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FUZZY AHP FOR PERFORMANCE ANALYSIS: MAPPING GREEN CURRICULUM AND DEVELOPING BLUE CURRICULUM FRAMEWORK

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Abstract

This research seeks to evaluate the efficacy of the green curriculum and formulate a blue curriculum framework through the application of the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method. By examining the integration of sustainability education within curriculum design, this study aims to create a more holistic and environmentally responsive educational model. The research begins with a comprehensive literature review to identify key criteria for the green curriculum. These criteria are then analysed using Fuzzy AHP to prioritize their performance. The findings indicate that environmental, economic, and social dimensions hold substantial significance within the green curriculum. Building on these insights, the blue curriculum framework is proposed, emphasizing the cultivation of ocean literacy skills among students. The study's recommendations underscore the importance of implementing both green and blue curricula across various educational levels. Furthermore, it highlights the necessity of embedding sustainable practices within the educational system to ensure the longevity and effectiveness of sustainability education. The research thus provides a dual-focused approach to curriculum development, addressing both terrestrial and marine environmental concerns, and advocates for a comprehensive integration of sustainability principles in education.

Keywords: Blue curriculum, Fuzzy analytical hierarchy process, Green curriculum, Green skills, Ocean literacy.

1. Introduction

Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is a multi-criteria decision-making method that has developed as a powerful tool for dealing with uncertainty and ambiguity in assessment [1]. By combining the principles of fuzzy logic with advanced computing technology, Fuzzy AHP enhances the traditional AHP's capacity to handle uncertain and vague judgments [2-4]. Fuzzy technology enables more flexible and realistic assessments, utilizing software and algorithms capable of processing complex and uncertain data with high efficiency [5, 6].

In the educational context, particularly for future curriculum development and evaluation, Fuzzy AHP has proven to be an effective tool for conducting performance analysis [7]. The application of Fuzzy AHP allows assessors to assign more accurate weights to various criteria, which are often subjective and uncertain [8, 9]. This capability is particularly relevant in green curriculum mapping, which aims to integrate sustainability principles in education. The Green Curriculum requires a comprehensive and holistic approach to assess various aspects such as environmental sustainability, social relevance, and economic efficiency.

Currently, there are still few studies regarding green curricula in educational programs. The novelty of this research lies in designing comprehensive green curriculum requirements using decision-making techniques like MCDM. The development of this green curriculum combines various criteria from previous research that adhere to global standards. This research has limitations, as the green curriculum criteria used were restricted to 20, and the Fuzzy-AHP method employed only the Chang Extent and Buckley's Fuzzy-AHP methods.

The problem formulation in this research includes identifying supporting criteria for a green curriculum, analysing the importance and priority order of these criteria using the Fuzzy-AHP Method and utilizing the results of this green curriculum mapping as a reference for developing a blue curriculum framework in the future. By using Fuzzy AHP, decision-makers can integrate various factors more precisely and balanced, resulting in an effective curriculum map. This analysis forms a strong foundation for developing the Blue Curriculum framework, which emphasizes innovation and technology in sustainable education.

Consequently, Fuzzy AHP not only aids in mapping and evaluating Green Curriculum performance but also plays a crucial role in designing a sustainable and innovative educational future through the Blue Curriculum Framework. This article aims to explore the application of Fuzzy AHP in Green Curriculum performance analysis and Blue Curriculum framework development, offering insights and practical guidance for educators and policymakers.

2. Methods and Materials

In this research, data on supporting criteria for the green curriculum were obtained using the Systematic Literature Review (SLR) method. The criteria were then processed using the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) method, specifically utilizing Buckley's Fuzzy-AHP Algorithm.

The SLR method gathered and synthesized results from previous studies to identify supporting criteria for the green curriculum. Using keywords like "green curriculum," "green skills," and "green TVET" in the Scopus database, 146 documents were initially found. After screening titles and abstracts, 72 documents remained, which were further filtered through eligibility criteria to 25 documents. These documents provided the competency criteria for the green curriculum, as depicted in the PRISMA flow diagram, Fig. 1.

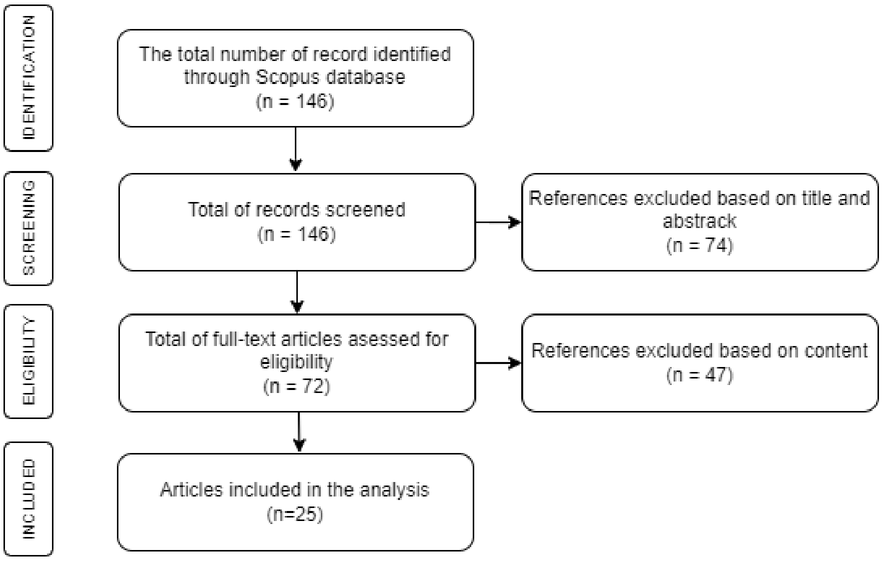

Fig. 1. PRISMA flow diagram.

The AHP method breaks down complex problems into a hierarchical order of criteria or variables, using Pairwise Comparison Matrices (PCMs) and a 1-9 scale for comparison. The consistency of these comparisons is checked using the Consistency Ratio (CR). In the Fuzzy-AHP method, the weights of the Triangular Fuzzy Number (TFN) scale pairwise comparison matrix are calculated, which influences the ranking of criteria. Buckley's Fuzzy-AHP algorithm was chosen for its practicality and accuracy in expanding to fuzzy cases, ensuring a single solution for matrix comparisons. The research concluded with the defuzzification process, converting fuzzy outputs into single-valued outputs to determine the final weights of each criterion. Some of the equations used in this study are shown below.:

$$r_i = \left(\prod_{j=1}^{m} a_{ij}\right)^{\frac{1}{m}} \tag{1}$$

$$\tilde{r}_i = (l_{ri}, m_{ri}, u_{ri}) = \left[\left(\prod_{j=1}^{n} l_{ij}\right)^{\frac{1}{n}}, \left(\prod_{j=1}^{n} m_{ij}\right)^{\frac{1}{n}}, \left(\prod_{j=1}^{n} u_{ij}\right)^{\frac{1}{n}}\right] \tag{2}$$

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \ldots \oplus \tilde{r}_n)^{-1} \tag{3}$$

3. Results and Discussion

3.1. Green curriculum supporting criteria

The green curriculum supporting criteria that will be used in this research are the criteria most widely used in previous studies. By conducting a literature study of twenty-five journals, the results of the criteria and the number of journals that used them were obtained, which are summarized in Table 1.

Table 1. Green curriculum supporting criteria.

No.	Criteria	Number of Journals
1	Waste Management	13
2	Environmental Awareness	12
3	Green Technology	9
4	Communications	8
5	Efficiency of Energy and Water	8
6	Environmental Pollution	8
7	Problem Solving	7
8	Eco-Design	7
9	Management	7
10	Innovation	6
11	Renewable Energy	6
12	Adaptation	5
13	Leadership	5
14	Eco-Friendly Products	4
15	Law of Environmental Protection	4
16	Social Responsibility	4
17	Procurement	3
18	Economic Responsibility	3
19	Energy Skills	3
20	Entrepreneurship	2

From the many criteria obtained, the author took the top 20 criteria that are most widely used in green curriculum competencies, namely: Waste Management (WM), Environmental Awareness (EA), Green Technology (GT), Communication (CM), Efficiency of Energy and Water (EW), Environmental Pollution (EP), Problem Solving (PS), Eco-Design (ED), Management (MG), Innovation (IN), Renewable Energy (RE), Adaptation (AD), Leadership (LS), Eco- Friendly Product (FP), Law of Environmental Pollution (LE), Social Responsibility (SR), Procurement (PR), Economic Responsibility (ER), Energy Skills (ES), Entrepreneurship (ET).

For concept analysis, based on the 20 green curriculum criteria, the 10 highest rankings were selected.

- **Waste Management (WM):** Recycling and reuse skills are crucial for reducing waste and minimizing pollution [10]. Workers in the industry must be competent in these skills [11], and countries implement practices like zero-waste and 4R (Reuse, Reduce, Recycle, Recovery) to prevent waste [12].
- **Environmental Awareness (EA):** Environmental awareness involves understanding sustainable development and addressing environmental challenges [13]. It fosters a responsible and problem-solving personality [14]. Green practices require alertness and patience in the workplace [11].
- **Green Technology (GT):** Green technology includes the development and use of products and systems to minimize environmental damage from industrial activities. It aligns with sustainable development and should be part of the TVET curriculum to prepare graduates for the green industry [10].
- **Communication (CM):** In the green industry, communication skills include verbal, non-verbal, and technological communication that minimizes energy consumption and is environmentally friendly. Industry prefers ICT as a communication medium to reduce paper use [12, 15].
- **Efficiency of Energy and Water (EW):** To address pollution caused by industrial activities, workers need skills to find solutions and help industries

adopt greener practices. These problem-solving skills must be integrated into the TVET curriculum [10, 13].

- **Environmental Pollution (EP):** Skills to control industrial pollution, especially chemical waste affecting water and soil, are essential. Including these in the TVET curriculum can help minimize environmental damage [10].
- **Problem Solving (PS):** Similar to EW, problem-solving skills are crucial for addressing industrial pollution and helping industries become greener. These skills should be part of the TVET curriculum [10, 13].
- **Eco-Design (ED):** Eco-design involves creating technologies, products, and processes that minimize carbon emissions. These skills are essential for producing environmentally friendly products and should be included in the TVET curriculum [10, 12, 15].
- **Management (MG):** Green management skills focus on efficient and adequate use of natural resources, reducing waste and pollution. These skills are vital for managing resources sustainably for current and future generations [10, 12].
- **Innovation (IN):** Innovation skills are needed to identify opportunities and create strategies to address green challenges. This includes developing creative programs and solutions for environmental problems [14, 16].
- **Renewable Energy (RE):** Knowledge of renewable energy reduces greenhouse gas emissions and environmental impact. This knowledge is essential for the TVET curriculum to promote sustainable industrial and daily activities [17].

3.2. Analytical hierarchy process (AHP) results

In the AHP method, a hierarchical structure diagram is used to prepare the green curriculum criteria which can be seen in Fig. 2.

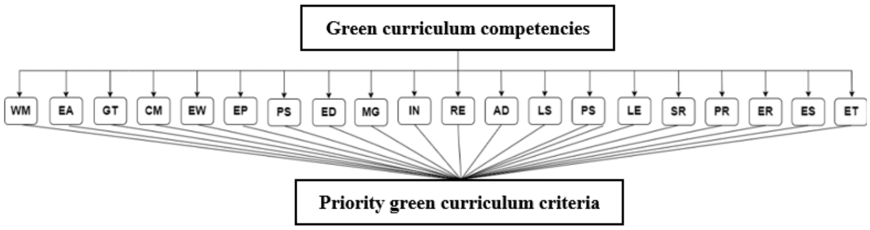

Fig. 2. Green curriculum competency hierarchy structure.

Figure 2 shows a structure diagram of the green curriculum criteria which consists of 20 aspects which will then be assessed using Fuzzy-AHP.

After creating the hierarchical structure above, the next stage in Fuzzy-AHP is creating a pairwise comparison matrix of order 20 × 20 adjusted to the number of existing aspects, then inserting TFN values into each order. Next, carry out calculations to determine the fuzzy geometric mean value according to equation (2) (Table 2). The geometric average fuzzy value has been calculated, then calculate the weight of each criterion according to equation (3) (Table 3). After the geometric mean fuzzy value has been calculated, you can calculate the CRISP value and then you can find out the weight value of each criterion by making the normalization shown in Table 4.

Table 2. Calculation of geometric mean values.

Criteria	AD	CM	...	SR	WM	$(\tilde{r}_i)$
AD	(1,1,1)	(1/4,1/3,1/3)	...	(1,1,1)	(1/8,1/7/1/6)	(1.51, 1.16, 1.17)
CM	(2,3,4)	(1,1,1)	...	...	...	(1.21, 1.22, 1.23)
⋮	⋮	⋮	⋱	⋮	⋮	⋮
SR	(1,1,1)	(1/6,1/5,1/4)	...	(1,1,1)	(1,1,1)	(1.13, 1.14, 1.15)
WM	(6,7,8)	(2,3,4)	...	(6,7,8)	(1,1,1)	(1.25, 1.26, 1.27)

Table 3. Fuzzy weight calculation.

Criteria	$(\tilde{r}_i)$	$(\widetilde{W}_i)$
AD	(1.51, 1.16, 1.17)	$(1.51, 1.16, 1.17) \oplus \left(\frac{1}{23.85}, \frac{1}{23.65}, \frac{1}{23.44}\right) = (0.04, 0.04, 0.05)$
CM	(1.21, 1.22, 1.23)	$(1.21, 1.22, 1.23) \oplus \left(\frac{1}{23.85}, \frac{1}{23.65}, \frac{1}{23.44}\right) = (0.05, 0.05, 0.05)$
⋮	⋮	⋮
SR	(1.13, 1.14, 1.15)	$(1.13, 1.14, 1.15) \oplus \left(\frac{1}{23.85}, \frac{1}{23.65}, \frac{1}{23.44}\right) = (0.04, 0.04, 0.04)$
WM	(1.25, 1.26, 1.27)	$(1.25, 1.26, 1.27) \oplus \left(\frac{1}{23.85}, \frac{1}{23.65}, \frac{1}{23.44}\right) = (0.05, 0.05, 0.05)$

Table 4. CRIPS values, normalization and criteria weights.

Criteria	$(\widetilde{W}_i)$	w_i	Normalized Weight
AD	(0.04,0.04,0.05)	0.049	0.049
CM	(0.05,0.05,0.05)	0.051	0.052
⋮	⋮		⋮
SR	(0.04,0.04,0.04)	0.048	0.048
WM	(0.05,0.05,0.05)	0.053	0.053
Total		1.001	1

After the weight values are known, then test their consistency, if the calculated consistency ratio is <0.1, then the results of the fuzzy AHP analysis can be used for decision making. The results of the consistency calculation are shown in Table 5 which begins with creating a pairwise comparison matrix. Then the calculation of the consistency index value is shown in Table 6. Next, determine the Consistency Ratio value. The results of the calculation show that the total values of λ_{max} =0.769, CI =0.0404, RI =1.5978, and CR = 0.025. The CR value of 0.025 means that the CR value is <0.1 and the results of the ranking criteria in the green curriculum can be used to make decisions.

Table 5. Pairwise comparison matrix.

Criteria	AD	CM	...	SR	WM
AD	1	1/3,	...	1	1/7
CM	3	1	...	5	1/3
⋮	⋮	⋮	⋱	⋮	⋮
SR	1	1/5	...	1	1
WM	7	3	...	7	1
Total	43.33	15.67		57.33	5.49

Table 6. Consistency index value.

Criteria	AD	CM	...	SR	WM	Average	CI
AD	1/43.33	0.033/15.67	...	1/57.33	0.14/5.49	0.025287	20.6093
CM	3/43.33	1/15.67	...		...	0.070505	20.914
⋮	⋮	⋮	⋱	⋮	⋮		
SR	1/43.33	0.2/15.67	...	1/57.33	1/5.49	0.017246	20.64555
WM	7/43.33	3/15.67	...	7/57.33	1/5.49	0.167837	21.27702
Total							20.76939

A CR value <0.1 means that the pairwise matrix is consistent, and the weight values can be used as a consideration for making decisions.

Figure 3 shows the results of the order of criteria weights, in this case the three largest will be taken with the consideration that starting from the fourth order onwards they have the same weight. The top three calculation results are Waste Management (WM), Environmental Awareness (EA), and Green Technology (GT). These results are in accordance with research which states that the issue of a more specific green curriculum as well as studies of green competencies, green skills and green jobs show that on environmental issues in an educational context, students need to be equipped first with the ability to recycle existing waste [18]. The next stage is awareness to protect the environment. This ability also illustrates that environmental awareness is a collective, social awareness that must be grown together [19, 20]. The third stage that needs to be carried out in the context of green education, especially in developing a green curriculum, is the integration of technology in the development of the green curriculum. The integration of technology in environmentally oriented education will make it easier to deal with environmental problems or develop various effective media by utilizing technology to teach about environmental issues [21, 22].

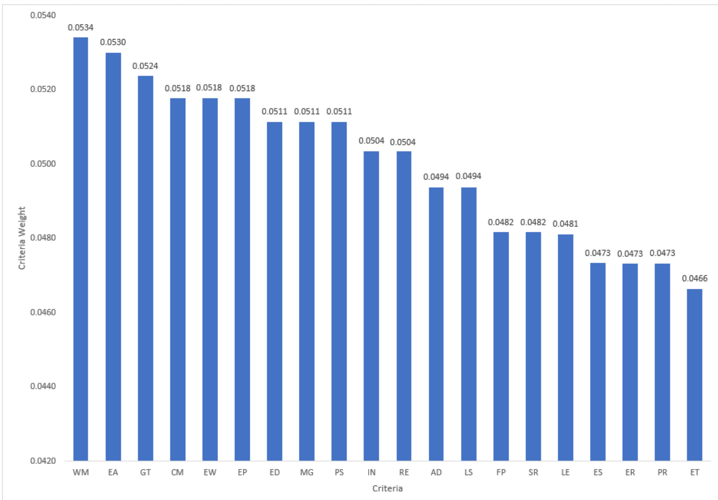

Fig. 3. Results of the order of criteria weights.

3.3. Development of the blue curriculum framework based on green curriculum mapping

Green Curriculum mapping can serve as a valuable reference for developing the Blue Curriculum framework in the future. The Green Curriculum, comprising 20 priority aspects, emphasizes sustainable education and environmental preservation. The insights and results from implementing the Green Curriculum provide a robust foundation for the Blue Curriculum, which will likely focus on marine resource conservation and maritime ecosystem sustainability. A key component of the Blue Curriculum is ocean literacy competency [8, 23, 24]. Additionally, the holistic approach of the Green Curriculum, which combines theory and practice, can be applied to the Blue Curriculum to ensure that students not only grasp theoretical concepts but also engage directly in marine conservation efforts. Therefore, the experiences and insights from the Green Curriculum form a solid basis for developing an effective and relevant Blue Curriculum.

4. Conclusion

Mapping the green curriculum by analysing 20 criteria illustrates the integration of sustainability education to preserve the environment. The characteristics of green competencies emphasize developing insight, attitudes, awareness, and skills that encourage student involvement in solving environmental problems. This approach requires students to be actively involved and collaborate with the community. Mapping the green curriculum provides a strong foundation for developing the blue curriculum concept, which focuses on ocean literacy. Ocean literacy is crucial because the sea, being the largest part of the earth, holds vast resources that can contribute to societal welfare.

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