A Raspberry Pi Experiment Board for Computer Engineering Undergraduate Training

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Abstract: Computer programming for lower-level engineering students in developing countries is particularly challenging. This is a major limitation that needs to be addressed because technical and programming skills are some of the major requirements for their academic pursuit. A low-cost, Raspberry Pi experiment board for basic programming and technical training purposes was developed and presented in this paper. The designed board is suitable for several electronic practical learning, capable of enabling its users to acquire the right understanding on the use of Raspberry Pi, coding and python programming language, as well as enable them to develop the unique set of instructions that can be used to drive any desired electronic experiment. The functionality and impact of the experimental training board was assessed and evaluated on the learning capabilities of the year III students of Computer Engineering Department, University of Lagos, Nigeria, by conducting a survey among the students that were involved in the use of the training board. The performance of the students and assessment of the conducted survey showed that the training board is particularly useful for learning computer programming. The interest and confidence level of the students in programming, before and after the training, were compared using a paired T-test and results showed $|t| = 12.161 > t_c = 2.093$ and $|t| = 18.116 > t_c = 2.093$, respectively. This shows that the training board has a positive impact on motivating the students to learn computer programming.

Keywords: Raspberry Pi, Python, Training board, Programming, Engineering.

1. INTRODUCTION

A Raspberry Pi is a small-sized low powered mini-computer that can be used for both software and hardware applications. It can be used to run multiple programs at the same time and can perform almost all the basic functions of a computer system. The purpose and functionality of this device are limitless because of its various models and unique interfaces which can be easily adapted to suit the purpose of the programmer.

The Raspberry Pi has been used to study different systems, used to build different projects, and has also been applied to several real-time scenarios [1-6]. The major argument of these authors in favour of the Raspberry Pi is its availability and low cost. In a study [7], the technical advancement in the latest version of the Raspberry Pi and the possibility of applying the mini-computer for teaching students programming was discussed and analyzed. This is similar to the work presented in another paper [8] where the possibility of using the Raspberry Pi to provide computing and programming access to the schools in rural areas of India was evaluated. Several other experimental boards have been developed for the teaching of electrical engineering laboratories as seen in some other papers [9-10]. The design and creation of a virtual laboratory with the aim of using the Raspberry Pi as the server for remotely accessing the devices in the virtual learning environment (VLE) was shown in another paper [11] where authors further justify the limitless possibility that the Raspberry Pi can proffer in hardware and software applications. Other authors [12-13] showcased schools in Cameroon where several Raspberry Pi devices has been installed to enable the use of spreadsheet and word processing packages by the learners and teachers. It can be seen in all of these works that the introduction of the Raspberry Pi in schools is used to facilitate proper technical, practical, and programming exposure to the students.

In all these reviewed works of literature, none has provided a permanent board with programming exploration for student learning purpose nor have used the Raspberry Pi to implement a compact and easily accessible experimental board that can be used for basic electronics practical learning activities. Motivated by the lack of technical and programming know-how of the engineering students in developing countries which has risen over the years and the need to develop a

simple experiment board that college students can relate with, this paper presents a Raspberry Pi experimental board that is capable of exposing computer engineering undergraduates to different interesting electronic phenomena and basic Python programming which is one of the skills required for their practical learning and career pursuits. Part of the innovations that can be achieved using the Raspberry Pi for classroom electronic practical teaching is demonstrated in this work. In this paper, the Raspberry Pi is used to develop a simple electronic experiment board for student learning. The board is low-cost, low-powered and its function extends to both hardware and software project applications, especially projects that cannot be carried out using a basic microcontroller like the Arduino.

The designed experimental board is user-friendly and developed from different electronic components and devices including resistors, capacitors, ceramic capacitor, transistors, diodes, peripheral interface controller (PIC), and dot matrix display which are permanently soldered on the printed circuit board (PCB). The training board enables its users to acquire the working principle of these devices, expose them to Python programming language, and enable them to learn and develop the unique set of instructions that can be used to drive any desired electronic experiment of their choice. The main contributions of this paper are to:

- design an experimental training board that can be used for a minimum of fifteen (15) basic electronic experiments,
- develop a platform for the introduction of Python programming skills to lower-level undergraduate students, and
- develop an interactive platform with which students can develop technical hands-on programming skills for electronic designs.

2. MATERIALS AND METHODS

The experimental training board presented in this work is designed as a teaching tool to develop simple electronic circuits and programming skills in computer engineering students. The purpose of this experimental board is to use the Raspberry Pi 3 to carry out simple electronic experiments that can enable undergraduates to learn how to code and expose them to the application of useful electronics technology.

2.1 Design and Construction Details

The choice of the electronic components and devices used in the construction of the experimental board presented in this paper is made with utmost attention to their rating, supply voltage, and maximum allowable current. These components and devices include: Raspberry Pi, Raspberry Pi power adapter, light emitting diodes (LEDs), pushbuttons, transistors, buzzer, 7-segment display, dot matrix display, liquid crystal display (LCD), peripheral interface controller PIC, resistors, variable resistors, ceramic capacitors, electrolytic capacitor, frequency oscillator, and other accessories like breadboard, T-cobbler, general-purpose input output (GPIO) cable, several connection wires, high definition multimedia interface (HDMI) screen, aluminium casing, mouse, keyboard, power cable, HDMI cable, and network cable. To reduce the complexity of the circuit required for the design of the experimental board, it is sectioned into five different modules which are the Raspberry Pi circuit module, power supply circuit module, LCD circuit module, 7-segment display module, and the dot matrix circuit module. Each of these circuits functions independently and depends on the Raspberry Pi which drives their respective operation.

The Raspberry Pi circuit module and the power supply circuit module are standalone circuits on the board while the LCD circuit module, 7-segment display module, and the dot matrix circuit module are permanently soldered on the printed circuit board with components like PICs, resistors, ceramic capacitor, LEDs, electrolytic capacitors and buzzer. The Raspberry Pi circuit in Figure 1 is the main circuit because all the components, devices and other sub-circuit are connected to it. Also, the programme required to run each of the designed experiment and to send the output message to the Inter-Integrated Circuit (I^2C) bus is run on the Raspberry Pi. The I^2C bus is used in this work for the intra-board communication for the LCD display, the dot matrix display, and the 7-segment display. Three PICs which can be likened to a programmable intelligent controller are connected to the LCD display module, the dot matrix display module, and the 7-segment display module, respectively.

The supplied voltage to the Raspberry Pi circuit, where all the LEDs D_1 to D_2 are connected, is $5V$. The attached resistors R_3, R_4, R_5, R_6, R_7, R_8, R_9, and R_{10} each has a resistance value of 220Ω and this is chosen to give enough room for tolerance being the nearest higher preferred value. The buzzer, buttons for the pulse width modulation, and all the LEDs are connected to different GPIO pins. Controlling the power supplied to each of the circuits is of utmost importance because most of the components and devices used are low powered and they have to be protected from overvoltage. The power circuit is designed to control the voltage and the power that will be supplied to each of the connected devices because they require different voltage values for their respective operations. All the required DC power levels required in the circuit are generated in the designed power circuit.

The dot matrix module is generally composed of arrays of LEDs whose lighting up and dimming formulates different characters and patterns. The dot matrix module used in this work is configured to display alphabets. HDMI screen is attached to the experimental board to display all the required python codes for each experiment. To protect the attached screen and for ease of movement, the completed designed experimental set-up and the screen are permanently fixed to an aluminium casing. A breadboard is also attached to the designed experiment board to give room for further exploration beyond the scope of this work.
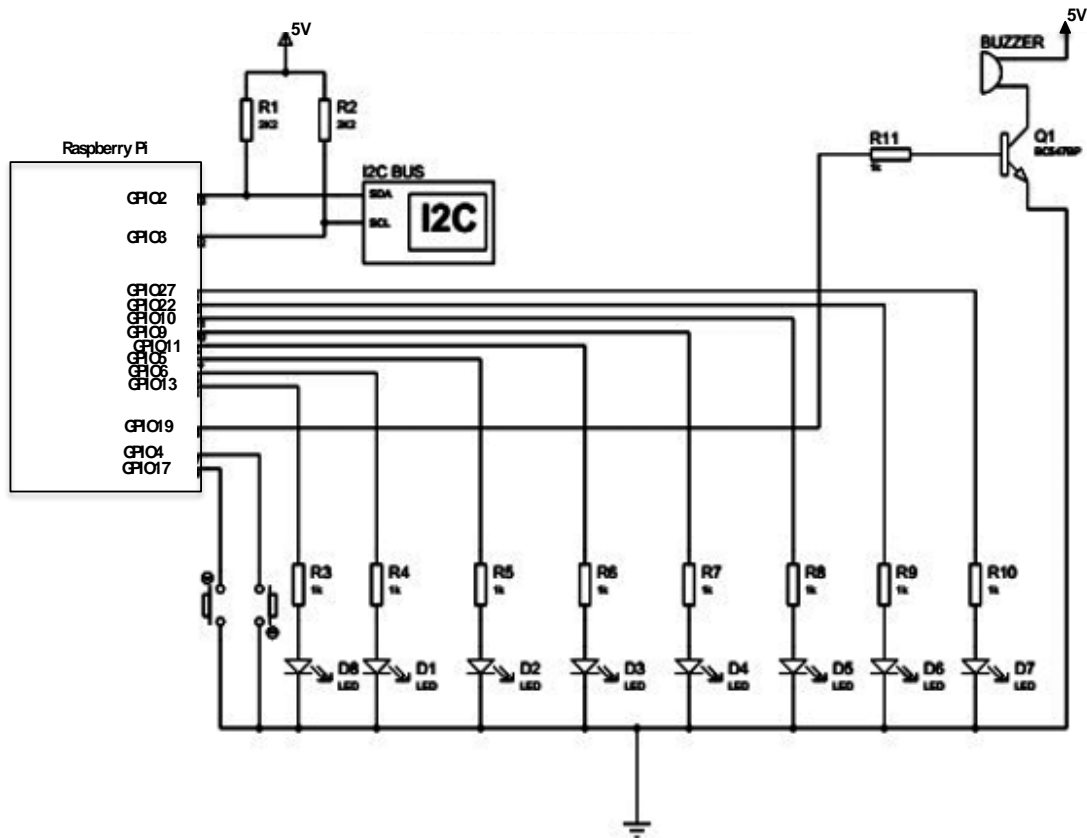
Figure 1: The Raspberry Pi Circuit Arrangement

2.2 Schedule of Experiments

The aim of the laboratory is to use experimental training board to teach lower-level undergraduate students the basic knowledge of the functionalities of the Raspberry Pi and to develop their interest in Python programming language in preparation for higher-level electronics and programming language courses. Python is the default educational programming language for the Raspberry Pi. It is used as an introductory language for many platforms, because of its easy-to-understand syntax. As a case study, Year III students of Computer Engineering, University of Lagos, Nigeria that used the designed training board in Year II were involved in a study survey. For the case study, a total of 20 out of the 65 students in the class participated. The goal is to assess the impact of the training board on the learning capabilities of the participating students. The students had a total of five laboratory experiments as fully discussed in the testing, results, and discussion section. For each laboratory experiment, students are required to do the following:

1. Read the instructions for the experiment carefully;
2. Familiarize themselves with the experimental training board;
3. Build the required electronic circuit on the electronic breadboard;
4. Turn on the Raspberry Pi and open the terminal window on the display interface;
5. Write the code to implement the circuit using Python programming language; and
6. Run the code.

3. TESTING AND RESULTS

The constructed experiment board was tested by a few Year II computer engineering students to ascertain the functionality of the designed circuit. The testing of the five major circuits was done separately and as a whole system. Also, some of the experiments were carried out on the finished designed board and the results are presented under this section. When the designed experimental board is not plugged to any source of power, all its circuits including the attached HDMI screen stay in their OFF state. Immediately the board is powered on to start experimenting on it, a standalone red LED on the board is lighted indicating that power has been supplied to the board and all its modules. Likewise, the attached HDMI screen starts its booting process. Some experiments that can be carried out on the designed board are discussed below.

a. Blinking LED

LED D_8 as connected in the Raspberry Pi circuit in Figure 1 was used in this experiment. The anode terminal of the LED was connected to a $220 \ \Omega$ resistor and the other terminal of the resistor connected to a $3.3 \ V$ supply controlled by the power adapter. The cathode of the LED was connected to the GPIO pin 27 of the Raspberry Pi. After the circuit was set-up,

a Python code written to blink the LED was run with a sleep time of 0.5 seconds. The LED blinked at this time interval until a set command "Ctrl c' was pressed to stop the programme. The image of the experiment board during the blinking LED experiment is shown in Figure 2.

b.   Effect of scrolling eight (8) LED

LEDs $D_8, D_1, D_2, D_3, D_4, D_5, D_6, D_7$ as connected in the Raspberry Pi circuit shown in Figure 1 was used in this experiment. The anode terminals of each LED was connected to a $220\,\Omega$ resistor and their other terminals were looped together and connected to a $3.3\,V$ supply controlled power adapter. The cathode terminals of the LEDs were connected to the GPIO pin 27, 22, 10, 9, 11, 5, 6, and 13 of the Raspberry Pi respectively. After this set-up, a Python code was written to show the effect of the scrolling light with a LED sleep time of 0.5 seconds and this is run on the attached screen. The LEDs started to blink at this time interval in an array from LED D_8 to D_7 until the set command "Ctrl c' was pressed to stop the programme.

c.   Gradually increase and decrease the luminance of an LED using the pulse width modulation (PWM) technique

An interesting phenomenon was shown under this experiment. The luminance of the LED D_7 was gradually increased and decreased using the pulse width modulation (PWM) technique. LED D_7 was connected to a $220\,\Omega$ resistor and the other terminal was connected to a $3.3\,V$ supply controlled by the experimental board power adapter. Two buttons connected to the GPIO pins 4 and 17 were used as a switch to create the ON and OFF pattern to stimulate voltage between $3.3V$ and $0V$. The modulation frequency was 50 Hz and the duty cycle was 25%. A Python code was written to gradually increase and decrease the luminance of an LED with a sleep time of 0.05 seconds at an interval of $0\%, 25\%, 50\%, 75\%, 100\%$ luminance. The cycle continues till the keyboard interrupt command "Ctrl c" was pressed.

d.   Drive an active buzzer to beep with a PNP transistor

An active buzzer which has an inbuilt oscillating source that can make a sound when electrified was used in this experiment. A $1\,k\Omega$ resistor was connected to the base of a PNP transistor, the emitter was connected to one of the terminals of the buzzer, the other terminal of the buzzer was connected to the $5\,V$ supply while the collector of the transistor was connected to the ground. The terminal of the resistor was connected to GPIO pin 19 and a Python programme that makes the buzzer beeps at 3 seconds interval was written and run. The scope of this experiment extends to the use of a passive buzzer and the buzzer can equally be programmed to make a jingle or any desired rhythm.

Figure 2: Blinking LED Experiment.

Figure 3: The display on the LCD 1602, 7-segment, and dot matrix display module.

e. Drive four 7-segment, dot matrix and the LCD 1602 to display numerical characters and strings using an 8-bit shift register

The LCD 1602 display module, dot matrix display module, and four 7-segment display module were connected to three different peripheral interface controllers (PICs) which act as a shift register. The three PICs were further connected to the I^2C bus and they were configured as bus and slave with address 13, 12, and 14 respectively. Each of the PICs responds depending on the address sent to them from the Raspberry Pi. The LCD 1602 was programmed to display 'LCD is ON' when it was tested. It can be made to display any short sentence or phrase depending on the programme written for it. Each of the 7-segment display modules was programmed to display any number from 0 to 9 while the dot matrix module can display alphabets in lower and upper case. The display on all three modules is shown in Figure 3 while the whole training board set up is shown in Figure 4. The designed experimental board can be connected to either a laptop or desktop screen for increased screen resolution as shown in Figure 5.

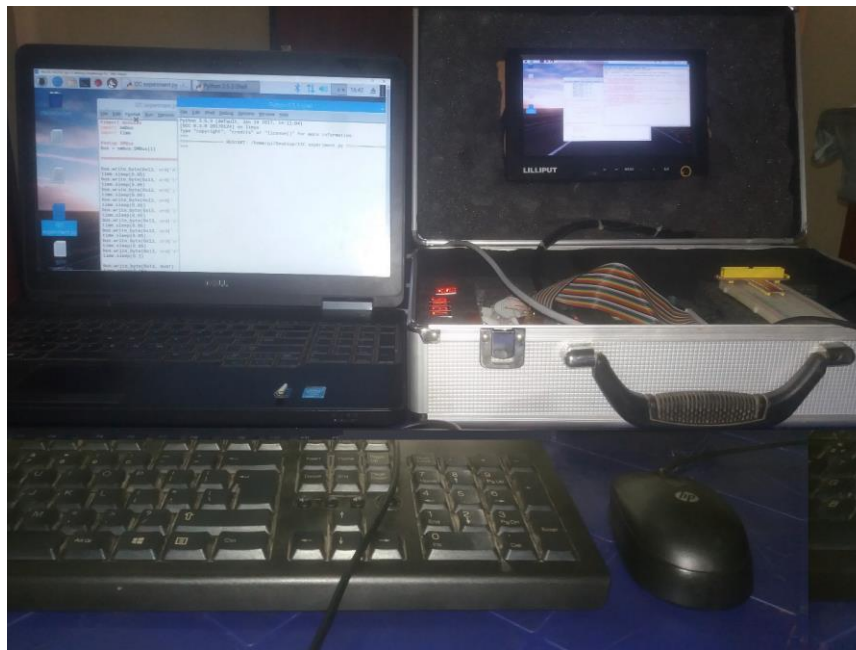Figure 4: Experimental Training board Set-up

Figure 5: The experiment board connected to a laptop via Cat 5 network cable

4. DISCUSSION OF RESULTS

The difficulty of understanding programming concepts at tertiary institutions in Nigeria is a thing of concern. Students find the concept difficult to comprehend and therefore fear the programming class. This problem motivated the development of the training board discussed in this paper. The goal is to use this board to motivate the students to develop an interest in computer programming.

A student impact survey was conducted before and after the training for the participating students to evaluate the impact of the training board on their attitude and motivation towards computer programming courses and their electronics circuit course. Data on the interest level of students in programming was collected before and after the training from the twenty participating students using a questionnaire. Students were assessed using a 5-point Likert scale: 1 – Not Interested; 2 – Not Very Interested; 3 – Neutral; 4 – Slightly Interested; 5 – Highly Interested. Students were also asked about their confidence level before and after the training and their answers were assessed on a 5-point Likert scale: 1 – Not Confident; 2 – Not Very Confident; 3 – Neutral; 4 – Slightly Confident; 5 – Highly Confident.

Students were also asked about their likelihood of taking a programming class in the future if they had an option before and after the training. Their answers were again based on a 5-point Likert scale: 1 – Highly Unlikely; 2 – Unlikely; 3 – Neutral; 4 – Likely; 5 – Highly Likely. Finally, the students were asked about their interest in electronics before and after the training. A 5-point Likert scale was again used: 1 – Not Interested; 2 – Not Very Interested; 3 – Neutral; 4 – Slightly Interested; 5 – Highly Interested.

A paired T-test was performed on the data collected before and after the training to determine if the difference between the paired data is big enough to be considered statistically significant. For the paired student's t-test, the t-value, which gives the information on the difference between the data collected before and after the training, is calculated using equation (1);

$$t = \frac{(\sum D)/N}{\sqrt{\frac{(\sum D)^2 - \left(\frac{(\sum D)^2}{N}\right)}{(N-1)(N)}}} \qquad (1)$$

where D is the sum of the differences between data collected before and after the training and N is the number of dependent data. Results of the t-test shown in Table 1 shows that the interest level and confidence level in computer programming was increased after the training. This shows that the interactive training board had a significant impact on motivating the students to learn programming. For clarity, the mean of the data collected before and after the training is showed in Figure 6.

Table 1: Result of Data collected from Students Before and After the training

Assessment	μ_1, SD_1	μ_2, SD_2	dF	$|t|$	t_c	P	α
Probability of future programming class	1.20, 0.523	3.10, 0.718	19	9.970	2.093	$P = 0 < 0.05$	0.05
Interest in Programming	1.25, 0.444	3.65, 0.933	19	12.161	2.093	$P = 0 < 0.05$	0.05
Confidence to Program	1.00, 0.000	3.45, 0.605	19	18.116	2.093	$P = 0 < 0.05$	0.05
Interest in Electronics course	4.10, 0.308	4.20, 0.523	19	0.809	2.093	$P = 0.4283 > 0.05$	0.05

From the table, the t-test results shows $|t| = 9.970 > t_c = 2.093$ for the probability of taking computer programing in the future where t_c is the 95% critical value accepted. Results for interest and confidence level in programming for participating students shows $|t| = 12.161 > t_c = 2.093$ and $|t| = 18.116 > t_c = 2.093$, respectively. Results for these three assessments showed $P = 0 < 0.05$ and it can, therefore, be concluded that the difference between the data collected before and after is big enough to be statistically significant. The result showed that the mean of the data taken after significantly increased for all three questions confirming that the training had a positive impact on motivating the students to learn programming. Results for the interest in Electronics is, however, different. The t-test shows a value of $|t| = 0.809 < t_c = 2.093$ and $P = 0.428 > 0.05$. Therefore, there is not enough evidence to show that the data collected before and after the training is different at the 0.05 significance level. We can, therefore, conclude that the effect of the training is not as significant for electronics courses as it is in stimulating student's interest in computer programming. In Table 1, μ_1, μ_2 are the mean of data collected before and after the training, SD_1, SD_1 are the standard deviation of data collected before and after the training, dF is the Degree of Freedrom $= N - 1$ and lastly, P is the probability that the results from the data collected occurred by chance and α is the threshold probability value that we measure our P value against.
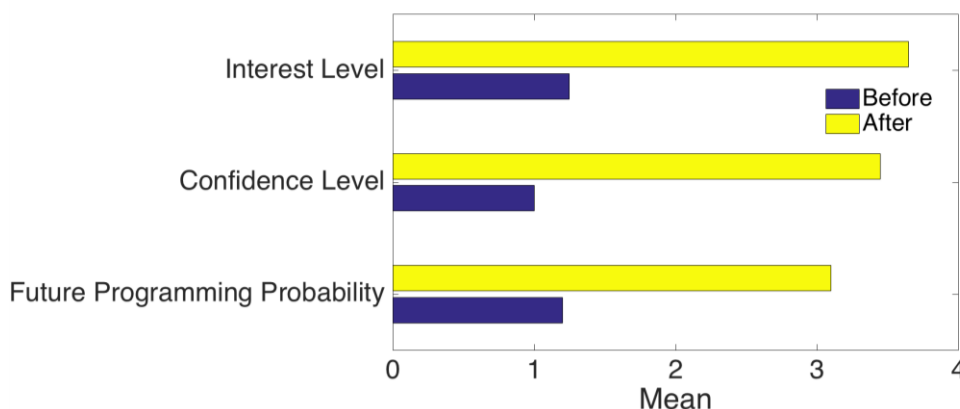

Figure 6: Mean of Data collected before and after the training

A student impact survey was conducted at the end of the first semester of Year III for the students involved in the use of the training board to compare their performance in the computer programming courses taken before and after the training. Figure 7 shows the performance of students before and after the training in computer programming classes in their second and third year at the department. Results showed tremendous improvement in the results of all of the participants.
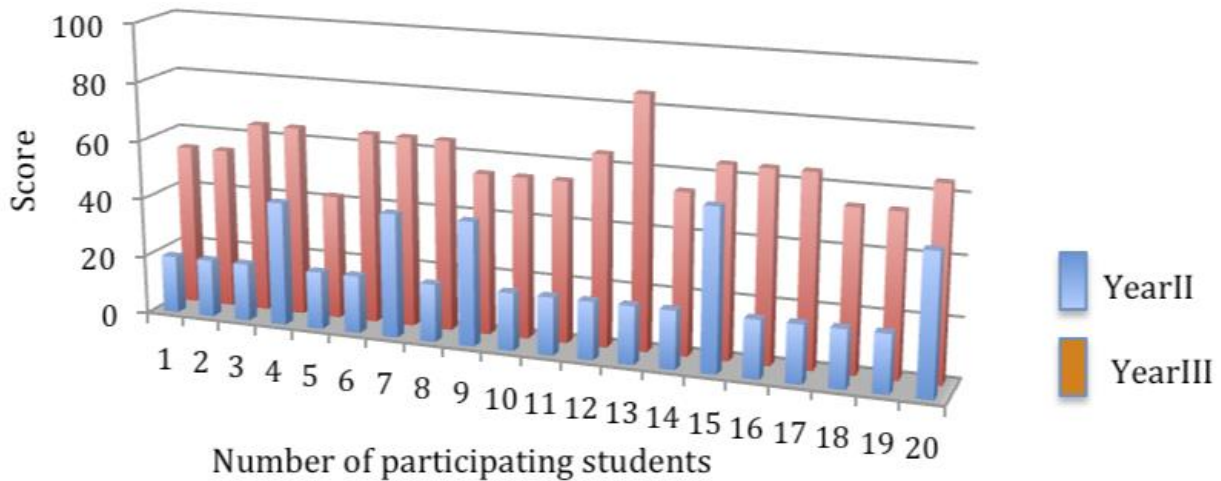
Figure 7: Performance of the students in programming courses

5. CONCLUSION AND RECOMMENDATION

The capability of the Raspberry Pi to drive electronic circuits and motivate students to develop programming skills was demonstrated in this paper. An experimental training board for basic electronic experiments, which is suitable for practical learning in the tertiary institutions, was designed and constructed in this work using the Raspberry Pi. The experiment board can be used to carry out several electronic experiments using Python programming language. Twenty students participated in this study through laboratory classes using our developed experimental board at the end of year II. The comparison of these students' experience before and after the training showed the efficacy of the training board as an educational tool for learning basic computer programming in the department. The performance of students and assessment of the survey conducted also showed that this training board is particularly useful for learning programming compared to learning electronic circuits. This may be due to the extensive hands-on laboratory used in teaching our electronic circuit course. The increased interest and confidence level of the participating students testified to the efficacy of the experimental training board in motivating students to learn programming.

Based on our findings, we recommend that the introduction of Raspberry pi training should be given to pre-university students in secondary schools in Nigeria to help them develop an early interest and understanding in programming. We also recommend training of secondary school teachers to give them sufficient knowledge that they can transfer to their students. We recommend that government and private secondary school owners should invest in the provision of Raspberry Pi for schools. These devices are low cost and can be purchased for less than ten thousand naira (₦10,000), which is far cheaper than laptops and desktop computers. The whole training board was developed with readily available devices at low and affordable cost. The scope of this work could also be expanded in the future by incorporating students from other engineering departments.

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