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Design and Implementation of a Trainer Board for Digital Logic Design Principles Lab

Mustafa O. Ali[1], Abeer A.S. Mohammed[2]
Electrical & Electronics Engineering, Nile Valley University[1]
Mechanical Engineering, UESTC[2]

Abstract- Educational institutions suffer from a scarcity of practical training due to the financial constraints imposed by the US sanctions on our country, Sudan, for more than three decades. Despite the availability and diversity of equipment and tools for practical educational applications on the global market, the economic reality of Sudanese educational institutions allows only training at the basic level in most cases. Our situation in the Digital Electronics Lab at Nile Valley University is similar to that of everyone else under the US sanctions situation. We used to train students on the basics with very simple equipment. We are barely able to implement 25% of the practical material covered in the course. This is because we use simple electronic components to implement the exercises, which complicates the application, consumes materials and effort, and takes a long time per the student. Through this paper, we aim to utilize the simple capabilities available in our lab and the local market to design and implement a laboratory board that isolates students from interacting with basic electronic components and enables them to directly apply digital logic. They then obtain the results of the exercise, enabling them to write the exercise report and achieve the desired objectives of the experiment. We also hope that the designed board will improve the achievement rate and raise up the percentage of practical work applied in the laboratory according to the course plan.

Keywords- Practical education, Digital electronics, Educational sanctions, Sudan, Laboratory training, Resource-constrained education

I. INTRODUCTION

Practical training is an essential component of engineering education, particularly in fields such as digital electronics, where hands-on experience greatly enhances students' understanding of theoretical concepts. However, in Sudan, educational institutions have long struggled to deliver adequate practical instruction due to severe economic limitations exacerbated by over three decades of U.S. sanctions. These sanctions have restricted access to advanced laboratory equipment and development tools, forcing universities to rely on outdated or improvised resources that fall short of modern educational standards.

At Nile Valley University, the Digital Electronics Laboratory faces similar constraints. Students are often limited to basic exercises using discrete components and breadboards, which significantly reduces the scope and efficiency of practical training. Current methods allow for the implementation of only about 25% of the intended lab content, limiting students' ability to apply and internalize key digital logic design principles.

Overview

Higher education curricula typically incorporate a simultaneous theoretical and practical learning model. The credit hours for a curriculum are the sum of both theoretical and practical hours. Most curriculum courses are of a scientific, practical nature. This necessarily requires students to spend hours learning the theoretical information of the course, followed by a practical's hours of application. Therefore, students' grades are calculated based on the sum of their theoretical and practical knowledge acquisition. As is well known, the requirements for theoretical learning are a lecturer, a classroom, students, and traditional or digital teaching aids; these are readily available at almost any educational institution. The challenge always lies in providing the necessary tools for practical learning, as this requires a well-equipped space, specific furniture, and equipment, which educational institutions possess in varying scales. Indeed, the fact that an educational institution possesses laboratories and workshops is a significant qualification differentiator.

II. THE PROBLEM STATEMENT

In the higher education and technical education institutions, computer science and engineering courses are considered core courses in electrical and electronics engineering programs and their branches, as well as in computer science and technology programs. Among the courses in these programs are digital design, digital electronic circuits, logic design, computer fundamentals. These courses share the fact that the practical application prescribed for them usually covers the basics of logic circuits design. Students begin with learning the concept of logic and its relationship to electricity—current and voltage. They learn the levels of logic (high-level and low-level logic) followed by the basic laws of logic, logic gates, and truth tables. The students' progress to learn how to design logic circuits with special functions, simplification theorems, and so on [1][2].

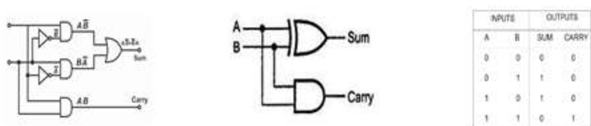
There are mainly two models for practicing lab regarding the aforementioned courses. The first method involves the student building the circuit to be practiced using various electronic components: integrated circuits (ICs), resistors, wires, LEDs, switches, a breadboard, and a DC power supply. This method may require the use of a measuring device (Multimeter). Let's call this method a "Traditional Method". The second method involves the student using pre-fabricated boards, whose fronts display are logic symbols indicating inputs and outputs. The student only has to assemble the components of the experiment using connecting wires. The switches (inputs) and LEDs (outputs) are already available on the board's surface. The student often doesn't need to arrange an external dc-power supply, as it's already built into the board. Nor does he need measuring devices, as the board's electrical values are pre-set. Let's call this method a "Modern Method".

In this paper, we will discuss the two methods and analyze them scientifically based on our practical experience at Faculty of Engineering and Technology founded in the Nile Valley University. We will then present the results of this experiment, which yielded a clear distinction between the traditional and modern methods, leading to the design and implementation of a modern-style logic board.

The "Traditional Method"

According to the work pattern of the Digital Electronics Laboratory in our Department of Electrical and Electronics Engineering, the "Traditional Method" was the criteria of work followed to train students to perform the digital electronics experiments. The student must assemble his exercise circuit from basic electronic components and connect in between using the jumpers' wires. The student must adjust the supply voltage and observe its polarity during connection. Sometimes, the student uses switches as inputs, or they may substitute direct connection to the positive and negative terminals of the source to implement (high-logic) and (low-logic) according to the sequence of the truth table. To obtain the result of the applied logic, the student must provide an ideal output, which consists of a LED connected in series with a load resistor connected to ground. Of course, the more components used in the experiment, cause the more connection of wires, which consequently increases the complexity of the electrical connections.

For example, the half-adder circuit (HA), which the student studies theoretically, consists of three AND-gates, two NOT-gates, and one OR-gate, this is a “Basic Design” as shown in Figure (1-a). Or it consists of only two gates, an XOR-gate beside an AND-gate, an “Advanced Design” as shown in the figure (1-b). Both designs express the truth table shown in the figure (1-c) [2]. In the lab, the student must implement the circuits whose realizes the truth table for both designs, so this requires him to identify all the electronic components required for the implementation, which are as shown in table (1).



(a) (b) (c)

Fig 1: Half Adder logical Design (a) Basic Design, (b) Advanced Design, and (c) Truth Table

As seen in table (1), as number of electronic elements is a smaller number of wires is less too, and accordingly the complexity becomes less too. But as it is well known while the student progresses forward in his course, circuits design and assembler become more complicated. Therefore, the student consumes more time and effort to accomplish his experiment implementation task.

Table 1: Half Adder Circuit Design Implementation Requirements

#	Element	Details	Basic Design	Advanced Design
1.	And-gate	7408	1 IC (3 gates)	1 IC (1 gate)
2.	Not-gate	7404	1 IC (2 gate)	No need
3.	Or-gate	7432	1 IC (1 gate)	No need
4.	XOR-gate	7486	No need	1 IC (1 gate)
5.	Resistor	220Ω	2	2
6.	LED	Green/Red	2	2
7.	Switch	DPDT Switch*	2	2
8.	Wires	Male to Male Jumper Wire	22	14
9.	Board	Bread Board	1	1
10.	DC-Source	+5V DC Power Supply	1	1

These in general problems, along with considering three effective parameters: large number of students’ sub-groups, Limited of laborites equipment’s, and Limited of time due to scheduling of weekly time- table. Altogether, the above highlighted problems and the three mentioned parameters drive the cost of practical to be double many times versus less of exercises number.

The “Modern Method”

In this method the student is going to deal with logic circuit instead of detailed electronic circuit. The dealing with logic circuit is similar to work with block diagram rather than work with electronic circuit. Whereby, the student not forced to involve with electronic elements’ features. As it's well known, if the student has any of truth table, logical circuit, or logical function; he must be able to conclude the other two logical forms. Accordingly, keeping away the electronics details, satisfying only with the student's basic knowledge of logic issues, the experiment task will be implemented successfully in a short time with less effort. To achieve this goal, the student must be insulated from electronics details in practical. This aim can be realized by using two layers: Application Layer and Execution Layer.

Application Layer: It is a surface layer, where the student applies his work. It looks like a collection of disconnected various logic blocks; each block has its own inputs/outputs connection points and a symbol written on. Besides logic blocks, the “Application Layer” may contain: main inputs (switches), main outputs (LEDs), clock source point, set/reset sources, seven-segment display unit, and main power on/off switch. These logical blocks and units must be distributed in the surface panel in a suitable systematic manner avoiding crowd and complexity; this will offer both the student and the trainer easiest tracing and comfortable readability for exercise assembling and wiring connection.

Execution Layer: It's an often-hidden layer lying under "Application Layer", consists of logic functional ICs, electronics elements, connection board, wiring, power supply unit or source plug, pulse generator unit, etc. Wire connections in this layer is fixed, power and pulse values are preadjusted, and keep out of students reachable. The existence of much components in this layer, supports applying of multiple practical exercises over the "Application Layer" and vice voce.

Figure (2-a) shows an "Application Layer" for a "Modern Method" simple module, where on the left side there is two switches type of (DPDT). The center terminal of each switch connected to a female "Banana-Jack", and the end terminals are connected to the "Execution Layer", a "1" to the +5VDC and a "0" to the ground (GND). In the middle, symbols of dual XOR-gate and And-gate are located, each of them tied to two female "Banana-Jack" as inputs and the third one as output. On the left side of the panel outputs are located, they are two LEDs each of their anodes is tied to a "Banana-Jack", while the cathode of each is tied to the (GND) in the "Execution Layer" through a load resistor [3]. The fruity valuable result is achieved when the student managed to implement the practical task as shown in Fig (2-b), where he used only six wires to construct the HA advanced model, and attained the ideal HA's truth table states.

It may be seeming that the "Modern Method" is a development of the "Traditional Method". But the fact is, the "Modern Method" uses the "Traditional Method" elements for constructing an "Execution Layer"! This attitude attains excellent solutions for the problems that we have listed in the previous section. Insulation the student from dealing with "Execution Layer" keeps the inner electronic and logical elements save and capable to run for long operation life. A complaining sight may rise here, the cost of two layers together is higher than using one layer – "Execution Layer"- only! But our experience shows fake of this thought; The philosophy of this comes out because it's an initial limited cost only, it's not a renewable cost. Where in the "Traditional Method" the cost is renewable beside increasable every semester's patch.

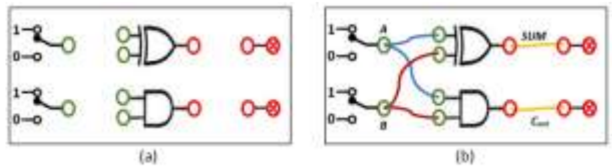


Fig 2: Simple "Modern Method" Logical Panel (a) Application Layer. (b) Advanced HA Wiring

III. DIGITSTAR LAB" PROTOTYPE

Although educational training equipment and devices have a wide market and available in a variety of options, but ensuring their availability in the laboratories and workshops of educational institutions poses a challenge to the administrations. This short of supplies may occur due to scarce resources and funding. Taking our country "Sudan" as an example, we find that the economic sanctions imposed for more than three decades has impoverished the country's institutions, particularly educational ones [4]. Educational institutions in Sudan, both university and pre-university, generally suffer from a scarcity of resources and funding, the primary negative factor. They also suffer from the economic sanctions imposed on the country, which prevents them from contracting and purchasing internationally, as they are owned by a banned government. A technology tool that can be purchased for $10 anywhere in the world, costs in Sudan ten times its original value. Under such a situation, purchasing a basic digital logic board is a luxury that administrations completely ignore. Consequently, most educational institutions in our country lack basic equipment and devices and have instead resorted to simple, "Traditional Method" with limited functionality. Therefore, and due to the highest cost of practicing with "Traditional Method", we involved to use the facilities available in our lab and in our local markets to innovate a digital logic design panel. We named the innovated panel “DIGITSTAR LAB”.

Targeted Experiments

The syllabus of the target courses related to logic design in our department, mainly stands of “Digital Systems Principles and Applications”- the reference which written by Ronald J. Tocci et. al. [1]. So, we used to refer to this reference “Tocci” and advice our student to do the same; Tocci’s reference is delved in the details easily step by step and gives valuable tips for technical lab work. According to sequences of the digital logic principles taken from ref. [1] and comparing to some lab’s manuals such as ref. [5-9]; many of experiments can be listed: Basic Gates, Combination Gates, Boolean Algebra Laws, DeMorgan’s

Theory, NAND/NOR Techniques, Adders, Subtractors, Comparators, Decoders, Multiplexers, Latches, Flip-Flops, Registers, Counters, and Memory.

Due to the three parameters, we have reported ago in the section of the “Traditional Method” problems, some of the listed experiments can’t be practiced well and most are impossible to implemented. For example, implementation of a “2-Bit Comparator”, although its logic circuit seems simply, but it cost student long time and rase his stressing factor very high due limit of time. Figure (3) shows the digital logic design for 2-bit comparator as per ref. [2].

Actually, it’s meaning less if the student implemented the experiment as partitions, each part performs outputs one by one! Of course, there is no chance for instance compare will be observed. In the other hand, if the student goes for implementing the total logical circuits of the comparator, indeed large number of logical, electronic, and electrical elements in addition to large number of wires are needed; Then complicated issues appear in while implementation.

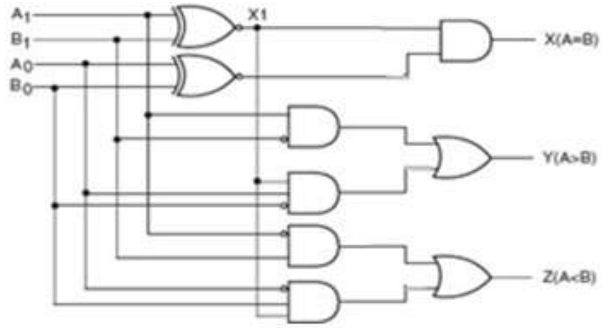


Fig. 3: 2-Bit Comparator Logical Circuit

The experiments listed previously normally classified into two groups. First group concluded the combinational logic design experiments concluded Basic Gates, Combination Gates, Boolean Algebra Laws, DeMorgan’s Theory, NAND/NOR Techniques, Adders, Subtractors, Comparators, Decoders, and Multiplexers. Second group is for sequential logic design experiments concluded Latches, Flip-Flops, Registers, Counters, and Memory. Of course, second group is too difficult to involve in “Traditional Method” practicing due to its sensitivity for clock pulses and issues of synchronous/asynchronous. Table (2) shows the combinational logic design experiments listed in the first group along with their requirements elements needed to practice in lab as per “Traditional Method”. To reduce complexity only dual inputs basic digital logic gates are used, mainly belong to 74LSxx TTL series. For comparator we used to replace 3-inputs AND-gate with dual inputs AND-gate due to its availability in our lab, so by installing two AND-gate in series we will get 3-inputs AND-gate simply [1,2]. Also, power supply and bread board are not mentioned in the table considering their necessary existence in all experiments' practicing.

In our lab, the experiments whose needs more than 18 wires are often ignored to save time and efforts as well avoiding high cost. This attitude shows how much less practice that the students can exactly do! A fifty percentage of the combinational logic practice beside the sequential logic practice, altogether are ignored out of lab total practice activities. That means we could perform approximately a 25% only out of the syllabus practice activities. Mainly, this is the outcome of using “Traditional Method” for past dedicates of academic years in our lab. The bright side of this suffering, that it forced us to have challenge of using our limited facilities to establish a "Modern Method" module in our lab, which leads to innovate "DIGITSTAR LAB" prototype.

Table 2: The Requirement Elements of Combinational Logic Experiments for "Traditional Method"

#	Experiments	AND	OR	XOR	NOT	NAND	NOR	SW	LED	R (Ω)	WIRES
1.	Basic Gates	3	3	1	1	1	1	4	2	2	12
2.	Boolean Algebra Laws	4	4	-	4	-	-	3	2	2	20
3.	DeMorgan's Theory	1	1	–	3	–	–	2	2	2	12
4.	NAND and NOR Techniques	1	1	–	1	4	4	2	2	2	18
5.	Half Adder – Basic Design	3	1	–	2	-	-	2	2	2	22
	Half Adder – Advanced Design	1	–	1	-	–	–	2	2	2	14
6.	Half Subtractor	1	-	1	1	–	–	2	2	2	16
7.	2-Bit Full Adder	2	1	2	-	–	–	2	2	2	22
8.	2-Bit Full Subtractor	2	1	2	2	–	-	2	2	2	26
9.	2-Bit Comparator	7	2	2	6	–	–	4	3	3	46
10.	2X1 Multiplexer	2	1	–	1	–	–	3	1	1	20
11.	1X2 De-Multiplexer	2	–	–	1	-	-	2	2	2	16
12.	2X4 Decoder	-	-	-	2	4	-	2	4	4	18

IV. DESIGN AND LAYOUT OF "DIGITSTAR LAB

The main goals we aim by facing towards designing a "Modern Method" module are increase the number of logic experiments can be practicing in the lab, with a maximum amount of saving time, effort, and cost. The table (2) automatically becomes our first reference on planning our needs, since it provides us with the suitable number of elements satisfying for rolling the implementation of all desired practicing experiments. Simply, we have extracted a table (3) from the table (2) where each element listed along with its corresponding largest number found in the table (2). This directly offered us the total amount of primary elements needed for desired logical board prototype design.

Table 3: The Requirement Elements' Numbers and Specifications

Elements	AND	OR	XOR	NOT	NAND	NOR	SW	LED	R (Ω)	WIRES
Maximum Number Utilized	5	4	2	5	4	4	4	4	4	46
Number of Utilized ICs	2	1	1	1	1	1	-	-	-	-
Element's Description	74LS08	74LS32	74LS86	74LS04	74LS00	74LS02	DPDT	Red626	220Ω	0.24 gauge

The table (3) contents are for implementing the logic of the experiments of basic logic gates directly. But the experiments numbered (7 to 12) in the table (2), each of them is available as a complete logic designed in a single chip - (IC). So, for more useful these units must be adding to the prototype's design. Moreover, selective sequential experiments are required to be concluding in the prototype's design, in order to accomplish its maximum useful utilization. Table (4) shows the details of these additional (ICs) for sequential logic suggested to be concluding to the prototype.

Although, all of these functional logic chips are important, but utilization of all in the same prototype makes the application very crowded with inputs/outputs connector points. Therefore, some of these functional chips must be select while ignoring others. Where some of them can be used together sharing the same inputs/outputs but insulating between by using enabling points, such as full-adder and comparator.

Table 4: The Additional Functional ICs

#	IC - Number	Chip Function	Inputs	Outputs	Control
1.	74LS83	4-Bit Full Adder	8	5	1
2.	74LS85	4-Bit Comparator	8	3	3
3.	74LS47	7-Segment Decoder Driver	4	7*	3
4.	74LS138	3X8 Decoder	3	8	3
5.	74LS153	4X1 Multiplexer	4	1	2
6.	74LS155	1X4 De-Multiplexer	1	4	2
7.	74LS73	JK Flip-Flop	2	2	2
8.	74LS75	D Flip-Flop	1	2	3
9.	74LS95	4-Bit Shift Register	5	4	3
10.	74LS190	4-Bit Up/Down Counter	4	4	4
11.	74LS89	64-Bit (16X4) Memory	8	4	2

Figure (4) shows our first prototype layout surface "Application Layer". As it's clearly shown in Fig. (4), the prototype consists of 12 functional blocks: 4 AND-gates, 4 OR-gates, 4 XOR-gates, 6 NOT-gates, 4- Bit Adder, 3X8 Decoder, 4-Bit Up/Down Counter, 4-Bit Shift Register, 4 Switches (Inputs), 8 LEDs (Outputs), Pulse Generator Output, and Main-power On/Off switch. These functional blocks represent the prototype's "Application Layer". Each functional block contains the logical function name surrounded with connection points. These connection points represent inputs (green circles), outputs (red circles), and control signals (blue circles). Along with the "4-Bit Counter" block in its corners, a four connection points are added. Two of them are "High-Logic" sources while the others are "Low-Logic" sources. These are attached to serve for applying control signals. The connection point is a female "Banana-Jack", which uses as a connector between the "Application Layer" and the "Execution Layer". Where the student over the "Application Layer" will use a group of connection wires to perform his lab exercise; Each of these connection wires has a pair of males "Banana-Jack" attached to its ends.

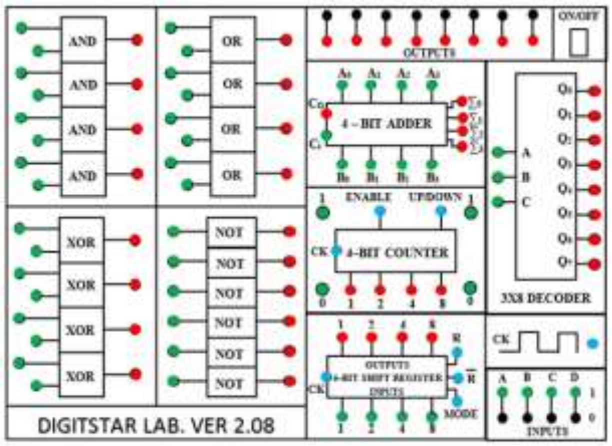


Fig. 4: The First Prototype Layout

The "Execution Layer" for the implemented prototype shown in Fig (4), consists of different electronic and logical elements matching to these functional blocks over "Application Layer". Where these elements by referring to the tables (3) and (4) are: 74LS08, 74LS32, 74LS86, 74LS04, 74LS83, 74LS138, 74LS160, 74LS95, 4- DPDT internal wires, 8-Resistors (220Ω) attached to output LEDs, 555's pulse generator circuit, and 5 VDC power supply controlled by the Main-power ON/Off switch.

Both 555's pulse generator and DC-power supply designs used in the "DIGITSTAR LAB" prototype are adopted as per the reference [3]. The 555 timer is simply, cheaply, and accurately serves as square-wave generator. It's suitable for a 5-volt supply and directly compatible with TTL applications, beside its wide frequency range up to 2MHz that can be adjustable by RC simple circuit. The DC-power supply is 5 VDC, 750 mA adjusted by a famous regulator circuit "7805".

Both layers of the implemented prototype – "Application Layer" and "Execution Layer" – have been contained in a small suit case. We have named our innovated prototype "DIGITSTAR LAB", it looks as shown in Fig. 5.

Fig. 5: The "DIGITSTAR LAB" Prototype (a) Application Layer, (b) Execution Layer.

V. COMPARISON STUDY BETWEEN TRADITIONAL AND NOVEL WORK

We will derive the basics of the comparison between the traditional and modern methods, from our practical experience in the digital electronics laboratory for more than two decades. Where we have been using the "Traditional Method" until 2009, then developed this prototype and began using it in training the students up to day. We will limit our comparison discussion around how the implemented prototype able to provide an impressive solution to the five problems those we identified in the introductory of this paper, as follows:

Case (1): In the "Traditional Method" the student deals with the electronics and logic elements directly. During handling these small elements two cases of crashes used to be happened, pins broken or inside current-short burnout the ICs due to opposite their polarity. These faults have avoided in the "Modern Method" because the students totally insulated from "Execution Layer", so no pins will be broken, as well as no ICs opposite polarity can't be occurred.

Case (2): Instead of using jumper wires with a thin pin's ends, the student in the "Modern Method" become using wires with terminals of males "Banana-Jack"; Which are smoothly utilized in compatible manner with the female "Banana-Jack" that fixed on the "Application Layer" surface. Of course, this development made the student practicing easier and for sure has dismissed all the consumption and wear of jumper wires and bread boards.

Case (3): Again "Banana-Jack" connectors play a big role in deny errors occurrence due to elements or wires dysconnectivity, because of high robust of connectivity they have. Moreover, because of using "Banana-Jack" the error detection become easier because the errors occurrence will consist only in logical connection mistakes done by the students neither the errors of disconnection of wires.

Case (4): The implemented prototype help both of lecturer and student to omit repeated details in every practicing session. This caused because of full insulation of "Execution Layer" which riches with much detailed electronic and logical concepts should be taken into consideration while implementing directly with. Where in our prototype the "Application Layer" acts as a mask that hide these details and prevent the necessity of their consideration. This keeps the student focus only in investigating the states of functional logic, which is the main objective of his practice session.

Case (5): Since we have involved "DIGITSTAR LAB" in our practicing duty programs, we have observed directly how this prototype has saved time and decreased the amount of cost to more than 60% of the "Traditional Method" cost. Previously we used to prepare a list of total requirements elements for each incoming semester includes 50 pieces of each combinational ICs such as: 74LS08, 74LS32, 74LS86, 74LS04, 74LS83, and 74LS138. Also, around 200 pieces of Resistors (220Ω) and output LEDs. This list contains of course tens of 8-DIP switches and bread bords along hundreds of jumpers' wires. Fortunately, all these quantities of listed elements are simplified into a small quantity of them implemented internally in the "Execution Layer" of "DIGITSTAR LAB" prototypes, which we have made five's unit of it. A happy news is these five implemented units are still on service until date since 2009.

Generally, our implemented prototype has scored high level of acceptance an satisfies from both lecture and student, where it investigates their passionate and feed richly their practicing with robust, reliability, correct logical states with enjoyable comfortable manner of practicing.

V. CONCLUSION

As per long time of real practicing for more than ten years during sequential of academic semesters using the innovated prototype discussed over this paper, we strongly declare that, this innovated prototype has approved successful services, and offered many distinguish valuable results which can be summarized in the following points:

Simplified Procedure: Before this prototype, students were used to constructing their experiments manually using ICs and wires. This procedure was very complicated and full of hesitation and stress. Also follow up and trace the errors was very difficult silly process.

Spare Time: As the time of lab is limited and controlled by the main time-table, so most of the students couldn't finish their tasks successfully, due to complicate of much wiring of the experiment details. But the invited prototype spare much of time.

Less of Efforts and Stress: Also due to the limitation of time, most of students get stressing and then become excocted while performing their demanded tasks. But while using "DIGITSTAR LAB" prototype, students feel comfortable with the easiest of use and clearest direct results.

Lowest Cost of Materials: While experiments, students used to make some mistakes by installing ICs in wrong way physically or invers the polarity connections; These cases caused damage of the ICs directly, also cutting of wires and connections. All these are types of cost are become limited or totally prevented by using the "DIGITSTAR LAB".

Saving Teaching Hours: Of Corse using the "DIGITSTAR LAB" has saved much of teaching hours due to the all above mentioned valuable characteristics. This means automatically teaching hours are decreased in both manner time and business cost.

Practice More: The “DIGITSTAR LAB” increases the percentage of practicing exercises up to 80%
of required courses’ practicing; Before it was around 25% as we mentioned earlier.

We are excited to declare that, our innovated digital logic prototype named “DIGITSTAR LAB” have successfully offered time, efforts, and cost of materials and teaching hours.

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