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Low-cost Single-Board-Computers and Learning-Sets and the Relation to the "Digital" Didactic Goals of the 21st Century

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Abstract: *This paper gives an overview of the existing single-board computers under 100$ on the market, which are more or less suitable to fulfil the digital competences of the curricula of individual school types from primary to high school. For this purpose, a quantitative analysis of single-board computers under 100$ available on the market was carried out and the characteristics of the relevant products were extracted from the technical documents of the products and binarized using a qualitative deductive meta-analysis. The resulting skill- and property- fulfilment was supplemented horizontally with the snapshot price information, combined, and ranked vertically. The resulting list of more or less suitable products was presented in a network graphic, taking into account a horizontal dynamic price weighting, in order to allow the decision-maker to take into account his own financial possibilities of possibly limited budgets in his decision. The study points out that the market for single-board computers is divided into 2 different product types and that the SOC variants can definitely replace a PC. Furthermore, it was found that there are currently no learning stets that match the price and content requirements of the curricula. The study concludes with a summary and an outlook.*

Keywords: *21st century skills; STEM Didactic; Education Tools; Computer used in Education; Single Board Computers.*

1. Introduction

The continuing digitization requires new approaches in research and education. Particularly in the individual grades of schools, in colleges and also in universities, many changes and new content have been adopted in the curricula during the last decades which lays the focus on the teaching of digital content. These topics have been summarized, subdivided and ordered by the KMK into content-related and process-related competences (KMK, 2017).

In a study by Nothacker and Lavicza in 2020, the core topics of the knowledge to be taught were worked out and summarized across the various types of schools in the German-speaking DACH region (Nothacker & Lavicza, 2020, p. 350). The classic topics to be learned, such as hardware, software, operating systems, networks, databases and programming, as well as the newer topics to be learned, which include 3D printing, robotics, sensors and actuators, Industry 4.0, Big Data, artificial Intelligence, machine learning, high performance computing, block chain, data mining and simulation, were also listed. Nothacker and Lavicza have also recorded the programming languages and models mentioned in the curricula and listed them per school type and country, which can be realized accordingly with a single-board computer in the schools.

However, in order to find out the most suitable and cost-effective model of a single-board computer available on the market for this purpose, with whom all these competences, skills and programming languages/models can be taught, Nothacker and Lavicza point out the need for a further study.

This is exactly where this study comes in. The aim of this study is to find a suitable and monetarily affordable hardware in the form of a single-board computer for all types of schools, with which the digital competences specified in the respective curricula can be taught to the pupils/students. This would mean a considerable relief for both the teachers and the pupils/students, who could then concentrate exclusively on the task creation or problem-solving level without having to familiarize themselves with a new platform every time.

2. Research design and Methods

In order to be able to fulfil the objectives of this study, the "Mixed Methods" method according to Creswell is applied (Creswell, 2014, p. 50).

First, the devices and learning sets on the market are recorded using the method of quantitative analysis. This can be done initially with a "best price" tool available on the internet, such as "geizhals.eu" or similar platforms available on the internet, which reflect the product range as broadly as possible. In this study, the platform "geizhals.eu" was chosen. It is an online price comparison platform available in various countries with a focus on hardware and consumer electronics, which helps its users to make the best choice for them among a large number of retailers and products based on selection criteria. This comprehensive overview is narrowed down to the first result set by a deductive approach with suitable filters in order to obtain a result set that corresponds to the specifications.

Afterwards, the performance portfolio of the individual products is called up via the manufacturer's pages of the products in the results list and the products are evaluated with a qualitative analysis according to Mayring (Mayring, 2014, p. 26) using technical terms as categories. Suitable keywords are the analysis of the hardware and software characteristics, which result from the combination of the result list of the "Combined Skills that can be covered by a Single-Board-Computer by School Levels and Countries" of the study by Nothacker and Lavicza from 2020 (Nothacker and Lavicza, 2020, p. 356) and the results of the previously determined suitable hardware. According to the methodology of ranking and weighting, one then gets a list of one or more hardware models that are suitable to achieve the goal of the study.

The application of the ranking methodology and its weighting according to the coverage of the competences to be taught by the characteristics of the products and their price, results in an ascending list of devices which, due to their characteristics, are better (high score) or worse (lower score) at achieving the objective of this study. The MAXQDA2020 Analytics Pro software in combination with Microsoft Excel was used to record the hardware and its characteristics, as well as to record the corresponding filters and create the evaluations and graphics. By forming a relation of the skills with the features and the price of the products, the suitability of individual products crystallizes with a scalable value, which allows a ranking of the individual products. The study concludes with a recommendation for the use of different hardware in relation to the subject area of education with justification.

In Table 1, the examination procedure is shown in a diagram as an example.

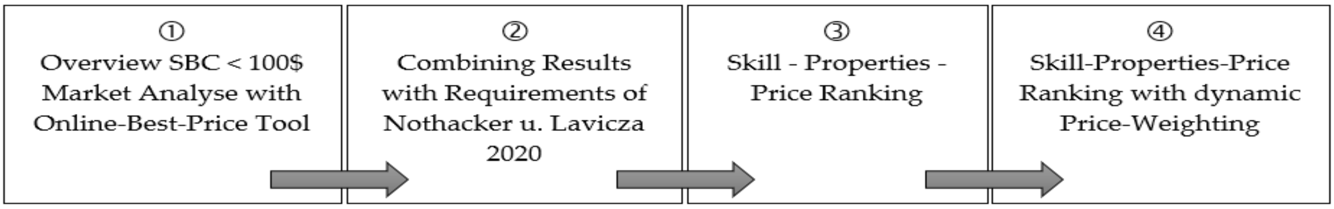

Table 1. Research-Procedure, Author

The author points out that the quantitative survey is a snapshot of the items and prices currently available on the market at the time of the survey. It is possible that at the time of publication of this study, new products will add to the variety of choices. For this reason, the selection criteria were chosen in such a way that new products can easily be included in the evaluation scheme.

3. Results

In the following, the examination results are listed according to the flow chart of Table 1.

3.1. Overview SBC < 100$ Market Analyze with Online-Best-Price Tool

The list of results from the quantitative analysis for low-costs computers (costs < 100$) yielded 767 hits in the hardware category across Europe. This also showed that there is a substantial distinction between microcontroller units (MCU) and system on a chip (SOC) for single-board computers (SBC). There were 142 hits for MCU-based boards and 97 hits for SOC-based boards. The other hits fell into the categories of accessories for single-board computers, which resulted in 142 hits for power supplies, 123 hits for housings, 10 hits for screens, 85 hits for sensors, 109 hits for expansions, 44 hits for installation material, 31 hits for memory incl. software, 56 hits for assembly & diagnostics, 12 hits for actuators & robotics and 33 hits for segment displays & LEDs. Of particular interest in this study are the categories SOC-based and MCU-based boards.

3.1.1. MCU-based Boards

For MCU-based boards, 22 board manufacturers were found that have installed microcontrollers from 9 different semiconductor manufacturers. These include microcontrollers from Microchip with its well-known AVR, ATmega, ATSam, ATtiny, AT90USB and PICXX model series (Microchip, 2021), NXP with its MK and MKL series models (NXP, 2021), Espressif with its ESP32 series (Espressif, 2021), Nordic with its nRF5x series (Nordic Semiconductor, 2021), the manufacturer Intel with its Quark D2000 series (Intel® Quark™ Microcontroller D2000, 2021), the manufacturer ST-Microelectronics with its STM32 series (STMICROELECTRONICS, 2021), the manufacturer Texas Instruments (TI) with its MSP series (Texas Instruments Inc., 2021) and, since 2021, the manufacturer Raspberry Pi Trading Ltd with its Pico series (Raspberry Pi Trading Ltd, 2021). The microcontrollers all have one processor core, except for the ESP32 from Espressif and the Raspberry Pi Pico, newly released in 2021, with 2 processor cores. The MCUs have a base clock of less than 8 MHz to 240 MHz and all have a main memory of 8 kilo Byte (kB) to 32 Mega Byte (MB) in SRAM technology. Depending on the version, all microcontrollers have a flash memory for programme storage with a size of 8 kb to 32 MB. Three of the MCU boards have a LAN connection (Arduino Ethernet, Arduino Yun, and NXP Freedom). The boards of the manufacturer Espressif with the ESP32, the NanoESP of the board manufacturer Conrad-Elektronik and the Arduino MKR1000 WIFI, the Arduino 101 Industrial, the Arduino UNO WIFI, the Arduino YUN Mini and the Arduino Yun of the board manufacturer Arduino, as well as the Banana Pi G1 IoT Hub of the board manufacturer Banana Pi with the STM32 MCU have wireless LAN. The ESP32 and the Banana Pi G1 IoT Hub have also a Bluetooth interface. The prices range from about 4.81$ (ESP32) to about 94.68$ for an Arduino UNO learning package with an Atmega328 microcontroller including extensive accessories for experimenting. Other learning packages or bundles are available from the manufacturer micro: bit: collaboration with the board BBC micro: bit and the MCU nRF5x, the manufacturer Joy Labs with the Makey Classic Kit and the MCU Atmel ATmega32u4 and the Franzis Verlag with the board Arduino UNO SMD or Arduino Leonardo. Furthermore, there are also devices from Arduboy, Hard kernel and Make block, which are equipped with various buttons, a small colour display or LEDs. The boards range in size from 12 x 30 mm to 53 x 68 mm. After combining the identical boards and eliminating the special designs, 11 comparison models remained in the given price range. Since some MCU boards have additional devices built in, a distinction was made between on-board interfaces and on-board devices. The most important properties of the MCUs are shown in Table 2.

Categories	MCU	Ard UNO	Ard MKR W	Ard Nano	Ard Nano BLE	ESP32	Micro:Bit	MSP430	NXP K64F	Quark	RPI Pico	STM32
On Board Interfaces												
ADC	■	■	■	■	■	■	■	■	■	■	■	■
Audio Connector	■					■	■	■	■		■	
AV Connector												
Battery Socket	■						■					
Operating System	■										■	
Bluetooth	■		■		■	■	■		■			
CSI												
DAC	■	■	■		■	■		■			■	
Debugging	■					■		■	■		■	■
DSI	■									■		
Ethernet	■					■			■			
Firmware	■					■			■	■	■	■
GPIO	■				■	■	■	■	■	■	■	■
HDMI												
I²C	■		■	■	■	■	■	■		■	■	■
I²S	■					■					■	
Microphone	■					■	■					
Micro SD												
PCIe												
Power over Ethernet	■											
PWM	■	■	■	■	■	■	■	■		■	■	■
SPI	■	■	■	■	■	■		■	■	■	■	■
UART	■	■	■	■		■	■	■	■	■	■	
USB 2.0	■	■	■	■	■	■	■		■		■	■
USB 3.0	■											
USB Power	■		■		■				■		■	■
WLAN	■		■			■						
CAN	■					■						
On Board Devices												
LED Matrix	■						■					
Accelerometer	■						■		■			
Buttons	■			■		■	■		■		■	■
Compass	■						■					
Flash / EEPROM	■		■	■		■	■			■		
GPU												
Hall-Sensor	■					■						
Pulse-Counter	■					■						
Infrared-Controller	■	■				■			■	■		
build-in Speaker	■						■					
Temperature	■	■				■	■	■			■	
Touch-Sensor	■					■	■					
Real Time Clock	■		■			■			■	■		
Real Time Counter	■										■	
Dual Core CPU	■					■					■	
Quad Core CPU												
Hexa Core CPU												
4K @ 60 Hz												
Keyboard												
Σ SUM	37	8	12	8	9	26	18	10	15	11	18	10

Table 2. Most important properties of less 100$ MCU’s.

3.1.2. SOC-based Boards

For SOC-based boards, 14 manufacturers were found that have installed SOC chips from 11 different semiconductor manufacturers. These include All winner with their A, H and R series (All winner Technology, 2021), Broadcom with the BCM2 series (Broadcom, 2021), Samsung with the Exynos series (Samsung Semiconductor, 2021), Rock chip with the RK3XXX series (Rock chip, 2021), Texas Instruments with the Sitara series (Texas Instruments, 2021) , Media tek/MTK with the MT series (Media Tek, 2021), NVIDIA with the Tegra series (NVIDIA, 2021) , Octavo with the OSD series (Octavo Systems, 2021), Intel with the Atom series (Intel, 2021), Am logic with the S905 (Am logic, 2021) , Ankya with the AK3918 (Anyka, 2021).

The number of processor cores varies between 1 and 8 cores. The base clock of the products varies between 260 MHz and 2 GHz. The main memory of the boards ranges from 4MB DDR2 memory to 8 GigaByte (GB) LPDDR4 random access memory (RAM) and have 0 to 32 GB flash memory on board. All boards have a High-Definition Multimedia connection (HDMI), depending on the board in different versions Micro, Mini, Standard.

The board models from ASUS (ASUS, 2021), Banana Pi (Banana-PI, 2021), Friendly ARM Nano Pi (Nano Pi 4, 2021), Hard kernel ODROID-Go (ODROID-GO, 2021), Pine A64+ (PINE64, 2021) and the Raspberry Pi models (Raspberry Pi, 2021) can be connected to an external display via a MIPI Display Serial Interface (MIPI DSI) using a ribbon cable. The ASUS Tinker board, the Banana Pi and the Nano Pi board from Friendly ARM also offer a Low Voltage Differential Signaling (LVDS) interface for older standards according to ANSI/TIA/EIA-644-1995, as well as a Composite Video Baseband Signal (CVBS) interface, which provides a Phase Alternating Line (PAL), National Television Systems Committee (NTSC) or Séquentiel couleur à mémoire (SECAM) signal. The ASUS Tinker board, the Banana PI, the ODROID-Go, the Pine A64+ and the Raspberry Pi have a 3.5 mm jack socket for transmitting the audio signal.

Depending on the model, all units have a Universal Serial Bus (USB) interface in version 2.0 and/or 3.0. The interfaces are designed as external USB-A or micro-USB connectors on some models. Models that do not have flash memory have an SDHC/SDXC micro-SD card slot for storing the operating system, programmers and/or data.

The Intel, Raspberry Pi, Media tek/MTK and NVIDIA models have a WLAN interface according to 802.11 standard and a Bluetooth module from version 4.0. A wired connection to other devices is realized on 97% of the models via a 20 - 42-pin General Purpose Input Output (GPIO) connector strip, using the various GPIO standards Universal Asynchronous Receiver Transmitter (UART), Serial Peripheral Interface (SPI), Inter-Integrated Circuit (I^2C), Inter-IC Sound (I^2S), Pulse Wide Modulation (PWM), Controller Area Network (CAN), Sony/Philips Digital Interface (S/PDIF) and Analog Digital Converter (ADC). The boards range in size from 35 x 39 mm to 80 x 100 mm.

Bundles or learning packages for SOC's are offered by the manufacturers Beagle Board, element14, hard kernel, Raspberry Pi, Seed studio and Wave share. However, the bundles only contain the power supply unit, a housing, the actual board and cables for screen or network connection and, for devices without flash memory, a micro SD card with the operating system. Developer kits are also offered, which in the case of NVIDIA consist only of a heat sink and a motherboard and in the case of Raspberry Pi consist of a breakout board, whereby the compute module for the breakout board must be purchased in various configurations as required. With the "ODROID-Go Advanced", hard kernel offers a complete device that is modelled on the Nitendo Gameboy Advance and thus has a keyboard and a display integrated in the housing. An alternative to the "ODROID-Go Advanced" is the "Raspberry Pi zero W GPi CASE Bundle" by Reichelt electronic, which revives a copy of the old Gameboy by Nintendo from the 1980s as a retro game handheld console. Game consoles are not the subject of the investigation but were mentioned for the purpose of completeness.

The prices of the boards or learning kits range from 6.79$ to 98.37$. A very comprehensive learning kit is available from Joy-IT for the Raspberry Pi, which comes with numerous sensors and accessories and a 7'' screen, but at around 290$ is far above the limit of 100$ acquisition costs set for this study and the actual SOC is not yet included in the price. 10 models remain after the identical ones have been eliminated. The most important properties of the SOCs are shown in Table 3.

Categories	SOC	ASUS	BananaPi	BPI zero	NanoPi	Nvidia Jetson Nano	RPi 4	RPi 400	RPi CM	RPi Zero W	Rock Pi 4
On Board Interfaces											
ADC	■		■								■
Audio Connector	■	■	■		■	■	■	■	■	■	■
AV Connector	■						■				
Battery Socket	■								■		
Operating System	■	■	■			■	■	■	■	■	
Bluetooth	■	■	■	■	■	■	■	■	■	■	■
CSI	■	■		■		■	■	■	■	■	■
DAC	■		■						■		
Debugging	■		■				■	■	■	■	
DSI	■	■					■	■	■	■	■
Ethernet	■		■		■	■	■	■	■	■	■
Firmware	■		■				■	■	■	■	■
GPIO	■	■	■		■	■	■	■	■	■	■
HDMI	■	■	■	■	■	■	■	■	■	■	■
I²C	■	■	■		■	■	■	■	■	■	■
I²S	■	■	■			■	■	■	■	■	■
Microphone											
Micro SD	■					■	■	■	■	■	
PCIe	■		■		■				■		■
Power over Ethernet	■					■	■	■	■	■	■
PWM	■	■	■		■	■	■	■	■	■	■
SPI	■	■	■		■	■	■	■	■	■	■
UART	■	■	■		■	■	■	■	■	■	■
USB 2.0	■	■	■	■	■	■	■	■	■	■	■
USB 3.0	■		■		■	■	■	■	■		
USB Power	■	■					■	■	■	■	
WLAN	■	■	■	■	■	■	■	■	■	■	■
CAN											
On Board Devices											
LED Matrix											
Accelerometer	■						■	■	■	■	
Buttons	■					■	■	■	■	■	
Compass	■						■	■	■	■	
Flash / EEPROM	■						■	■	■	■	
GPU	■	■	■	■	■	■	■	■	■	■	■
Hall-Sensor											
Pulse-Counter											
Infrared-Controller	■		■				■	■	■	■	
build-in Speaker											
Temperature	■						■	■	■	■	
Touch-Sensor											
Real Time Clock	■		■		■				■		■
Real Time Counter											
Dual Core CPU	■				■						
Quad Core CPU	■			■			■				
Hexa Core CPU	■										■
4K @ 60 Hz	■					■	■	■	■		
Keyboard	■							■			
Σ SUM	39	16	22	7	16	20	31	30	33	27	21

Table 3. Most important properties of less 100$ SOC's.

3.2. Combining Results with Requirements of Nothacker u. Lavicza 2020

In order to determine which type of SBC's are more suitable for the subject area Education for the individual school types, the classical skills with the process- and content-related competences to be learned must be summarized and combined with the hardware characteristics of the individual devices. The list was shortened by the non-hardware-dependent competencies. The skills were marked as accessible as soon as the device had the property to mediate the skill, i.e. for structure and network or computer and networks the product needs a network interface, for communicating and collaborating e.g. a forum - for communicating data and coding with other computers an own development environment and/or user interface or the possibility to store data and programs.

Categories	MCU	Ard UNO	Ard MKR W	Nano	Nano BLE	ESP32	Micro:Bit	MSP430	NXP K64F	Quark	RPI Pico	STM32
Modern Skills												
3D-Printing	■	■	■	■	■	■	■	■	■	■	■	■
Robots	■	■	■	■	■	■	■	■		■	■	■
Sensors	■	■	■	■	■	■	■	■	■	■	■	■
Actuators	■	■	■	■	■	■	■	■		■	■	■
Industrie 4.0	■		■		■	■					■	
Big Data	■							■				
Künstliche Intelligenz												
Machine Learning	■					■						
Deep Learning												
High Performance Computing												
Blockchain												
Data Mining												
Simulation	■						■					
Process-related Competences												
Structure and Network	■		■			■			■			
Modelling and Implementing	■	■				■						
Communicating and Collaborating	■										■	
Content-based Competences												
Algorithms	■	■				■			■	■		
Data and Coding	■	■	■	■	■	■	■		■		■	■
Computers and Networks	■		■			■			■			
Computerlanguages/Models												
Java	■	■										
C / C++ / C#	■										■	
Python / Micro Python	■	■				■	■				■	
Scratch	■											
Viusal Basic												
Basic												
∑ SUM	18	9	8	5	6	12	7	5	6	5	9	5

Table 4. Digital Skills combined with MCU Properties

Categories	SOC	ASUS	BananaPi	BPI zero	NanoPi	Nvidia Jetson Nano	RPi 4	RPi 400	RPi CM	RPi Zero W	Rock Pi 4
Modern Skills											
3D-Printing	■	■	■		■	■	■	■	■	■	■
Robots	■	■	■		■	■	■	■	■	■	■
Sensors	■	■	■	■	■	■	■	■	■	■	■
Actuators	■	■	■		■	■	■	■	■	■	■
Industrie 4.0	■					■	■	■	■	■	
Big Data	■		■	■	■				■	■	■
Künstliche Intelligenz	■		■				■	■	■	■	
Machine Learning	■	■			■	■	■	■	■	■	■
Deep Learning	■		■		■	■					
High Performance Computing	■		■		■	■	■	■	■	■	
Blockchain	■				■		■	■	■		
Data Mining	■		■		■	■			■		■
Simulation	■		■		■		■	■	■	■	
Process-related Competences											
Structure and Network	■	■	■	■	■	■	■	■	■	■	■
Modelling and Implementing	■						■	■	■	■	
Communicating and Collaborating	■						■		■		■
Content-based Competences											
Algorithms	■					■	■	■	■	■	■
Data and Coding	■	■	■	■	■	■	■	■	■	■	■
Computers and Networks	■	■	■	■	■	■	■	■	■	■	■
Computerlanguages/Models											
Java	■						■	■	■	■	
C / C++ / C#	■		■				■	■	■	■	
Python / Micro Python	■				■		■	■	■	■	■
Scratch	■		■				■	■	■	■	
Viusal Basic	■						■	■	■	■	
Basic											
∑ SUM	24	8	15	5	15	13	21	20	23	20	13

Table 5. Digital Skills combined with SOC Properties

3.3. Skill - Properties - Price Ranking

In order to get an overview of which products are best suited to fulfill the specified skills in the specified price range of 100$, the results from 3.1 and 3.2 must be supplemented accordingly with the price information. Previously, the data was collected in individual tables and sorted in ascending or descending order according to the percentage shares and ranked according to the %- share. As a result, the following data tables for MCUs are shown in Table 6 and for SOCs in Table 7, descending order by skills and characteristics and ascending by price.

MCU

Nr	Sort by Skill-Fulfilment	Skill	(%)	Prop(46)	(%)	Price ($)	Price (€)
	MCU	18	75,0	37	80,4		
1	ESP32	12	50,0	26	56,5	8,42	6,90
2	Ard UNO	9	37,5	8	17,4	12,19	9,99
3	RPI Pico	9	37,5	18	39,1	6,04	4,95
4	Ard MKR W	8	33,3	12	26,1	34,04	27,90
5	Micro:Bit	7	29,2	18	39,1	20,13	16,50
6	Ard Nano BLE	6	25,0	9	19,6	26,35	21,60
7	NXP K64F	6	25,0	15	32,6	66,39	54,42
8	Ard Nano	5	20,8	8	17,4	5,42	4,44
9	MSP430	5	20,8	10	21,7	22,88	18,75
10	Quark	5	20,8	11	23,9	21,80	17,87
11	STM32	5	20,8	10	21,7	15,84	12,98

Nr	Sort by Prop	Skill	(%)	Prop(46)	(%)	Price ($)	Price (€)
	MCU	18	75,0	37	80,4		
1	ESP32	12	50,0	26	56,5	8,42	6,90
2	Micro:Bit	7	29,2	18	39,1	20,13	16,50
3	RPI Pico	9	37,5	18	39,1	6,04	4,95
4	NXP K64F	6	25,0	15	32,6	66,39	54,42
5	Ard MKR W	8	33,3	12	26,1	34,04	27,90
6	Quark	5	20,8	11	23,9	21,80	17,87
7	MSP430	5	20,8	10	21,7	22,88	18,75
8	STM32	5	20,8	10	21,7	15,84	12,98
9	Ard Nano BLE	6	25,0	9	19,6	26,35	21,60
10	Ard Nano	5	20,8	8	17,4	5,42	4,44
11	Ard UNO	9	37,5	8	17,4	12,19	9,99

Nr	Sort by Price	Skill	(%)	Prop(46)	(%)	Price ($)	Price (€)
	MCU	18	75,0	37	80,4		
1	Ard Nano	5	20,8	8	17,4	5,42	4,44
2	RPI Pico	9	37,5	18	39,1	6,04	4,95
3	ESP32	12	50,0	26	56,5	8,42	6,90
4	Ard UNO	9	37,5	8	17,4	12,19	9,99
5	STM32	5	20,8	10	21,7	15,84	12,98
6	Micro:Bit	7	29,2	18	39,1	20,13	16,50
7	Quark	5	20,8	11	23,9	21,80	17,87
8	MSP430	5	20,8	10	21,7	22,88	18,75
9	Ard Nano BLE	6	25,0	9	19,6	26,35	21,60
10	Ard MKR W	8	33,3	12	26,1	34,04	27,90
11	NXP K64F	6	25,0	15	32,6	66,39	54,42

Table 1. MCU Skill – Properties – Price – Sort by Skill-, Properties-, Price-Fulfillment

SOC

Nr	Sort by Skill-Fulfilment	Skill	(%)	Prop	(%)	Price ($)	Price (€)
	SOC	24	100,0	39,0	84,8		
1	RPi CM 2GB 16 EMMC incl.	23	95,8	33	71,7	96,25	78,89
2	RPi 4	21	87,5	31	67,4	68,32	56,00
3	RPi 400	20	83,3	30	65,2	85,40	70,00
4	RPi Zero W	20	83,3	27	58,7	13,58	11,13
5	BananaPi	15	62,5	22	47,8	93,23	76,42
6	NanoPi	15	62,5	16	34,8	68,32	56,00
7	Nvidia Jetson Nano	13	54,2	20	43,5	76,68	62,85
8	Rock Pi 4	13	54,2	21	45,7	114,01	93,45
9	ASUS	8	33,3	16	34,8	84,08	68,92
10	BPI zero	5	20,8	7	15,2	24,77	20,30

Nr	Sort by Prop	Skill	(%)	Prop	(%)	Price ($)	Price (€)
	SOC	24	100,0	39	84,8		
1	RPi CM 2GB 16 EMMC	23	95,8	33	71,7	96,25	78,89
2	RPi 4	21	87,5	31	67,4	68,32	56,00
3	RPi 400	20	83,3	30	65,2	85,40	70,00
4	RPi Zero W	20	83,3	27	58,7	13,58	11,13
5	BananaPi	15	62,5	22	47,8	93,23	76,42
6	NanoPi	15	62,5	16	34,8	68,32	56,00
7	Nvidia Jetson Nano	13	54,2	20	43,5	76,68	62,85
8	Rock Pi 4	13	54,2	21	45,7	114,01	93,45
9	ASUS	8	33,3	16	34,8	84,08	68,92
10	BPI zero	5	20,8	7	15,2	24,77	20,30

Nr	Sort by Price	Skill	(%)	Prop(46)	(%)	Price ($)	Price (€)
	SOC	24	100,0	39	84,8		
1	RPi Zero W	20	83,3	27	58,7	13,58	11,13
2	BPI zero	5	20,8	7	15,2	24,77	20,30
3	NanoPi	15	62,5	16	34,8	68,32	56,00
4	RPi 4	21	87,5	31	67,4	68,32	56,00
5	Nvidia Jetson Nano	13	54,2	20	43,5	76,68	62,85
6	ASUS	8	33,3	16	34,8	84,08	68,92
7	RPi 400	20	83,3	30	65,2	85,40	70,00
8	BananaPi	15	62,5	22	47,8	93,23	76,42
9	RPi CM 2GB 16 EMMC	23	95,8	33	71,7	96,25	78,89
10	Rock Pi 4	13	54,2	21	45,7	114,01	93,45

Table 2. SOC Skill – Properties – Price – Sort by Skill-, Properties-, Price- Fulfilment

3.4. Implementing Dynamic Price-Weighting

In section 3.3, the data was sorted accordingly by skill fulfilment and properties in descending order and by price in ascending order. However, a useful list only emerges after the individual parameters have been combined. For this purpose, the values of the individual rows are added horizontally. In addition, the price rank is parameterised with an influence of 0-100% in order to be able to consider the different budget strengths of the individual institutions. The combination of the parameterised data results in the final ranking of the products. The resulting product rankings are shown in Table 9 and in a clear network graphic in Figure 1. All the values of the price weights were shown in the network graphic Figure 1. No relevant product changes were discernible in the intermediate values.

Nr	Sort by Alphabet	Skill	S(%)	Prop	P(%)	Price ($)	Skill-Points	Prop-Point	Price-Points	SPP(100)	SPP(90)	SPP(80)	SPP(70)	SPP(60)	SPP(50)	SPP(40)	SPP(30)	SPP(20)	SPP(10)	SPP(0)
	MCU	18	75,0	37	80,4					100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
1	ESP32	12	50,0	26	56,5	8,42	11	11	17	39	37,3	35,6	33,9	32,2	30,5	28,8	27,1	25,4	23,7	22
2	RPI Pico	9	37,5	18	39,1	6,04	9	9	19	37	35,1	33,2	31,3	29,4	27,5	25,6	23,7	21,8	19,9	18
3	Ard UNO	9	37,5	8	17,4	12,19	9	1	15	25	23,5	22	20,5	19	17,5	16	14,5	13	11,5	10
4	Ard MKR W	8	33,3	12	26,1	34,04	8	7	3	18	17,7	17,4	17,1	16,8	16,5	16,2	15,9	15,6	15,3	15
5	Micro:Bit	7	29,2	18	39,1	20,13	7	9	9	25	24,1	23,2	22,3	21,4	20,5	19,6	18,7	17,8	16,9	16
6	NXP K64F	6	25,0	15	32,6	66,39	5	8	1	14	13,9	13,8	13,7	13,6	13,5	13,4	13,3	13,2	13,1	13
7	Ard Nano BLE	6	25,0	9	19,6	26,35	5	3	5	13	12,5	12	11,5	11	10,5	10	9,5	9	8,5	8
8	Quark	5	20,8	11	23,9	21,80	1	6	7	14	13,3	12,6	11,9	11,2	10,5	9,8	9,1	8,4	7,7	7
9	STM32	5	20,8	10	21,7	15,84	1	4	13	18	16,7	15,4	14,1	12,8	11,5	10,2	8,9	7,6	6,3	5
10	MSP430	5	20,8	10	21,7	22,88	1	4	6	11	10,4	9,8	9,2	8,6	8	7,4	6,8	6,2	5,6	5
11	Ard Nano	5	20,8	8	17,4	5,42	1	1	20	22	20	18	16	14	12	10	8	6	4	2

Table 3. Combined MCU Skill-, Properties-, Price-Rank with Price Weighting of 0-100%

The same procedure was followed for the SOCs. All the values of the price weights were shown in the network diagram Figure 2 as no relevant product changes could be detected in the intermediate values.

Nr	Sort by Alphabet	Skill	S(%)	Prop	P(%)	Price ($)	Skill-Points	Prop-Point	Price-Points	SPP(100)	SPP(90)	SPP(75)	SPP(70)	SPP(60)	SPP(50)	SPP(40)	SPP(30)	SPP(20)	SPP(10)	SPP(0)
	SOC	24	100,0	39	84,8					100%	90%	75%	70%	60%	50%	40%	30%	20%	10%	0%
1	RPi CM 2GB 16 EMMC incl. B	23	95,8	28	60,9	96,25	10	7	2	19	18,8	18,5	18,4	18,2	18	17,8	17,6	17,4	17,2	17
2	RPi 4	21	87,5	31	67,4	68,32	9	8	7	24	23,3	22,25	21,9	21,2	20,5	19,8	19,1	18,4	17,7	17
3	RPi Zero W	20	83,3	21	45,7	13,58	7	5	10	22	21	19,5	19	18	17	16	15	14	13	12
4	RPi 400	20	83,3	34	73,9	85,40	7	10	4	21	20,6	20	19,8	19,4	19	18,6	18,2	17,8	17,4	17
5	NanoPi	15	62,5	16	34,8	68,32	5	2	7	14	13,3	12,25	11,9	11,2	10,5	9,8	9,1	8,4	7,7	7
6	BananaPi	15	62,5	22	47,8	93,23	5	6	3	14	13,7	13,25	13,1	12,8	12,5	12,2	11,9	11,6	11,3	11
7	Nvidia Jetson Nano	13	54,2	20	43,5	76,68	3	4	6	13	12,4	11,5	11,2	10,6	10	9,4	8,8	8,2	7,6	7
8	Rock Pi 4	13	54,2	32	69,6	114,01	3	9	1	13	12,9	12,75	12,7	12,6	12,5	12,4	12,3	12,2	12,1	12
9	ASUS	8	33,3	16	34,8	84,08	2	2	5	9	8,5	7,75	7,5	7	6,5	6	5,5	5	4,5	4
10	BPI zero	5	20,8	7	15,2	24,77	1	1	9	11	10,1	8,75	8,3	7,4	6,5	5,6	4,7	3,8	2,9	2

Table 4. Combined SOC Skill-, Properties-, Price-Rank with Price Weighting of 0-100%

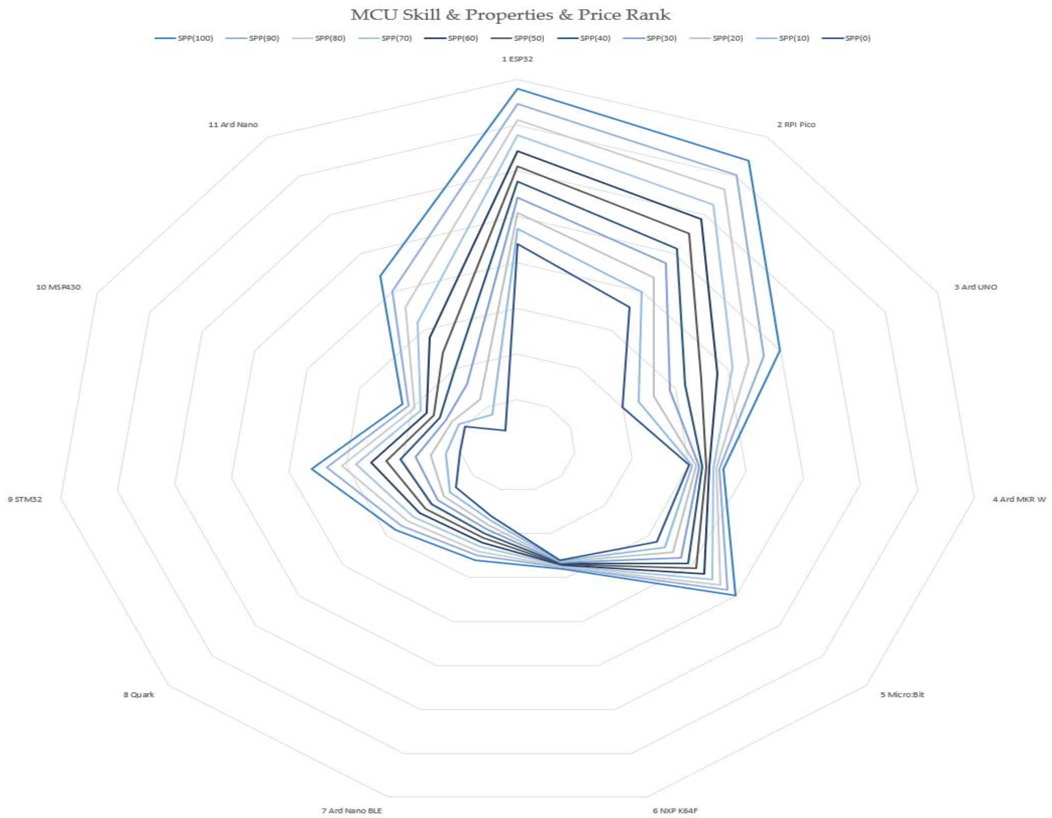

Figure 1. Combined MCU Skill-, Properties-, Price-Rank with Price-Weighting 0-100%

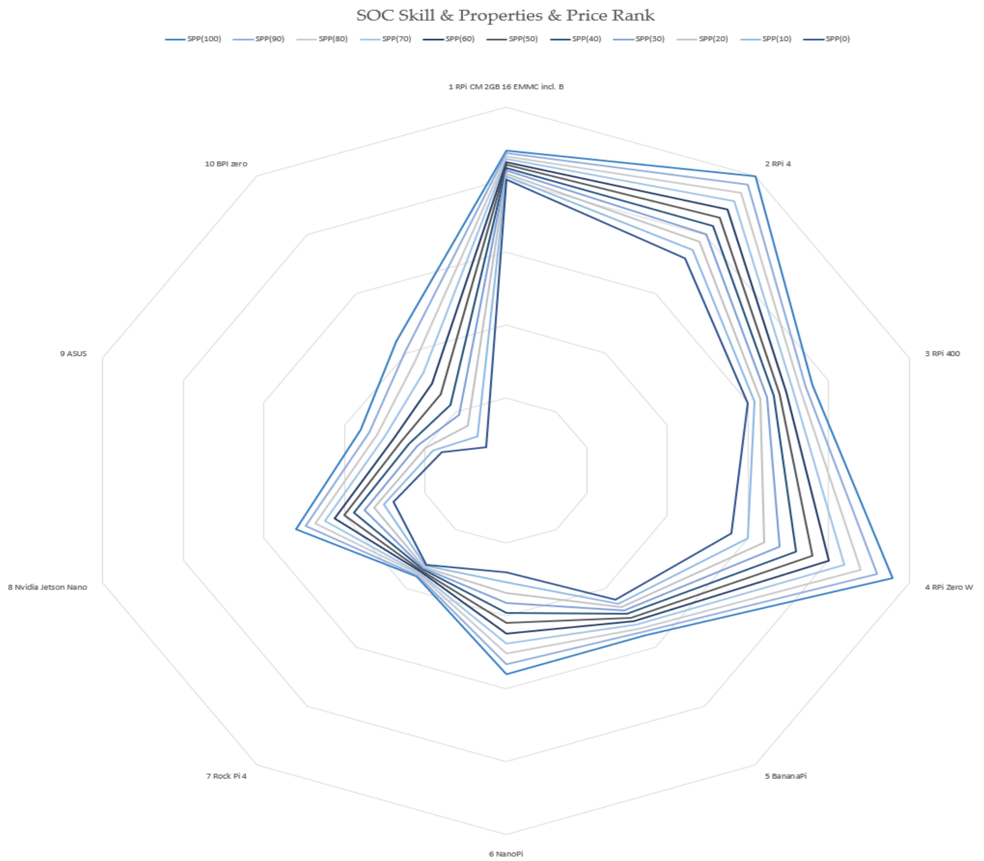

Figure 2. Combined SOC Skill-, Properties-, Price-Rank with Price-Weighting 0-100%

4. MCU or SOC?

The core question of this study was to find out which of the single-board computers available on the market is the most capable of covering the new "digital goals" of the curricula across several school types, has a price limit below 100$ and may be available as a learning set.

To address the research question, the author chose the Mixed Methods Research (MMR) method. After a quantitative market analysis, the interfaces were extracted from the technical data sheets and instruction manuals of the devices and binarized with the MAXQDA software using technical terms. The resulting results were scaled according to the number of objects found. The resulting skill, property and price values were evaluated horizontally, combined and ranked vertically. In order to incorporate the influence of different budgets into the decision-making system, the pricing was dynamically weighted with a factor between 0-100% and displayed in a network graphic. This way the reader can vary his or her priorities in terms of budgets when selecting a product.

During the study, it was found out that not all single-board computers are the same, and can be divided primarily into two classes, the MCU and the SOC. From the point of view of the diversity of the applications to be fulfilled and the skills to be covered, the SOC was able to completely cover all skills with 100% with its corresponding interfaces and partially supplied on-board devices. The MCU, on the other hand, was only able to achieve 75% coverage of the specified skills. This is also because the MCU does not have its own GPU and requires that an existing computer system in the form of a tablet or PC be available. However, these requirements are not met in some countries.

In terms of properties, the SOC with 84.8% fulfils the required properties more than the MCU with 80.4%. Only a few MCUs have Ethernet, WLAN or an HDMI connection on-board, which is the prerequisite for teaching most process and content related skills.

Ultimately, the SOC can meet all the needs of the new digital goals through its variety of interfaces and, depending on its performance, even replace a PC in the classrooms. For schools that do not yet have any digital equipment, the SOC is an inexpensive alternative to PCs or tablets. Keyboards and monitors can be connected to the existing interfaces or are already available as with the RPI 400 (keyboard). The SOCs can be expanded with accessories via the mostly 40-pin GPIO connections, which enables a wide range of experiments.

5. Conclusions and Outlook

This study fills the gap of a missing overview of the single-board computers existing on the market, which meet the hardware requirements of the digital goals of the 21st century of the current curricula. It can serve as a decision support for decision makers who do not yet know which product to use or procure. This study can also serve as a decision support to complement existing equipment or to get an overview of the possible features in the first place or serve as a template for further studies. This study also answers the question of existing SBC learning sets in the sense that there are no such learning sets under 100$ that meet the curriculum requirements. Thus, the following questions arise for subsequent studies: What must a learning set for computer science teaching contain that is designed for several school types? Is it possible to assemble a learning set for informatics teachers under 100$ per pupil/student that meets the requirements of the 21st Century Goals?

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