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Design And Construction Of A Cost-Effective Digital Electronics Logic Trainer Module For Students' Pedagogical Impact

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ABSTRACT
This article presents the design, construction, and pedagogical evaluation of a cost-effective Digital Electronics Logic Trainer Module developed, and simulated with a personal computer (PC) to enhance hands-on learning in undergraduate level. The research addresses the critical challenge of limited access to expensive commercial laboratory trainer by constructing a functional, durable, and affordable alternative using locally sourced components. The trainer features essential logic input switches, processing segments, and outputs using LEDs and seven-segment displays necessary for implementing foundational combinational and sequential logic circuits. Aside the technical development, this research assesses the device's pedagogical impact through a quasi-experimental study involving undergraduate students. Participants utilized the trainer to complete a structured laboratory curriculum. Data collected through pre- and post-tests, practical skills assessments, and student surveys indicate a statistically significant improvement in conceptual understanding and practical proficiency. The findings suggest that the developed cost-effective trainer not only serves as a viable substitute for commercial units but also actively enhances the learning experience by promoting deeper engagement and clarifying the hardware layer of digital systems.
Keywords: Digital Electronics, Logic Trainer, Educational Technology, Cost -Effective, Pedagogical Impact.

1.0 INTRODUCTION

The discipline of digital electronics forms the foundational bedrock for modern Physics,. computer engineering, electrical engineering, and information technology curricula. Mastery of concepts such as Boolean algebra, combinational and sequential logic, and state machine design is critical for students aspiring to work in industries ranging from consumer electronics to advanced computing systems (Mano & Ciletti, 2018). However, the pedagogical challenge lies in effectively bridging the gap between abstract theoretical principles and tangible, practical application.

Engineering education literature consistently emphasizes the indispensable role of the laboratory in fostering deep conceptual learning and developing essential professional competencies. Hands-on experimentation allows students to move beyond passive reception of information, engaging in active learning, troubleshooting, and the synthesis of design solutions (Feisel & Rosa, 2005). It is within the laboratory that theoretical knowledge is tested, verified, and internalized. (Lindsay and Good 2005) further assert that the laboratory experience is crucial for developing the intuitive understanding and practical skills that define a competent engineer.

Despite the recognized importance of practical work, many educational institutions, particularly in developing economies or those with constrained budgets, face a significant barrier such as the high cost of commercial educational hardware. Proprietary digital logic trainers, while functional, often carry price tags that limit the number of units an institution can procure (Watai, Brodersen, & Brophy, 2007). This scarcity results in large student-to-equipment ratios, reduced hands-on time, and a learning experience that is often more demonstrative than interactive. Consequently, the potential for genuine experiential learning is diminished, leaving students underprepared for the demands of the industry (Karri & Hourany, 2007).

Furthermore, the black box nature of many commercial trainers can be pedagogically limiting. When inputs and outputs are managed through abstracted interfaces, students may fail to appreciate the underlying hardware operations, such as switch debouncing, current limiting, or the physical integration of integrated circuits (ICs) (Milliken & Gomes, 2012). There is a growing call within the student's environment for tools that are not only affordable but also transparent and conducive to inquiry-based learning.

In response to these challenges, this research embarks on the design and construction of a cost-effective Digital Electronics Logic Trainer Module simulated with a PC. The primary objective is to develop an instructional tool that is financially accessible, robust, and pedagogically transparent. However, this project goes beyond mere technical development. It seeks to rigorously evaluate the pedagogical impact of this trainer on student learning outcomes. By integrating the developed module into a structured minimum standard of the National Commission for Colleges of Education (NCCE) laboratory curriculum for the Nigeria Colleges of Education, and employing a mixed-methods approach to assess student performance and perception, this study aims to provide empirical evidence on how a strategically designed, cost-effective intervention can enhance the educational experience in digital electronics, thereby ensuring access to quality hands-on practical education.

2.0 Literature Review

Hacker (2009) designed a low-cost student-constructed digital trainer. The module was developed to assist the student undertaken digital logic and basic electronics courses to perform and replicate the digital experimental exercise at home using a technology called Port Buffer. The system was inexpensive and portable, but the module is a software simulation-based functioning; its operations depend on computer application and could not perform SLC and other tasks. Godwin, *et al*, (2013) presented a microcontroller-based real time emulator for logic gate and structured logic devices aimed to find a way out to make the microcontroller become a convenient substitute for any digital device that is readily unavailable for use in the logic design. A system emulator was suggested to take the advantages of digital logic design which can lead to offer of low-cost laboratory equipment for efficient skills transfer in the educational systems. The design for SLC is more difficult task than CLC because of the feedback part and redundant states in sequential logic circuits. Tao, *et. al*. (2012) designed a module-level Evolvable Hardware (EHW) approach to design synchronous sequential logic circuits using Genetic Algorithm (GA) to minimize the circuit complexity, number of logic gates, wires attached, and obtain near-optimal state assignment. Therefore, sequence detectors, modulo counters, and ISCAS'89 circuit are used as the proof for the simulation evolutionary design approach. Also, genetic algorithm (GA) was used to design combinational logic circuits (CLCs) in the optimization of combinational logic circuits through decomposition of truth tables and evolution of sub-circuits presented in (Manfrini *et al*., 2014). The goal of the author is to minimize the number of logic elements in the circuit, by proposing a new coding for circuits using a multiplexer (MUX) at the output of the circuit. With reverence to the author's contribution in the area of digital electronic and logic circuit as review in this paper. Ajao, L. (2017) developed a system to put into the practices all the techniques, proof from the review paper about the circuit optimization, circuit complexity, and minimization. His work made apparent practicality by developing a low-cost digital logic training module for student laboratory experiment. The approach of "learn-while doing" on the digital electronics, logic circuit design, and embedded system projects will help students connect their reasoning from theoretical background to the practical development (Ajao, Olaniyi, Kolo & Ajao, 2015).

Milliken and Gomes (2012) described the design of a cost-effective digital logic trainer utilizing discrete 7400 series integrated circuits and a custom printed circuit board. Their design achieved significant cost reduction while maintaining the essential functionality required for introductory digital courses. Student feedback indicated that the transparent design actually enhanced learning by making the hardware more accessible and modifiable.

Prabhu *et al.* (2018) proposed a hybrid approach, combining discrete logic ICs with microcontroller-based monitoring and testing systems. Their design maintained the pedagogical transparency of discrete components while adding automated assessment capabilities that reduced instructor workload. This approach demonstrates the potential for thoughtfully designed educational tools that balance cost, functionality, and pedagogical effectiveness.

Milliken & Gomes, (2012) opined that early commercial trainer, such as those produced by E&L Instruments and Global Specialties, established the standard features that persist today debounced switches, buffered outputs, and regulated power supplies. These devices proved effective in classroom settings but were often priced beyond the reach of smaller institutions or individual students.

Sarik and Kymissis (2010) demonstrated how Arduino-based systems could serve as affordable platforms for teaching digital logic and embedded systems. Wolff (2015), argued that though microcontrollers offer flexibility, some educators caution that they can obscure the discrete logic operations that form the foundation of digital design

However, a significant gap remains. While numerous studies describe the technical development of cost-effective trainers (Milliken & Gomes, 2012; Prabhu *et al*., 2018), and others assess pedagogical interventions in digital electronics (Watai *et al*., 2007), few combine comprehensive technical development with rigorous pedagogical impact assessment. Furthermore, existing studies often lack detailed documentation that would enable replication by other institutions. This research addresses that gap by designing and constructing a cost-effective digital logic trainer with a simulation PC to compare the output result obtained from the digital trainer

with attention to both technical and pedagogical design criteria, providing complete, open documentation to enable replication, and rigorously assessing the trainer's pedagogical impact using established assessment methodologies and using the NCCE minimum standard for Nigerian Colleges of Education curriculum. The contribution is not merely a new device but a validated model for how institutions can develop their own effective, affordable instructional materials.

3.0 METHODOLOGY

The first step involved establishing a comprehensive set of design requirements derived from literature review findings and an analysis of existing commercial and research-based trainers. The requirements were categorized into technical specifications and pedagogical specifications. The technical specification includes among other components, regulated +5V DC with reverse polarity protection and short-circuit protection, several debounced toggle switches for logic level inputs, LED indicators with current-limiting resistors, one 7-segment display, manual debounced push-button for single-step clocking and variable frequency oscillator (1Hz to 1kHz), minimum of 400 tie-points for prototyping, standard 14-pin and 16-pin DIP ICs, 7400 series logic ICs for switch debouncing and pulse generation, compact and stackable for storage (target: 200mm x 150mm x 50mm). Tactile switches with mechanical life ratings exceeding 100,000 operations, high-quality solderless breadboard sockets from reputable manufacturers, the PCB material was made up of FR-4 grade, 1.6mm thickness with ENIG (Electroless Nickel Immersion Gold) finish for durability,

The pedagogical specification among other includes; visible and accessible circuitry to facilitate learning and withstand repeated use by novice students with clear labelling and logical layout.

The circuit schematic was designed using KiCad EDA (Electronic Design Automation) software, an open-source platform that facilitates design sharing and replication. Key design considerations included separate power and ground planes with adequate trace widths for 1A current capacity, RC networks with Schmitt trigger inverters for reliable switch operation, 555 timer-based astable multivibrators with variable frequency control, and series polyfused and reverse polarity protection diodes for circuitry protection.

Assembly was performed by the research team using standard soldering techniques. Each assembled prototype underwent comprehensive functional testing. Voltage regulation under varying loads (0-500mA) was carried out for power supply unit, oscilloscope measurement of switch transitions, oscillator frequency verification of 1Hz to 1kHz range, verification of all breadboard connection points, and full system integration through implementation of test circuits (logic gates, half adder, flip-flop, counter) to verify complete functionality.

Issues identified during prototype testing were documented and addressed through design revisions. The most significant issue involved oscillator frequency drift at low frequencies, which was resolved by adding a temperature-stable capacitor. Through the successful prototype validation, a module was fabricated for the pedagogical intervention phase.

The intervention consisted of a structured laboratory curriculum utilizing the developed logic trainers. The curriculum progressed from fundamental concepts to integrated system design:

i. Laboratory safety and equipment familiarization
ii. Basic gate verification (AND, OR, NOT, NAND, NOR, EX-OR, EX-NOR)
iii. Half adder and full adder implementation
iv. Tug of war design
v. Encoder and decoder, BCD Trainer
vi. Seven-segment display driver design

Each laboratory session followed a structured format such as reading and preliminary design, circuit construction and testing, and report writing and reflection.

SYSTEM DEVELOPMENT

Power Supply unit

This unit consists of a transformer which is used to step down the 220-240AC voltage, IN4007 diodes used to form a bridge rectifier to convert AC to DC, capacitor 1000uF which is used as a filter circuit and smoothening, LM317 regulator was used to obtain a +12VDC output regulated value, 330Ω resistor was used to limiting the current flow to the load, and LED was used as indicator light.

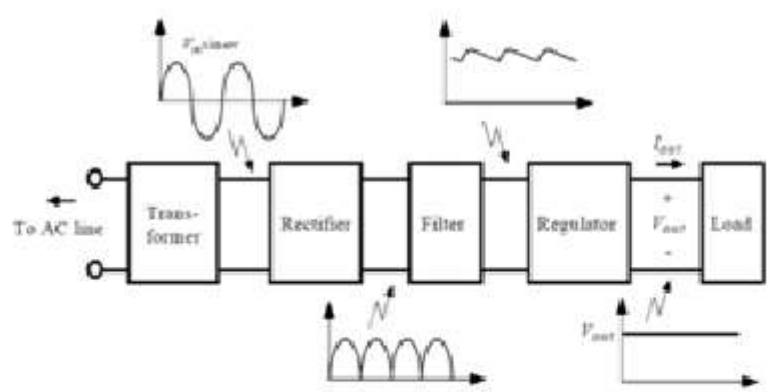

Fig. 1: Block diagram of a regulated power supply unit with sinusoidal signal.

Input Logic Circuit

The input logic circuit provides two logic states, logic 1 defined as voltage high level (+5 V) and the logic 0 defined as voltage low level (0 V).

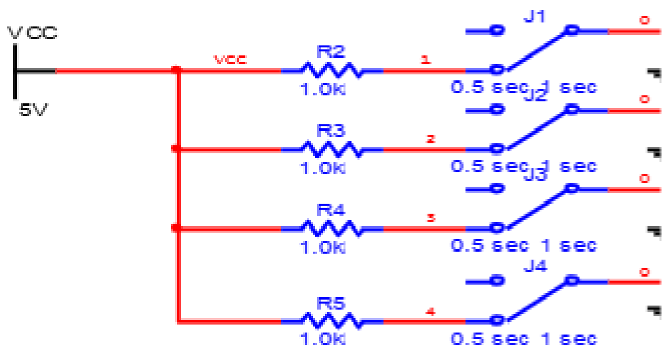

Fig. 2: Input time delay logic circuit

Integrated Circuit 555 Timers and Pulse Generator

The 555 IC timers, an integrated circuit (chip) that is applicable for the variety of timer, pulse generator and oscillator usefulness. The 555 was used to provide time delays, as an oscillator and to a flip-flop element in the design. The design of a flip flops chosen required the application of appropriate clock signals or pulses. This was achieved using the 555 timer IC configured in astable mode. While, the pulse generator is a piece of electronic that analyze equipment used to generate rectangular pulses as depicted in the figure 5

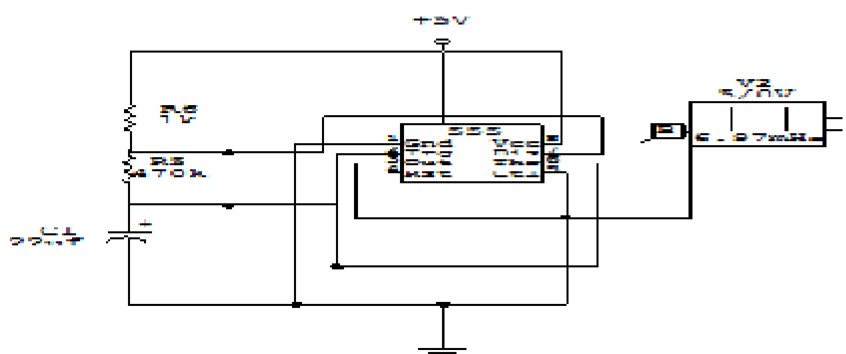

Fig. 3: Pulse generator circuit connected with 555 IC timers

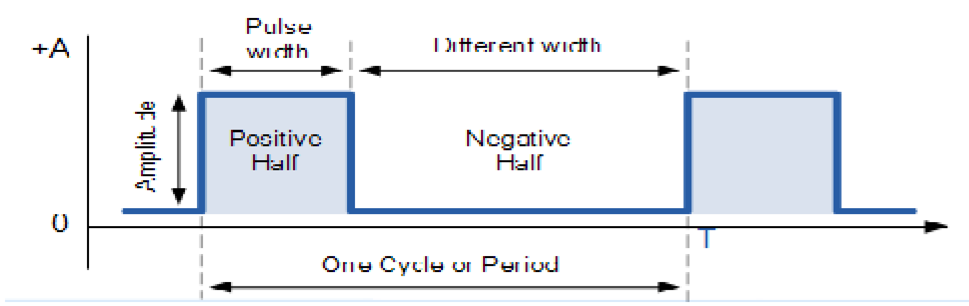

Fig. 4: Rectangular waveform of two pulse widths that are unequal time period

A 7-Segment LED Display

Eight numbers of LED were arranged in a digit form and labelled as 'a' to 'g' to count and display the decimal value from 0-9 using common cathode connections. A common cathode 7 segment display consists of (8 pins and 7 input pins) labelled from 'a' to 'g' and the 8th pin is identified as a common ground pin or decimal point (dp).

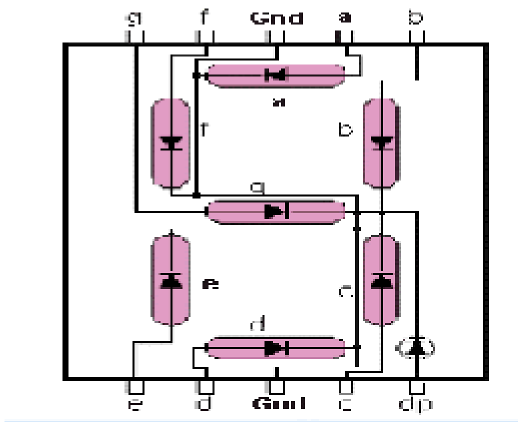

Fig. 5: Common cathode connection of 7-segment display

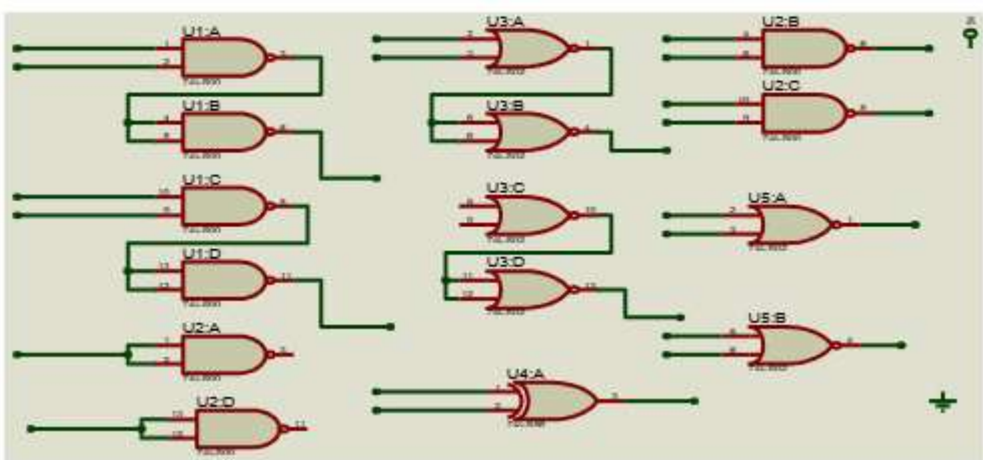

Fig 6: Combinational logic circuit connections

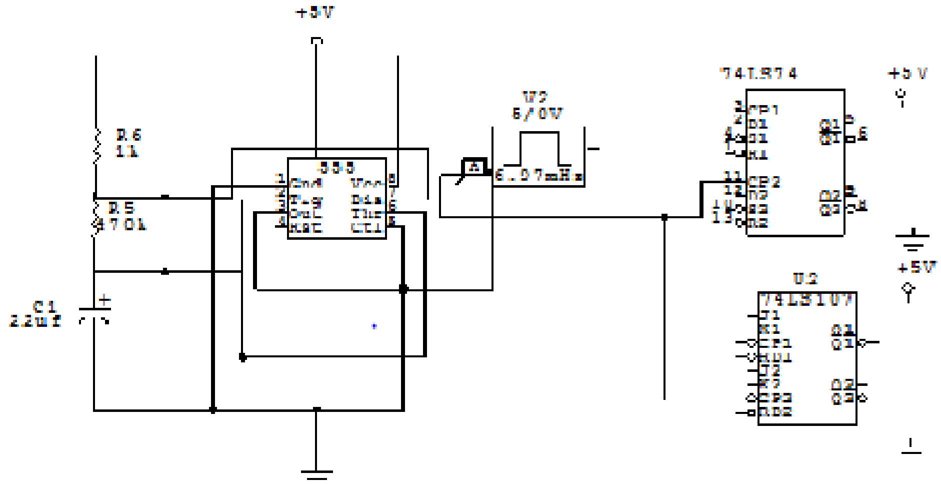

Fig 7: Sequential logic circuit connection with 555 IC timer

4.0 RESULTS

The design and development process resulted in a fully functional Digital Electronics Logic Trainer Module. Figure 8 represents the block diagram of a digital logic training module.

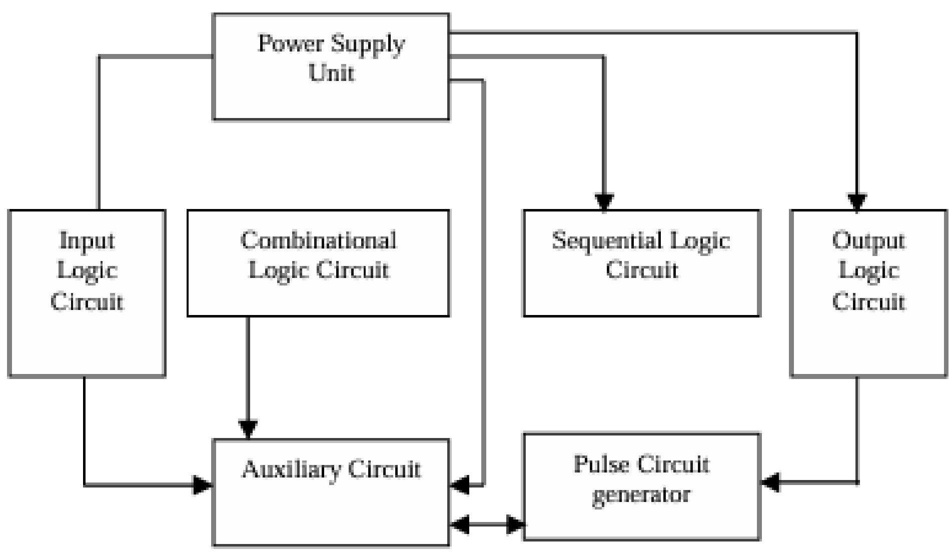

Fig 8: Block diagram of a digital logic training module

The module went through 72-hour continuous burn-in testing with dynamic load conditions. This showed that output voltage variation is less than 2% under load from 0-600mA, all the switches exceeded 10,000 actuations during testing without failure. In terms of oscillator accuracy, frequency drift below 5% over 0-50°C temperature range, and contact resistance remained less than 0.5Ω after 100 insertion and removal cycles in the breadboard. The results show significant improvement across all practical skill categories. The largest effect sizes were observed for troubleshooting, and overall composite score, indicating that the hands-on experience with the trainer substantially enhanced students' practical competencies. The result further shows that the obtained output from the logic trainer agrees with when simulated using a PC.

The logic trainer was successfully developed exceeding all technical specifications as the pedagogical impact of the module on the students demonstrated significant gains in conceptual understanding with largest gains in sequential logic and troubleshooting. Also, the result practical competencies improved significantly across all dimensions with troubleshooting showing the greatest improvement owning to the fact that students overwhelmingly rated the trainer positively, with most of them agreeing it improved their understanding and supporting its continued use. Finally, the students valued the trainer's transparency, the learning opportunities provided by troubleshooting, and the accessibility enabled by low cost. Though the module exhibited a construction defect as a result of solder bridge on oscillator circuit, which was identified during testing and fixed after troubleshooting prior to commissioning.

These findings suggest that practical experience with the trainer supports both conceptual and skill development.

5.0 CONCLUSIONS

This research set out to design and construct a cost-effective Digital Electronics Logic Trainer Module and simulate it with a PC to rigorously assess its pedagogical impact on student learning outcomes. The study employed a mixed-methods quasi-experimental design.

The results provide strong evidence that the developed trainer significantly enhances students' conceptual understanding of digital electronics. The overall normalized gain on the concept inventory exceeds the typical range for traditionally taught courses and compares favourably with published benchmarks for effective interactive-engagement pedagogies (Hake, 1998). The large effect size indicates that the improvement is not merely statistically significant but educationally meaningful.

Particularly noteworthy is the substantial gain in sequential logic gate a topic that students traditionally find abstract and challenging. The qualitative findings illuminate this result where students reported that building and observing sequential circuits on the trainer made the behaviour of flip-flops and counters tangible and intuitive. As some students expressed that, watching a "Tug of War Game" transformed an abstract concept into concrete understanding.

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REFERENCES

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education Research. *Educational Researcher*, 41(1), 16-25.

Ajao L. A., Agajo J., Kolo J. G., Adegboye M. A., Yusuf Y. (2016). Learning of Embedded System Design, Simulation and Implementation: A Technical Approach, American Journal of Embedded Systems and Applications. Vol. 3, No.3, pp. 35-42. doi: 10.11648/j.ajesa.20150303.12

Ajao L. A., Olaniyi O. M., Kolo J. G., Ajao A. O. (2015). Project-Based Microcontroller System Laboratory Using Bk300 Development Board with PIC16F887 Chip, International Journal of Embedded Systems and Applications, 5(3): 15-28

Feisel, L. D., & Rosa, A. J. (2005). The Role of the Laboratory in Undergraduate Engineering Education. *Journal of Engineering Education*, 94(1), 121–130.

Godwin U. O., Inyiama H. C., Chidiebele U. C., Ekene M. S. (2013). Microcontroller Based Real-Time Emulator for Logic Gate and Structured Logic Devices, International Journal of Science and Technology, 2(8).

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.

Hacker C. (2009). A Low-Cost Student Constructed Digital Trainer. Conference Proceedings, AaeE, Adelaide.

Karri, V., & Hourany, M. (2007). A progressive digital design curriculum using a single FPGA platform. *International Journal of Electrical Engineering Education*, 44(4), 319-331.

Lindsay, E. D., & Good, M. C. (2005). Effects of laboratory access modes upon learning outcomes. *IEEE Transactions on Education*, 48(4), 619-631.

Manfrini F., Helio J. C., Bernardino H. S. (2014). Optimization of Combinational Logic Circuits Through Decomposition of Truth Table and Evolution of Sub-Circuits, IEEE Congress on Evolutionary Computation (CEC).

Mano, M. M., & Ciletti, M. D. (2018). *Digital Design: With an Introduction to the Verilog HDL, VHDL, and System Verilog* (6th ed.). Pearson.

Milliken, T., & Gomes, L. (2012). A cost-effective digital logic trainer for introductory digital design courses. *Proceedings of the ASEE Annual Conference & Exposition*, San Antonio, Texas.

PhET Interactive Simulations**.** (2024). *Research-Based Design of Physics Simulations.* University of Colorado Boulder

Prabhu, S., Goyal, S., & Nair, B. (2018). Design and development of a cost-effective digital logic trainer with integrated assessment capabilities. *Journal of Engineering Education Transformations*, 31(3), 120-126.

Sarik, J., & Kymissis, I. (2010). Lab kits using the Arduino prototyping platform. *Proceedings of the IEEE Frontiers in Education Conference*, Washington, DC.

Tao Y., Cao J., Zhang Y., Lin J., Li M. (2012). Using Module-level Evolvable Hardware Approach in Design of Sequential Logic Circuits, World Congress on Computational Intelligence (WCCI)

Watai, L. L., Brodersen, A. J., & Brophy, S. P. (2007). Designing effective laboratory experiences for introductory digital systems courses. *Proceedings of the ASEE Annual Conference & Exposition*, Honolulu, Hawaii.

Wolff, T. (2015). *Digital Design: Principles and Practices* (5th ed.). Pearson.