finally and most importantly, the correctness of the solution provided. These principles were applied to all the students, both VIS and non-VIS. Every student is awarded several points depending on their attendance, on the theoretical development of each practical, on the description of the implementation (taking into account, the organization, cleanness, and tidiness of the implementation of every practical), and above all, on the solution they provide. In order to pass the subject, students have to obtain at least 50% in each of the proposed assignments.

6.1. Examination Results

According to those principles, Rafael obtained an overall qualification of 9.65 points (out of 10), which is highly remarkable. Rafael was an outstanding student and obtained a qualification grade of "A". The score for each practical is shown in Tab. 3. There, "Partial Score" stands for the score obtained by Rafael in every

practical; every practical is weighted using "Practical Weight" to sum up the final value; "Practical Score" is the value obtained by Rafael weighted in order to compose the "Global Score". "Practical Score" and "Global Score" are ranged from 0 to 10. In order to make a comparison with other students, several statistics about their evaluation are given. 47% of the students failed (obtained a result below 5 in any of the assignments). 27% of the students passed the assignments obtaining a "C" grade (in the range of 5 to 7). 11% of the students received a "B" grade (ranging from 7 to 9), and 15% of them were awarded an "A" grade (above 9). No student obtained an "A+" grade. As can be deduced from the results stated previously, most students pass the assignments, however, only few of them could obtain such a high grade, and Rafael was one of those students who obtained an "A" grade.

Table 3. Evaluation of the VIS Teaching Results

Adapted Assignments for the Visual Impairment Student	Partial Score	Practical Weight	Assignment Score
Laboratory equipment and safety, lecturer presentation	—	—	—
Instrumentation introduction	—	—	—
Basic logic gates	100%	5%	0.5
NAND, NOR synthesis	100%	5%	0.5
Combinational I	100%	5%	0.5
Combinational II	90%	10%	0.9
Adder/Subtractor	100%	15%	1.5
Combinational MSI devices I	100%	10%	1.0
Combinational MSI devices II	90%	10%	0.9
Counters	90%	15%	1.35
Registers	100%	15%	1.5
Flip-flop	100%	10%	1.0
Global Score (over 10)			9.65

6.2. Teaching Assistance

A VIS requires much more guidance than a non-VIS: for instance, a VIS can plug incorrectly a cable into a socket (not properly plugged, or plugging it in a nearby socket, etc.) It is also very common to guide the finger of a VIS to the first socket of each chip. The professors were advised in advance by Rafael and his tutors about some of these inconveniences. Due to that, a classmate and an assistant professor were assigned to help him. In most of the assignments, Rafael required a constant assistance from the assistant professor. Most times, the help required was that of taking his finger to the first socket of each chip used in the solution. Sometimes he also asked for help when debugging. In this task, most of the mistakes were due to wrong insertions of the cable into the sockets: he did not plug completely the connector into the socket. Rafael required little assistance from the assistant professor only in the first practical session, which was the easier one. Thus, his behavior about asking for help from the professor is similar to the one of his classmates: the only difference was that his requests for help was more continuous.

7. Conclusions and Enhancements

Three main aspects of this work are to be emphasized in this section. At first, the integration of a VIS with his classmates. At second, the learning process of the student. Finally, the lecturer assistance which is required. Finally, some

enhancements are suggested to improve this work.

VISs are able to carry out their work at the same time and in the same location as the other students. The fact that these students are not treated differently than their peer helps minimize any perception of preferential or discriminatory treatment. The opposite was also achieved: most non-VISs showed interests in performing their assignments using the same platform that Rafael used.

The learning process of a VIS has been designed to be easily affordable. In particular, the experience with Rafael has been highly positive as the student has notably assimilated the knowledge required in this course, mainly due to the high motivation he used to face the practical sessions.

On the contrary, the main weakness of this system is that the assistance of an additional lecturer is required. During the first five weeks, one sole lecturer is able to manage the situation. However, since week 6th, regular students require much attention from the lecturer, mainly due to learning problems with OrCAD. Thus, a second lecturer to assist the VIS is needed. In general, to count on two lecturers since the beginning of the course is advisable.

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