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SELECTING OPTIMAL EDUCATIONAL BOARDS BASED ON A DECISION SUPPORT APPROACH

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Abstract- Arduino-based technologies are very popular among teachers and researchers interested in finding appropriate solutions to develop electronic and digital devices. Therefore, Arduino educational boards have been included among the subjects taught in many secondary schools and universities nowadays. However, the research proposed methodology for selecting and ranking the Arduino educational boards is very minimal due to the conflict between the criteria selected. The paper aimed to bridge this gap based on the most critical decision-making methods. The ideal best-worst method (BWM) was adopted to compute the criteria weights. As well, it was integrated with the multi-objective optimization based on the ratio analysis (MOORA) method to choose an optimal alternative. The results of the study present that the best board to the Arduino Tre, while the worst board was the Arduino Micro. These results confirm that the best boards depend on a great level of accuracy and efficiency. The implication of the study shows a clear interest from students, teachers, and researchers that enables them to choose the best Arduino board and help in deciding to use it in real experiments.

Keywords: Arduino Educational Boards, BWM Method, MOORA Method, MCDM, Criteria Conflict.

1. INTRODUCTION

In 2005, an Arduino microcontroller was launched that is easy to use, open source, and can be programmed in real-time. This type of board has been widely used by students, researchers, and hobbyists. It is helped to build many devices that contain various sensors and actuators to operate in different environments [1], [2].

Recently, various types of Arduino Educational Boards (AEB) have proliferated in the market to be used in various educational and industrial projects. Currently, most high schools and universities have already relied on technical fields of study, incorporating Arduino-based technologies into their curricula or through various summer courses, workshops, and science events [3-5]. All the programs and the basic schematics for this type of electronic board are free to use and subject to modification. The main programming language for Arduino boards is C. C++ and Wiring. The wiring language is an extension of the C language with a set of more intuitive extra commands [2].

Nowadays, Arduino boards are the most promising software components that have been used in scientific and industrial sectors. Each board differs from the other in terms of dimensions and basic components such as the hardware used and the amount of memory available. One of the most used Arduino boards is the Arduino Mini [6], which is the smallest among the Arduino boards. The Arduino Nano [7] has a USB port, which helps to load and manage the Arduino logic easier compared to the others. The Arduino Micro [8] includes a built-in power adapter that is used to process signals typical of the mouse or keyboard. The Arduino LilyPad [2] is primarily designed for integration with textiles and clothing, where the logic used in this board can create different patterns on the clothes. The Arduino TRE [9] has a double high-performance processor designed to implement specific tasks that distinguish it from many other Arduino boards. The Arduino Uno [3] is also a commonly used board of the Arduino family where it is equipped with an ATmega 328 processor and has a USB connector.

To our knowledge, the contradiction between standards is considered the main challenges facing decision makers. Decision support techniques provided appropriate solutions to this problem when adopting multiple criteria [10-12]. Nine criteria were selected to identify their effect on the different Arduino educational boards (AEB). Nevertheless, inconsistency between criteria constitutes a major challenge when computing the weights of multiple criteria [13]. The AEB has been evaluated and selected the best one based on multiple criteria in this paper [14-16]. In this study integrated the best methods to evaluate and select the optimal alternative of Arduino educational boards based on decision support techniques. This study applied the best decision-making methods to compute the weights of each criterion as in the BWM method, and the MOORA method was used to choose the optimal Arduino educational boards (AEB) [17], [18]. The contribution of the study was to propose a new approach for selecting Arduino educational boards by integrating the best-worst method with the MOORA method. It provides different rankings for several alternatives represented in AEB based on multiple criteria.

1.1. Data Collection of Arduino Educational Boards

The data for the Arduino educational boards were collected based on literature [19]. The dataset included six types of Arduino educational boards as alternatives based on nine criteria. Figure 1 shows the different types of Arduino educational boards model.

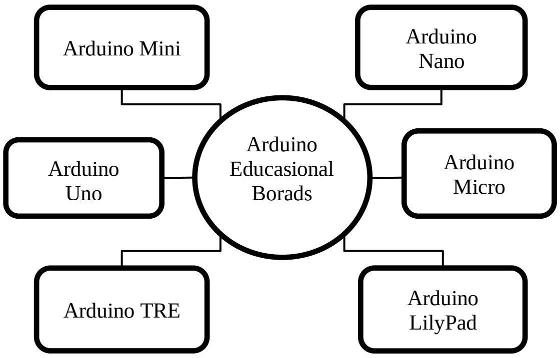

Figure 1. Arduino educational boards' model

The decision matrix is assigned according to the number of alternatives (i.e., Arduino educational boards) and multiple criteria (operating voltage, digital Input/output ports, PWM port, analog input ports, DC current / per-pin, portable storage, SRAM, timer speed, and board weight). Table 1 illustrates the dataset for the various Arduino educational boards.

2. RELATED WORKS

According to the literature, many studies dealt with Arduino boards used in various fields. Arduino boards are considered one of the most promising technologies in the industry and education sector. Currently, Arduino educational boards are widely adopted through courses and lectures covering various disciplines at high school and university levels. Several of Arduino educational boards have been produced for use by students and researchers in the development of various devices [3].

C.C. Chung and S.J. Lou [20] proposed educational content and practical learning activities applied in the real world to solve various problems in Arduino boards using the strategy of the physical computing. This study adopted the DBL (Design-Based Learning) programming approach, which was applied as a special computing strategy in Arduino boards. M.K. Anushree and R. Krishna [21] developed smart projects using Internet of Things technology to improve agricultural production. Arduino boards were used and included two main parts for the sensor and control system that were programmed in Python. P. Kanade, and J.P. Prasad [22] developed an automatic irrigation system using ML and IoT to solve bad distribution or lack of control of the water.

This system depends on multiple sensors such as the pH sensor, temperature sensor controlled by the Arduino module, and the IoT module. On the other hand, Arduino boards are mainly based on various decision support methods according to the literature. The MCDM approach provides an alternative ranking method for resolving the conflict problem between multiple criteria. E.M. Silva and R.J. Goncalves [23] proposed a new methodology based on selecting the most suitable devices based on multiple criteria according to user requirements. This methodology used various Arduino boards as hardware alternatives, during the development of smart systems to improve the choice of hardware platforms. K. Jayanta, et al. [24] developed Autonomous Vehicles (AV) to solve the problem of road accidents due to manual errors. The AV prototype is equipped with an ultrasonic sensor for automatic maneuverability and an Arduino Nano board.

Table 1. Dataset for Arduino educational boards

Arduino model	Criteria								
	Operating Voltage (V)	Digital Input/output Ports	PWM Port	Analog Input Ports	DC Current Per-Port (mA)	Portable Storage (KB)	SRAM (KB)	Timer Speed (MHz)	Board Weight (g)
Arduino Mini	3.35	14	6	6	40	32	2	8	25
Arduino Nano	5	22	6	8	40	32	2	16	7
Arduino Micro	5	20	7	12	20	32	2.5	16	13
Arduino LilyPad	5.5	14	7	6	40	16	1	8	20
Arduino Tre	5	14	7	6	40	32	2.5	8	25
Arduino Uno	5	14	6	6	20	32	2	6	25

3. MATERIAL AND METHODS

The MCDM techniques are considered a proper solution for many issues in real time. Evaluation and selection of Arduino educational boards using appropriate decision support methods in this study. In two basic stages, the research methodology is applied. Basically, BWM method used to compute overall weights of the criteria selected as in first stage, while applying the MOORA approach to select the optimal alternative as in second stage. Thus, the selection approach relies on the results of the first step essentially. Figure, 2 shows the evaluation and selection of Arduino educational boards' architecture. The methodology will be discussed in detail as follows.

3.1. System Design

This section includes the proposed system for solving the research problem. This system consists of two main stages. Figure 2 shows the architecture to evaluate and select of Arduino educational boards. The proposed system will be discussed in detail as follows:

- The first stage: the BWM method
- The second stage: MOORA method

3.1.1. BWM Method

The BWM method is considered important under the decision support approach that provides optimal and reliable results according to decision-makers [17].

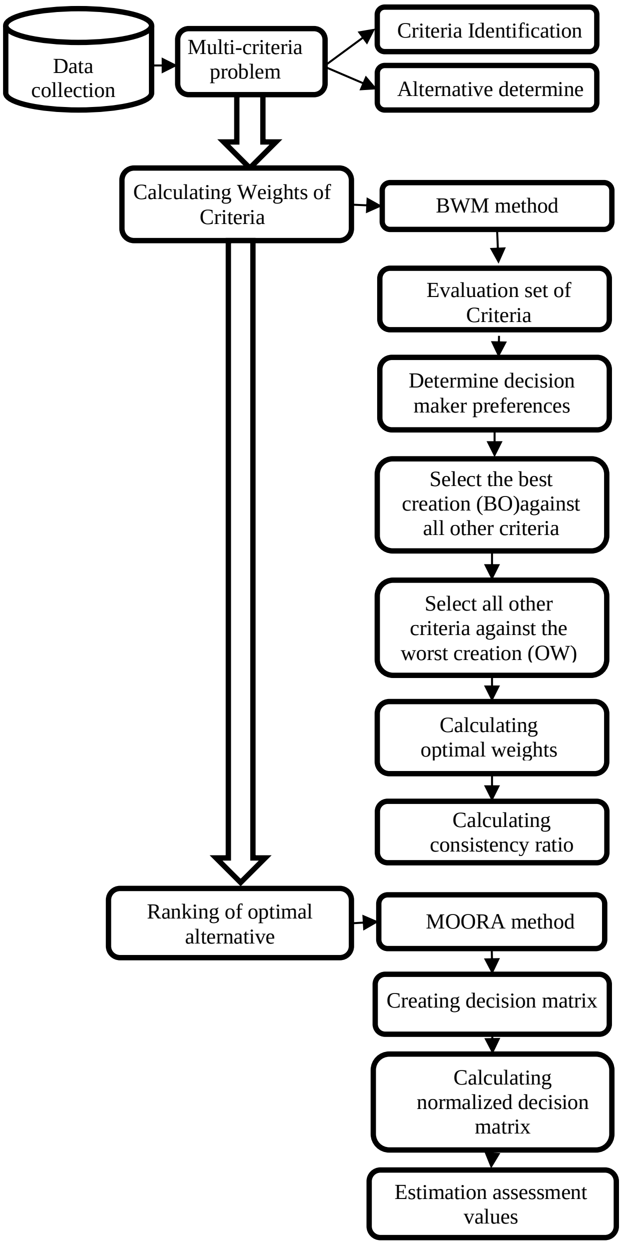

Figure 2. Evaluation and selection of Arduino educational boards' architecture

This method was developed to overcome some of the problems identified (as in the Analytic Hierarchy Process), due to a large number of comparisons in pairwise criteria. In deeply understanding of how the best-worst method works. It is mainly based on a pairwise comparison between two criteria. The best criterion is (more important or more desirable), while the worst criterion refers to (least important or least desirable). Thus, the operation of comparison represents a great challenge for the decision-maker and represents the point of inconsistency between the criteria [17].

This technique is often used to assess a group of alternatives according to specific criteria. This technique is implemented according to a systematic comparison in two rounds: In the first round, decision-makers compare the better standard compared to all further standards. In the second round, the other standards are compared to the worst standard. The better standard is considered the most important, which often has a decisive role in decision-making, while the worst standard has the opposite importance [25].

This method is applied according to a specific scale (1 to 9) based on a systematic comparison of various criteria to select the best and the worst between them. Two sets of comparisons and correlation are used as input to the optimization problem, by the optimal results based on the criteria weights. Therefore, this method considered is simple, and more accurate, without redundant secondary comparisons. The overall steps of the BWM method will be discussed as follows [26], [27]:

A) Criteria are evaluated by the decision maker in this step, as in $\{C_1, C_2, C_3, ... C_n\}$.

B) Decision-making strategy applied by selecting the best criterion (more significance or more desirable) and the worst standard (lower significance or lower desirable).

C) The scale (1 to 9) is used to select the best standard overall criteria, where scale 1 represents equal importance, while scale 9 represents the more priority for the best standard overall criteria. Therefore, the best criterion (BO) can be represented against the other criteria as in Equation (1):

$$AB = (a_{B1}, a_{B2}, a_{B3}, ..., a_{Bn}) \tag{1}$$

where, the best criterion B over criteria j to be represented as a_{Bj}, and presented in the formula as $a_{BB} = 1$.

D) Overall other criteria are compared with the worst criterion using a scale (1 to 9). Comparing the other against the worst criterion (OW) is represented in Equation (2):

$$AW = (a_{1W}, a_{2W}, a_{3W}, ..., a_{nW}) \tag{2}$$

where, other criteria j over the worst criterion W to be represented as a_{jW}, and presented in the formula as $a_{WW} = 1$

E) Determining the absolute significance of the criteria when calculating the optimal final weights as in the formula $(w_1^*, w_2^*, ..., w_n^*)$ based on the Equation (3):

$$\min \max{}_j \left\{ \left| \left(\frac{w_B}{w_j}\right) - aB_j \right|, \left| \left(\frac{w_j}{w_w}\right) - aj_w \right| \right\}$$

$$\text{Subject to} \quad \sum_j w_j = 1 \tag{3}$$

$$w_j \geq 0 \quad \text{for all } j$$

Therefore, non-negative condition and the summation of weights should be considered, then the following problem has resulted:

$$\min \xi$$

$$\left| w_j - aj_w w_w \right| \leq \xi \quad \text{for all } j \tag{4}$$

$$\sum_j w_j = 1, \; w_j \geq 0 \quad \text{for all } j$$

where, w_B represented the best weight and w_w represented the worst weight, a_{Bj} represented the selection of the more significance for the best criterion over criteria j, and a_{jw} represented the selection other criteria j against the lowest significance of the worst criterion.

F) The consistency ratio represented as in (Ksi) to check the level of dependability for the comparisons between criteria based on the Equation (5):

$$K_{si} = \xi^* / CI \quad (5)$$

Table 2, shows the consistency index (CI) values are a same as the consistency ratio computation method which is applied in the AHP method. The lowest value of consistency ratio (equal to zero) refers to high accuracy of consistency, while the higher consistency ratio (equal to one) refers to lower accuracy of consistency according to pairwise comparisons.

Table 2. Scales of the consistency index in BWM method

a_{BW}	1	2	3	4	5	6	7	8	9
CI	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

3.1.2. MOORA Method

Brauers and Zavadskas proposed a new method that multi-objective optimization is based on ratio analysis which known as MOORA method [18]. This method included two types of attributes that have maximum value as (beneficial attributes) and the other attributes have minimum value as non-beneficial attributes. This method could be applied to select the best Arduino board for education based on beneficial and non-beneficial attributes [28]. As a first step, the DM is generated to calculate the normalization values according to Equation 6 represented in x_{ij}, whose value is between 0 and 1.

Thus, the matrix is developed where m indicates the numeral of Arduino boards as alternatives and n refers to the number of criteria for these alternatives. Therefore, ith is represented as an alternative, and jth is represented as criteria by normalization operation to be referred to positive and negative values as beneficial and non-beneficial attributes respectively. The relationship between alternatives and criteria is represented as x_{ij}. Thus, the matrix (x_{ij}), ($m \times n$) is defined. MOORA method is represented in Equations (6), (7) and (8) [29], [30]:

A) Creating a decision matrix.

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array} \quad (6)$$

where, the matrix (x_{ij}), ($m \times n$) represented as $A_1, A_2, \dots, A_m$ to be choosing the optimal boards based on the perspective of decision-makers (i.e., Arduino education boards), and criteria given as x_{ij} represented in $C_1, C_2, \dots, C_n$.

B) Calculating normalized decision matrix

$$x_{ij}^* = x_{ij} / \sqrt{\sum_{i=1}^{m} x_{ij}^2} \qquad i = 1, 2, \dots, m;\ j = 1, 2, \dots, n \quad (7)$$

C) Estimation of assessment values

$$y_i = \sum_{i=1}^{m} w_j x_{ij} - \sum_{j}^{n} = w_j x_{ij} \quad (8)$$

4. RESULTS AND DISCUSSION

Two types of the results have been obtained based on the new approach was applied.

- The first result included the process for computing the criteria weights selected using BWM method.
- The second result referred to the ranking operation for each alternative based on the MOORA method.

Farther more details the results are discussed in this section as follows:

4.1. Calculating Weights Using BWM Method

The calculating weights an essential step to evaluate the criteria selected. In this section, the BWM method applied due to considered the most similar to the AHP approach in the criteria evaluation method. Table 3 shows the selected criteria, used to create the decision matrix as in step 1, according to the perspectives of the experts. Whereas, Table 4 illustrates the best and worst criteria selected according to step 2. Thus, Table 5 shows the comparison between the best standard against the rest of the criteria according to step 3. Table 6 also indicates the comparison between the rest criteria against the worst standard according to step 4. Next, Table 7 identifies an ideal weight for each criterion as in step 5. The proportion of consistency between criteria is calculated according to the values of the consistency index found in Table 2. Thus, the values of the weights for the criteria obtained from Equation (4) are adopted. Criteria weights are an essential step to be used in the next section as an input to the MOORA method to select between criteria.

Table 3. Identification of decision matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
Criteria Names	Operating Voltage	Digital Input/output Ports	PWM Port	Analog Input Ports	DC Current Per-Port	Portable Storage	SRAM	Timer Speed	Board Weight

Table 4. Best and worst criteria selection

Best Criteria Selection	Operating Voltage
Worst Criteria Selection	Board Weight

Table 5. Decision maker selecting the best-to-others criteria

Best -to -others	Operating Voltage	Digital Input/output Ports	PWM Port	Analog Input Ports	DC Current Per-Port	Portable Storage	SRAM	Timer Speed	Board Weight
Operating Voltage	1	2	3	4	5	6	7	8	9

Table 6. Decision maker preference of the others criteria compared with worst criterion

Others to Worst	Board Weight
Operating Voltage	9
Digital Input/output Ports	8
PWM Port	7
Analog Input Ports	6
DC Current Per-Port	6
Portable Memory	4
SRAM	4
Timer Speed	2
Board Weight	1

4.2 Calculating the Ranks Using MOORA Method

The MOORA method is even applied using the weights values of the standards that have been calculated in the BWM method. Recently, three basic phases adopted in the MOORA method have been discussed. In Step 1 is the created the decision matrix which represents an essential step. This step was applied to collect the dataset according to Table 1. In Step 2, the normalized values are calculated for each decision matrix value according to Table 8. The various Arduino boards are ranked as in step 3. In this step, calculating the beneficial criteria values subtracted from the non-beneficial criteria values according to Equation 8. Table 9 shows the ranking for each alternative (i.e., Arduino educational boards). The best alternative was selected the Arduino TRE board, while the Arduino Micro board was the worst among the six alternatives. The best board was chosen based on the level of accuracy and efficiency. See Figure 3, which depicted the ranking of several Arduino educational boards according to their values.

Table 7. Calculating the weights of criteria

Weights	Operating Voltage	Digital Input/output Ports	PWM Port	Analog Input Ports	DC Current Per-Port	Portable Storage	SRAM	Timer Speed	Board Weight
	0.315	0.192	0.128	0.096	0.077	0.064	0.055	0.048	0.027

Table 8. Normalization of decision matrix

Criteria / Arduino model	Operating Voltage	Digital Input/output Ports	PWM Port	Analog Input Ports	DC Current Per-Port	Portable Storage	SRAM	Timer Speed	Board Weight
Arduino Mini	0.281649	0.342791	0.375735	0.319801	0.471405	0.436436	0.396059	0.258199	0.500701
Arduino Nano	0.420372	0.538672	0.375735	0.426401	0.471405	0.436436	0.396059	0.516398	0.140196
Arduino Micro	0.420372	0.489702	0.438357	0.639602	0.235702	0.436436	0.495074	0.516398	0.260365
Arduino LilyPad	0.462409	0.342791	0.438357	0.319801	0.471405	0.218218	0.19803	0.258199	0.400561
Arduino Tre	0.420372	0.342791	0.438357	0.319801	0.471405	0.436436	0.495074	0.258199	0.500701
Arduino Uno	0.420372	0.342791	0.375735	0.319801	0.235702	0.436436	0.396059	0.516398	0.500701

Table 9. Ranking of alternatives for Arduino education boards

Criteria / Arduino model	Operating Voltage	Digital Input/output Ports	PWM Port	Analog Input Ports	DC Current Per-Port	Portable Storage	SRAM/	Timer Speed	Board Weight	SUM (y_i)	Rank
Arduino Mini	0.281649	0.342791	0.375735	0.319801	0.471405	0.436436	0.396059	0.258199	0.500701	0.053388	4
Arduino Nano	0.420372	0.538672	0.375735	0.426401	0.471405	0.436436	0.396059	0.516398	0.140196	0.05131	5
Arduino Micro	0.420372	0.489702	0.438357	0.639602	0.235702	0.436436	0.495074	0.516398	0.260365	0.022418	6
Arduino LilyPad	0.462409	0.342791	0.438357	0.319801	0.471405	0.218218	0.19803	0.258199	0.400561	0.073662	3
Arduino Tre	0.420372	0.342791	0.438357	0.319801	0.471405	0.436436	0.495074	0.258199	0.500701	0.093724	1
Arduino Uno	0.420372	0.342791	0.375735	0.319801	0.235702	0.436436	0.396059	0.516398	0.500701	0.090576	2

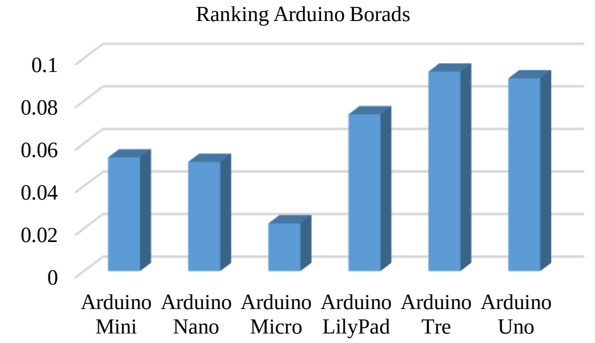

Figure 3. Shows ranking Arduino educational boards

5. CONCLUSION

Arduino-based technologies are considered promising equipment for both the education sector and industry alike. Currently, Arduino boards are widely used by students and researchers, especially in the field of robotics and modern technologies. Various Arduino boards have been developed to suit all educational and industrial projects. Thus, it depends on the set of attributes and criteria which is represented a complex problem when selecting the best board for educational purposes. Research contribution identified by proposing a new approach based on decision support techniques represented by the BWM method and the MOORA approach for classifying Arduino learning boards in real time. The results identified the optimal alternative represented in the Arduino TRE model, while the worst alternative was the Arduino Micro model according to their criteria. The limitations identified in this study are the lack of adequate studies using decision-support methods to select Arduino educational boards, and not all boards on the market have been covered. In future work, different educational boards can be evaluated andcompared using other methods such as machine learning algorithms. In addition, the decision-making methods have provided many techniques that can be used in another case study.

NOMENCLATURES

1. Acronyms

AEB	Arduino Educational Boards
BWM	Best-Worst method
MOORA	Multi-Objective Optimization based on the Ratio Analysis
g	Weight measurement unit
KB	Storage capacity unit
mA	Electric current measurement unit

2. Symbols / Parameters

V: Electrical charge unit

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