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STEM Education and a Comparative study of Raspberry Pi in the 2020s

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***Abstract*— The Raspberry Pi Foundation from London, UK has made a number of Single Board Computers for a decade. These boards being critically acclaimed by computer scientists throughout the world are well known for their reliability, robustness, high processing power and tools for educating Science, Technology, Engineering and Mathematics to the young minds. After making Single Board Computers, Raspberry Pi Foundation has started working into the field of microcontrollers. On 2020, the foundation has made Raspberry Pi 400 which is a CPU embedded keyboard followed by their first microcontroller, Raspberry Pi Pico on 2021; whereas again on 2021, they made Raspberry Pi Zero 2W, an upgraded version of one of their Single Board Computers Raspberry Pi Zero W. Keeping these three boards as the reference points, I explored different aspects and compared different parameters of these boards with the older versions of Raspberry Pi and Arduino Uno, the widely used microcontroller from the Arduino Family.**

Keywords*— *Raspberry Pi; Arduino; Single Board Computers; Education; STEM; Microcontroller;

I. INTRODUCTION

When it comes to the education of Science, Technology, Engineering and Mathematics, Raspberry Pi is well known for promoting them and making new ways for better accessibility. The main aim in this paper is to introduce how far Raspberry Pi has evolved. We will not come into the point that how good their boards are. Several Single Board Computers (SBCs) as well as Microcontrollers are available in the market; even new ones will be designed in the future. A comparison between these boards will be a help to understand which one will be ideal for a user's desired mode of application.

Since its inception, Raspberry Pi Foundation has made many boards from the year 2012. These boards came into popularity with their models Raspberry Pi Zero W & Raspberry Pi 3B+ (Fig. 1) which were made on 2017 and 2018 respectively. After that they came up with another model on 2018, which is Raspberry Pi 3A+, the downgraded version of 3B+ in terms of size and storage. On 2019, they made Raspberry Pi 4 which is an upgraded version of Pi 3B+ with three variants of 1 GB, 2 GB and 4 GB RAMs, followed by another 8 GB RAM variant on 2020. Again in the middle of 2020, they have made Raspberry Pi 400 which is a keyboard with the CPU embedded on it, working like Pi 4. Starting from 2021, Raspberry Pi Foundation has making microcontrollers with Raspberry Pi Pico (Fig. 4) being the first one. On 2022, they upgraded the microcontroller with Raspberry Pi Pico W, adding an additional Wi-Fi connectivity module. On 2021, the foundation also launched Raspberry Pi Zero 2W (Fig. 5), the upgraded version of Raspberry Pi Zero W.

Fig. 1 Raspberry Pi 3B+ connected with power supply, display and different peripherals.

As Raspberry Pi computers have been extensively used, a huge amount of research has also been performed on them, which inspired to write this paper. Nearly for half a decade, Raspberry Pi has been a subject for making Cities smart. A solar PV emulator has been designed with the help of rectifier, DC-DC converter and current & voltage sensors, which serves as a substitute for controlled light source [1]. With Raspberry Pi 4B, a home intelligent control system is designed which is capable of password unlocking, remote unlocking and face recognition [2]. In [3], the authors designed a luggage carrying trolley using Raspberry Pi 3B+. The trolley is designed in such a way that it will not require any person to push or pull the luggage; the trolley is also capable to avoid collision with external objects coming in front of it. In [4], a water dispenser system has been designed by voice based automation using Raspberry Pi 3B+.

With Raspberry Pi, people can check the safety of their homes in real time when they are away; this is done by

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designing a smart home surveillance system [5]. Raspberry Pi has also found beneficial for visually impaired people as a smart glass has been made through which people with this disability can identify their family members [6]. Many types of cell phones have also made with Raspberry Pi. In [7], the authors used a GSM Module for receiving and making calls, LCD touch screen for display and the Camera Module to make such cell phones. The operating system used is NOOBS. However, the authors in [8] did the same for visually impaired people, the reason for naming this device as optophone.

II. STEM EDUCATION

STEM is an abbreviation of Science, Technology, Engineering and Mathematics. In the recent years, especially after the COVID-19 pandemic, the importance of STEM Education has been a trending topic all over the world. For sustainability in economic and social development, the potential of a citizen needs to be increased. So, we should enhance the quality of STEM at all educational levels, whether in schools or in colleges or universities [9]. Computational thinking and problem solving are the skills which help us to identify how data are related to each other and what information is required at a scenario we have been provided or have already faced. Every youth should acquire these skills so that they can develop in economic, global and social aspects of life. Finding creative and effective solutions for STEM Education are not only in the hands of educators; this is where engineers and scientists are in need. In this 21st Century, we need such kind of collaborations which require both verbal and written communication skills in utilizing multi-disciplinary approach [10]. Brands like Lego and IKEA are working in STEM Education for toddlers which comes the cognitive, affective and psychomotor skills as a result [11]. Lego uses blocks that can be joined together and taken apart. On the other hand, IKEA toys teach shapes by matching them to its appropriate slot. In [12], the authors discovered a proton precession magnetometer (PPM) which is very useful in conducting physics experiments, particularly nuclear physics. The PPM sensor is an electronic instrument made of copper, which is measured based on physical equations given on the sensor.

Another approach for educating STEM is students practicing computer programs, for which the encouragement of the teacher is highly anticipated. Code.org is a non-profit organization which teaches code by conducting online events like Hour of Code and joining hands with schools and educators to conduct various events. The educators are first given training and then they are able to teach coding to students. Arduino is also doing the same by conducting Do-It Yourself (DIY) projects using their boards, mainly Arduino Uno and Arduino Nano. Other than inventing boards, Raspberry Pi Foundation is also conducting numerous ways, most notably Study Jams for maximum reach of STEM education to the youngsters. Scratch is a programming language which they recommend for teaching programming to kids. It is designed in such a way that the kids will learn programming in a fun way. This also leads to acquiring problem solving and critical thinking of kids. For computer pedagogy, Raspberry Pi Foundation publishes Hello World which is a tri-annual magazine that intends for teachers to enhance STEM Education. The foundation also publishes MagPi and Hackspace, two different monthly magazines which describes about DIY projects using Python Programming along with their boards and technologies like Machine Learning, Artificial Intelligence and Internet of Things (IoT).

III. ARDUINO

Before we step into Raspberry Pi, we must take an overview of Arduino, another popular microcontroller. Arduino initially started as a project in 2005 with an aim of creating devices in low cost and effective way so that the sensors and actuators can interact with their environment. The first device, Arduino RS-232 was made by Smart Projects in Italy. The most popular boards of Arduino are Arduino UNO (Fig. 2) and Arduino Nano. Arduino UNO consists of a crystal oscillator, voltage regulator and an Analog-to-Digital Converter [13]. It is operated on an external supply ranging from 7-12 V. UNO also has a clock of 16 MHz frequency, 14 digital I/O pins as well as 6 analog pins, each pin being provided 10 bits as resolution. Arduino Nano, on the other hand is small and breadboard-friendly microcontroller which has 8 analog pins and 5-20 V external supply. Nano requires Mini USB-B for power supply unlike UNO that requires USB-B. Both boards run on Arduino IDE (Integrated Development Environment) which runs on C++ language. Arduino also designs wearable boards like LilyPad and Gemma [14]. Gemma is considered ideal for wearable technologies whereas LilyPad is preferred for E-Textiles and IoT wearables.

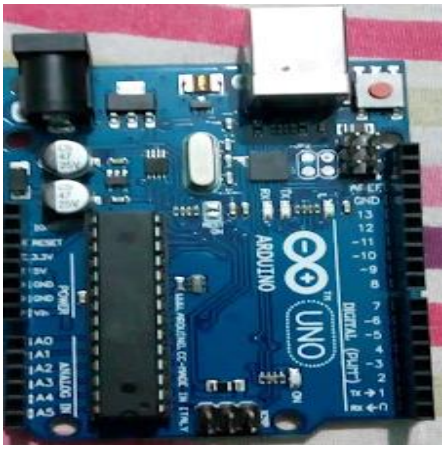

Fig.2 Arduino UNO Board.

IV. RASPBERRY PI 400

After Raspberry Pi 4, on 2020 the foundation came up with Raspberry Pi 400, a keyboard computer as it has the CPU embedded on the keyboard, which makes it All-in-One (Fig 3). Pi 400 has Broadcom Processor BCM2711. Inside Pi 400; the custom heat sink is connected with the SoC (System-on-Chip) with a thermal pad, so that it can work silently to keep Pi 400 from heat. This also enables the processor to run at 1.8GHz base speed. Under the heat sink, the printed circuit

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board uses a different layout to previous Raspberry Pi models. The Pi 400 board has Ethernet port at its left, followed by the USB and HDMI ports, the SoC in the middle, the GPIO and keyboard connectors, and ends at the right with the wireless LAN and Bluetooth radio.

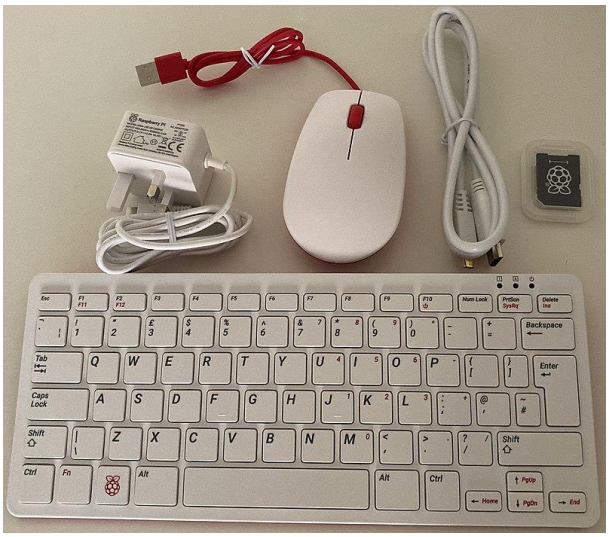

Fig.3 Raspberry Pi 400 Keyboard along with the kit.

Just like any other Raspberry Pi board, Pi 400 also has the regular 40 General Purpose Input Output (GPIO) pins which are widely used for projects on electronics. It has 3 USB Ports, out of which two are USB 3.0 and the other one is USB 2.0. For display support, Pi 400 has 2 micro HDMI ports, making it a dual display support by connecting two monitors at a time; each display supports up to 4k quality. The dimensions of Raspberry Pi 400 are 286 mm × 122 mm × 23 mm. It operates on Micro USB Type-C Power Supply. It has a micro SD Card slot, which is used for Operating System (OS) support. Raspberry Pi Foundation recommends Raspbian as the default OS for operating Pi 400, which is made by the foundation itself. However, there are many third-party OSes that can be used pretty well on Pi 400 like Ubuntu Mate, Windows IoT Core, RetroPie, etc. The foundation, however also recommends three softwares for programming on Pi 400: Scratch, Thonny (for Python Programming) and Visual Studio Code.

V. RASPBERRY PI PICO AND PICO W

Following Pi 400, The Raspberry Pi Foundation made their first microcontroller named Raspberry Pi Pico (Fig. 4) on 2021. Just like Arduino Nano, Pico is small and breadboard friendly. Pico works on a microcontroller chip named RP2040 which is an Application Specific Integrated Circuit (ASIC) designed by the foundation. It requires Micro USB Type-B for power supply as well as connecting with the computer. The pins at the Pico are the traditional GPIO Pins that have been designing on every Raspberry Pi SBC. Unlike previous boards, Pico runs on a specific programming language named MicroPython. To operate the language, the firmware of MicroPython needs to be installed in the Pico as well. After that Thonny IDE is installed in the computer where Pico is connected and we can write the programs to run the Pico. As Thonny supports both Python and MicroPython, the foundation prefers it as the IDE for Pico.

Fig.4 Raspberry Pi Pico

Pico although considered to be beneficial for physical computing over other boards, it lacked a Wi-Fi module that enables internet conectivity. To overcome this issue, Raspberry Pi Foundation made an upgraded version of Pico on 2022 named as Raspberry Pi Pico W. Pico W has the same specifications like Pico with the addition of a Wi-Fi module named CYW43439 wireless chip; also supporting Bluetooth. The wireless chip is connected to RP2040 chip via Serial Peripheral Interface (SPI).

VI. RASPBERRY PI ZERO 2W

After launching Raspberry Pi Pico, the Foundation came up with another SBC named Raspberry Pi Zero 2W (Fig 5), the upgraded version of Raspberry Pi Zero W, keeping the form factor identical to the latter. Like its predecessor, Zero 2W has no Ethernet port but two micro USB Type-B ports; one for the power supply and the other one for OTG support so that the peripherals can be connected to operate it. The thing that this model differs from Zero W is the addition of a Quad-core processor, which runs five times faster as claimed by the foundation. Also, it supports Mini HDMI for the display support. The SoC chip in Zero 2W is BCM2710A1, which is a custom Raspberry Pi SiP (System-in-a-Package) RP3A0.

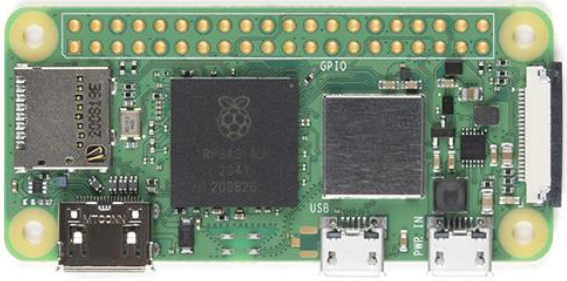

Fig. 5 Raspberry Pi Zero 2W.

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VII. COMPARISON OF THE THREE MODELS WITH OTHER BOARDS

After exploring all the things, we compared the three boards with their counterparts in tables I, II and III. Firstly, we compared Pi 400 with the older versions of Raspberry Pi, followed by Pico with Arduino Uno and Arduino Nano. Lastly we compared Zero 2W with Raspberry Pi Zero W.

TABLE I: COMPARISON WITH RASPBERRY PI 400 WITH THE OLDER VERSIONS OF RASPBERRY PI

Board	Cost	SoC Chip	Display Support	Power Supply & SRAM	CPU & GPIO Pins	USB Ports
RPi 400	$70	Broadcom BCM 2711	Dual Display Micro HDMI	5V (Micro USB-C), 4 GB RAM	4x Cortex A72 1.8GHz, 40 Pins	3 (2 x USB 3.0 + 1 x USB 2.0
RPi 4B	$35-$75	Broadcom BCM 2711	Dual Display Micro HDMI	5V (Micro USB-C), 1/2/4/8 GB RAM	4x Cortex A72 1.5GHz or 1.8 GHz, 40 Pins	4 (2 x USB 3.0 + 2 x USB 2.0
RPi 3B+	$35	Broadcom BCM 2837 B0	Single Display HDMI	5V (Micro USB-B), 1 GB RAM	4x Cortex A53 1.4GHz, 40 Pins	4 x USB 2.0

TABLE II: COMPARSION OF RASPBERRY PI PICO WITH OTHER BOARDS

Board	SoC Chip	Pins	Commu-nication	Power Supply	Clock Speed	SRAM
RPi Pico	RP2040	40	SPI, UART, I2C, PWM	1.8-5.5 V	133 MHz	264 kB
Arduino Uno	ATmega 328P SKU: A000066	32		7-12 V	16 MHz	2 kB
Arduino Nano	ATmega 328 SKU: A000005	40		7-12 V	16 MHz	2 kB

TABLE III: COMPARSION OF RASPBERRY PI ZERO 2W WITH RASPBERRY PI ZERO W

Board	Cost	SoC Chip	CPU	SRAM	Power Supply
RPi Zero 2W	$15	Broadcom BCM2710A1	4 x Cortex-A53 1 GHz	512 MB	5 V via Micro USB
RPi Zero W	$10	Broadcom BCM2835	1 x ARM1176J ZF-S 1 GHz		

In table I, we see that Raspberry Pi 400 has specifications almost similar to Raspberry Pi 4B except SDRAM and the no. of USB ports. Pi 400 has USB Ports lesser than Pi 4B by one. In table II, Pico has more advanced specifications than both Arduino Uno and Nano. This is due to the reason that both boards of Arduino were discovered at the 2000s but they are heavily used due to its low power consumption. Finally in Table III, we see that Pi Zero 2W, being little costlier has an upgraded SoC Chip and a quad core processor, leading to run Pi Zero W five times faster than Pi Zero W.

After comparing all the three tables, we finally tabulate all the three boards to compare each other for its application. Tables IV and V show the comparison between the boards. Table IV shows about the components used to make the boards work like SoC Chip, types of CPU, Bluetooth, whereas Table V compares the connectivity of the boards with the peripherals along with the pricing of the boards. The Application have labeled in table V against each board are of the author's opinion.

TABLE IV: COMPARSION OF ALL THE THREE RASPBERRY PI BOARDS

Board	SoC Chip	Instruction Set	CPU	WiFi IEEE 802.11 Wireless	Blueto-oth
RPi 400	Broadcom BCM2711	ARM v8-A (64/32-bit)	4x Cortex A72 1.8GHz	b/g/n single band 2.4 GHz	5.0
RPi Pico	RP2040	ARMv6-M	Dual Core Arm Cortex-M0+	None	
RPi Zero 2W	Broadcom BCM2710 A1	ARM v8-A (64/32-bit)	4 x Cortex-A53 1 GHz	b/g/n/ac dual band 2.4/5 GHz	4.2 BLE

TABLE V: COMPARSION OF ALL THE THREE RASPBERRY PI BOARDS

Board	SD RAM	Power Supply	Display Support	USB/ Micro USB Ports	Cost	Applicatio-ns
RPi 400	4 GB	5V (Micro USB-C)	Dual Display Micro HDMI	3 (2 x USB 3.0 + 1 x USB 2.0	$70	Teaching Aids for Programmi-ng
RPi Pico	512 MB	1.8 – 5.5 V (Micro USB-B	N/A	1 Micro USB (for Power Supply	$4	Physical Computing
RPi Zero 2W	264 kB	5V (Micro USB-B	Single Display Micro HDMI	2 Micro USB (for Power Supply and OTG Support	$15	Physical Computing and IoT

VIII. CONCLUSION

As we compared the three Raspberry Pi boards, we saw that Pi 400 with its keyboard layout as a low cost computer can be beneficial for studying and teaching basic programming languages like Python and Scratch. With Visual Studio Code and 4 GB RAM, Pi 400 is also preferred for Software Development projects like Android/iOS app Development, Machine Learning, Web Development, etc. However, physical computing like projects on electronics can also be

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performed on it; but only in this case, we prefer open circuitry boards like Raspberry Pi Zero 2W. Raspberry Pi Pico, on the other hand has high processing power than microcontroller boards like Arduino Uno; but it lacks only the wireless connectivity with Internet and Bluetooth, both of which have been overcome by Raspberry Pi Pico W. If we as responsible citizens can be able to make and teach the optimum use of boards according to the need, then only the STEM Education among the youngsters will be achieved.

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