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Prioritizing Elements of Science Education for Sustainable Development with the MCDA-FDEMATEL Method Using the Flipped E-Learning Scheme

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Abstract: Selecting and ordering components for sustainable science education is a critical issue, which is presently obtaining increased attention because of being at an early stage and scarce application in higher education. Though the flipped e-learning scheme is one of the novel information and communication technologies (ICTs), it can be of great relevance in a long-term learning program for various sustainable science education criteria. This research presents an approach to identify and analyze elements for science education for sustainable development with multi-criteria decision analysis-fuzzy decision-making trial and evaluation laboratory (MCDA-FDEMATEL) method by flipped e-learning system. With the method proposed, the main elements are collected as science-education, sustainable-development, technology-infrastructure and flipped-e-learning elements. The final results' analyses with sixteen sub-elements are assessed with weighted linear combination (WLC) and sensitivity-analysis (I to VI implementations) in the context of the MCDA-FDEMATEL method. The most important element and sub-element for science education for sustainable development through flipped e-learning teaching are sustainable-development (as an element), VI implementation with 0.540 weight, and environmental contents (as a sub-element) with 0.570 weight. Consequently, this proposed approach could be used in different studies to validate the most important aspects of science education for sustainable development through flipped e-learning teaching elements and sub-elements with equivalent and comparable education settings.

Keywords: sustainability; science education; flipped classroom; MCDA-FDEMATEL; e-learning program; sensitivity-analysis

1. Introduction

The aims, values, exercises and standards of sustainable education, based on the decade of education for sustainable development (DESD) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in the United Nation (UN) and UNESCO 2015-2030 Agenda, promote public consciousness and aim to advance a life-long education and spread importance in various educational domains [1–6]. Here, Sterling stated that sustainable education is a change for educational culture of human potential instruction and economic, ecological and social interdependence, which will undertake into transformative learning [3]. In the context of transformative learning, Mezirow denoted that the obligation of educators is to support leaners, who can accomplish their targets in a more autonomous and reliable manner [7]. In the pedagogical and cultural context, teaching processes and purposes concentrate on approving learners together with values, skills, information and a mind-set, which perform as transformation mediators to sustainability [8–10]. Also, science education for sustainable development is associated with knowledge including the values and beliefs for sustainable education although a definite research area can relate with its own capacities, methodologies and competences and scientific and technical skills [10–12]. Yet, sustainable science education in a higher education is still at an early stage and scarce application exists, although many roles and parts have been enacted in transforming societies by educating decision-makers. In these demanding and challenging situations, science education over a life-long cycle can create a chance of pedagogical niche for flipped e-learning teaching [13–15].

An e-learning system is considered to be a teaching and learning procedure on the basis of a proper educational mode that lets flexible learner-focused education owing to information and communication technologies (ICTs), being virtual and online learning platforms, in science education for sustainable development [16–19]. Here, Hansen highlighted that students in flipped e-learning programs generally have a better perception of experience and knowledge that precedes positive and affirmative transformative learning education [19–22]. Also, Paechter et al. specified that students' learning accomplishments and achievements are closely connected to the characteristics of flipped e-learning programs and systems, i.e., education schemes' flexibility and knowledge altercation as multi-dimensional communications [13]. Together with ICTs and novel information, flipped e-learning teaching for sustainable science education can be of great relation in actual life-long learning education for sustainable development along with various elements and sub-elements [23,24]. Yet, it is still for general e-learning cases and is required to do a research on specific flipped e-learning models' efficiency and effectiveness. Recent and current works published describe the examination and debate in detail and in-depth analysis and assessment for science education for sustainable development through flipped e-learning systems in higher education [23,25]. Due to these reasons and the lack of literature, we aim to identify and analyze the elements and sub-elements of flipped e-learning systems for sustainable science education.

This research identifies and analyzes a distinct approach to prioritize elements and sub-elements in science education for sustainable development with MCDA-FDEMATEL method by flipped e-learning teaching. The main elements to achieve this objective are delineated, evaluated, weighted and assigned to four element groups, science-education, sustainable-development, technology-infrastructure and flipped-e-learning, and sub-elements with their computation on weight coefficients. The final results' analyses with 16 sub-elements are gauged with weighted linear combination (WLC) and sensitivity-analysis (I to VI implementations) in the context of MCDA-FDEMATEL method. Then, this work shows the adaptation likelihood of the offered six implementations and their sub-elements. Here, the research questions that this study aims to answer are:

- RQ 1: Does a MCDA-FDEMATEL method contribute to identify and prioritize elements and sub-elements for science education in sustainable development by flipped e-learning teaching?
- RQ 2: Do the selected elements and sub-elements analyze the prioritization results by WLC and sensitivity-analysis in science education for sustainable development by flipped e-learning teaching?
- RQ 3: Does the suitability implementation show the suitability in science education for sustainable development by flipped e-learning teaching?

2. Materials and Methods

In this part, this method, MCDA-FDEMATEL, is applied to these four elements and sixteen sub-elements proposed. Here, as an operational application, MCDA-FDEMATEL method together with WLC and sensitivity-analysis is used to identify and analyze the most important components in sustainable science education for long-term flipped e-learning scheme. A conceptual modeling of MCDA-FDEMATEL evaluation is demonstrated in Figure 1. To estimate the most important elements and sub-elements of science education for sustainable development through flipped e-learning systems, the approach is used with various sections and steps.

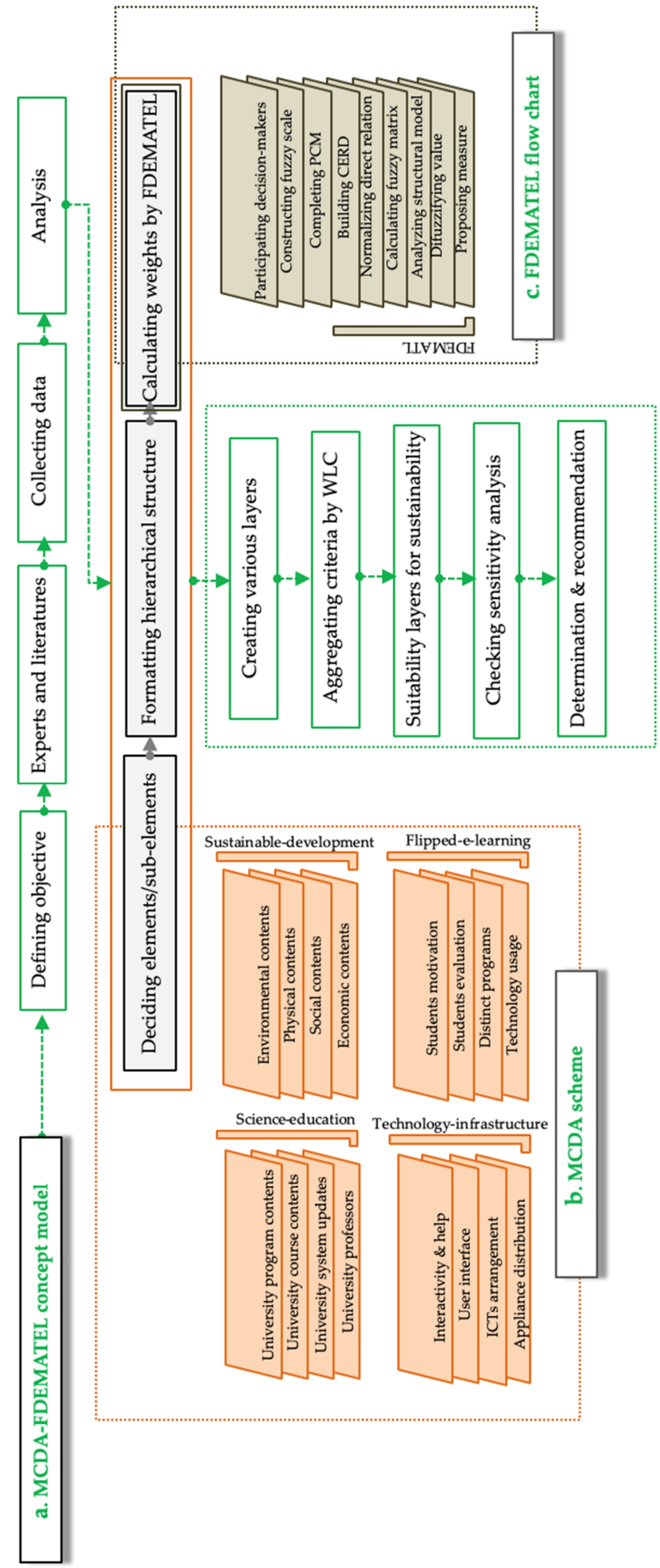

Figure 1. A conceptual modeling of MCDA-FDEMATEL assessment in three sections (a, b and c).

2.1. Targeting Sample

The proposed approach is applied into an introductory science course, entitled "teaching in matter and energy" that is a compulsory subject of the bachelor degree in Primary Education, Teacher Training College (Spain). Usually, seventy to eighty students enrolled the program in each year. As a core course in the program, "teaching in matter and energy" includes sustainability transitions, changes and theories in the section of energies. For the course of 2018/19, a total 75 students enrolled the subject with the specific demographic information as shown in Figure 2. Here, we can observe the sample distribution of a primary education group who actually are taking the suggested subject "teaching in matter and energy". Specifically, 75% of students were females and 25% of students were males, being the average age of the participants, 20.6 years old. The grade point average (GPA in a 0 to 10 scale) at the beginning of the second semester was 6.73. Based on the educational background, most of the students enrolled in this course did not have a strong science background. Precisely, 72% of the participants took social science courses in their mid- and high-school period, and only 19% of the students had taken science education in their mid- and high-school period. From their background, we can assume the previous contact of these pre-service teachers for science education for sustainable development has very limited. Therefore, this course will give a backbone information for their future teaching that they need to have the obligation to teach science and sustainable development for primary students.

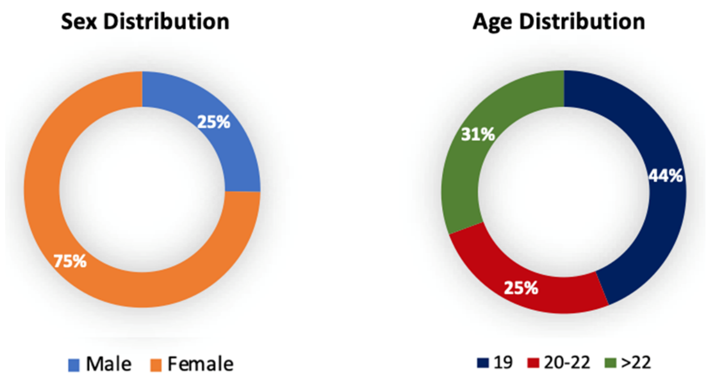

Figure 2. Targeting sample distribution of a primary education group for the course of teaching in matter and energy of 2018/19.

2.2. Elements' and Sub-Elements' Description

For prioritizing various criteria in science education for sustainable development together with many different disciplines and regulations, the multi-criteria decision analysis (MCDA) method can be applied along with the pairwise comparison method (PCM) and the analytic hierarchy process (AHP) through flipped e-learning system [26–29]. Here, Jain et al. described that multi-criteria decision-makings on multiple components could be used for initiating and ranking flipped e-learning systems of the extensive selection and assessment of flipped e-learning systems [30]. In a similar context, Islas-Pérez et al. mentioned that flipped e-learning tools and management systems are standard, benchmark and criteria set, which aimed to support users of flipped e-learning tools and management systems to make better and best choices [31]. Thus, the fuzzy decision-making trial and evaluation laboratory (FDEMATEL) method is used to customize a structural arrangement among the elements and their values [32–34]. Various aspects of flipped e-learning related applications using MCDA-FDEMATEL have been considered to display all recommendations are comparable for both flipped e-learning and traditional programs [34–36]. According to Garg and Jain and Yang et al., flipped e-learning science interfaces are employing with a hierarchical growth model on the basis of fuzzy MCDA method and FDEMATEL analytic grid procedure that found the influential weights jointly with the establishment [26,37,38]. Thus, these operational methods are necessary to adjust sustainable science education of flipped e-learning system with various decision-makers on multiple criteria.

As the first MCDA-FDEMATEL phase, the selection of elements and sub-elements has a robust and straight influence on the evaluation of possible components in science flipped e-learning systems for sustainable education. As shown in Tables 1–4, after the consultation with professors, researchers, educators, authorities, directors in total 39 professionals, the authors as the decision-maker determined the elements and sub-elements with the authentic data of an extensive bibliography and policies/directives of the European union (EU). Four clusters, namely four elements such as science-education, sustainable-development, technology-infrastructure and flipped-e-learning, have sixteen sub-elements, which combined in order to identify most important elements of flipped e-learning systems in science education for sustainable development.

Table 1. Elements and sub-elements considered in science-education.

Elements: Science-Education				
Sub-Elements	**Element Context**	**Weight**	**Name**	**Validation**
University program contents	Organization and explanation of university program contents in science education associated with the goals proposed	0.130	UPC	CR = 0.089 < 0.1
University course contents	Organization and explanation of university course contents in science education associated with the goals proposed	0.260	UCC	
University system updates	Organization and explanation of university system updates in science education associated with the goals proposed	0.050	USU	
University professors	Organization and explanation of university professors in science education associated with the goals proposed	0.560	UPR	

Table 2. Elements and sub-elements considered in sustainable-development.

Elements: Sustainable-Development				
Sub-Elements	**Element Context**	**Weight**	**Name**	**Validation**
Environmental contents	Organization and explanation of environmental contents for sustainable development associated with the goals proposed	0.570	ECO	CR = 0.083 < 0.1
Physical contents	Organization and explanation of physical contents for sustainable development associated with the goals proposed	0.250	PCO	
Social contents	Organization and explanation of social contents for sustainable development associated with the goals proposed	0.120	SCO	
Economic contents	Organization and explanation of economic contents for sustainable development associated with the goals proposed	0.060	EMO	

Table 3. Elements and sub-elements considered in technology-infrastructure.

Elements: Technology-Infrastructure				
Sub-Elements	**Element Context**	**Weight**	**Name**	**Validation**
Interactivity and help	Organization and explanation of interactivity and help in technology and infrastructure associated with the goals proposed	0.070	IHE	CR = 0.059 < 0.1
User interface	Organization and explanation of user interface in technology and infrastructure associated with the goals proposed	0.120	UIN	
ICTs arrangement	Organization and explanation of ICTs arrangement in technology and infrastructure associated with the goals proposed	0.540	IAR	
Appliance distribution	Organization and explanation of appliance distribution in technology and infrastructure associated with the goals proposed	0.250	ADI	

Table 4. Elements and sub-elements considered in flipped-e-learning.

Elements: Flipped-e-Learning				
Sub-Elements	**Element Context**	**Weight**	**Name**	**Validation**
Students motivation	Organization and explanation of students' motivation in flipped-e-learning associated with the goals proposed	0.240	SMO	CR = 0.091 < 0.1
Students evaluation	Organization and explanation of students' evaluation in flipped-e-learning associated with the goals proposed	0.050	SEV	
Distinct programs	Organization and explanation of distinct programs in flipped-e-learning associated with the goals proposed	0.570	DPR	
Technology usage	Organization and explanation of technology usage in flipped-e-learning associated with the goals proposed	0.140	TEU	

2.3. MCDA-FDEMATEL Method Application

As the second MCDA-FDEMATEL phase, with the extensive elements and sub-elements, FDEMATEL technique is an out-ranking method that computes their coefficients. It considers also their effect on the components of science education for sustainable development through flipped e-learning scheme in the setting of AHP method. In particular, the fuzzy logic set is engaged to standardize the elements and sub-elements data. The four aforementioned elements were quantified by 0 to 1 common ranking scale (0 designated less important and 1 designated more important rate). Here, decision-makers define each element's comparative importance weight on the basis of PCM due to not have the same importance weight of elements and sub-elements as shown in Table 5 [34]. Each element and sub-element weight with PCM can be selected in the context of consistency ratio (CR) matrix. A CR weight obeyed by a thumb rule can be controlled to be adequate only in the case that the weight is smaller than 10%. If not, decision-makers must revise and modify their weights of decisions and conclusions [39].

Table 5. The PCM comparative importance for calculating elements' numerical weights.

Nine Points Assessment Scale in PCM																
Less important									More important							
1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
Extremely		Very-Strongly		Strongly		Moderately		Equally	Moderately		Strongly		Very-Strongly		Extremely	

The fuzzy logic device is a robust device introduced by Zadeh and is dealing with the ambiguity of individual valuation in the procedure of decision-making [40]. During the procedure of decision-makings, it is essential to generate fuzzy numbers in practice. As shown in Equation (1), a fuzzified Likert scale is assigned to determine elements' average matrix. Also, a triangular fuzzy number (TFN) as shown in Figure 3 can be showed in the context of fuzzy marks and relationship functions.

$$P = \left[p_{ij}\right]c_i \times c_i \tag{1}$$

Basically, in this setting given, a triplet (l, m, u) is that l, m and u signify lower, medium and upper weight, respectively. These values can be described in a fuzzy set (x ≤ y ≤ z). TFN relationship functions define as depicted in Equation (2) [41]:

$$\mu(x) = \begin{cases} 0, & x < l \\ \frac{x-l}{m-l}, & l \le x \le m \\ \frac{u-x}{u-m}, & m \le x \le u \\ 0, & x \ge u \end{cases} \tag{2}$$

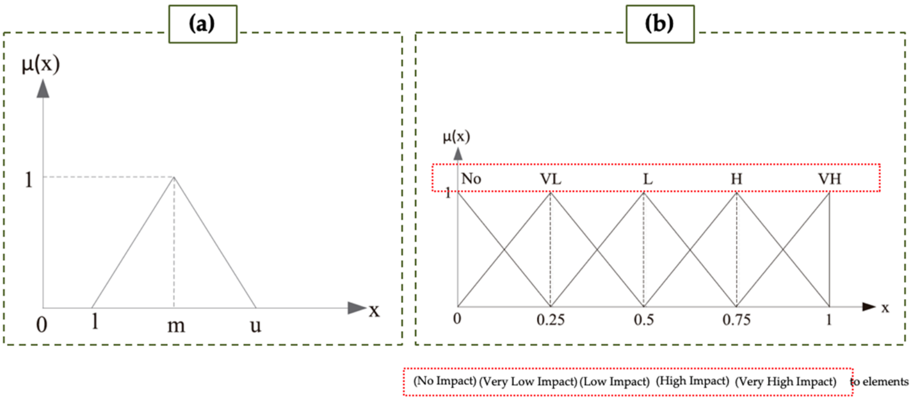

Figure 3. The fuzzy logic set, TFN: (**a**) The equivalent relationship of the linguistic relations and weight, and triangular fuzzy numbers; (**b**) Fuzzy marks and relationship functions explained [41].

As a direct relationship, it decides the average criteria matrix. In the weighting procedure, the authors as decision-makers after expert consultation make a direct average criteria relationship matrix. The combination of decision-makers' weightings is completed where p_{ij}^{e} conveys that e is the decision-maker preference and k is the entire digit of decision-maker as shown in Equation (3).

$$p_{ij} = \left(p_{ij}^{(l)}, p_{ij}^{(m)}, p_{ij}^{(u)}\right) = \left\{ \begin{array}{l} p_{ij}^{(l)} = \min\left(p_{ij}^{e}\right) \\ p_{ij}^{(m)} = \sqrt[k]{\prod_{i=1}^{k} p_{ij}^{e}} \\ p_{ij}^{(u)} = \max\left(p_{ij}^{e}\right) \end{array} \right\} \tag{3}$$

Thus, it defuzzifies the elements' weight coefficients, which the defuzzified features of the total relation matrix are used on the basis of Equation (4).

$$A = \left(a^{(l)} + 4a^{(m)} + a^{(u)}\right) \cdot 6^{-1} \tag{4}$$

2.4. WLC and Sensitivity-Analysis

As the third MCDA-FDEMATEL phase, WLC method is used to collect the standardized elements' and sub-elements' weights in science education for sustainable development through the flipped e-learning scheme. To validate the acquired results' stability against the subjectivity, a sensitivity-analysis was used although the decision-makers did consult with experts before selection [42,43]. In particular, a sensitivity-analysis was accompanied by entering different elements' and sub-elements' weights as described in Table 6, making six different implementations. Thus, it is possible to present different classes of correlations among the elements combined by properly choosing the weighting vector. Finally, it computes the suitability weight in multi-criteria decision-makings problems on the basis of the grading scale used for the suitability index is a common ranking scale 0 to 1 as described in Equation (5) [34]

$$SI_i = \sum_{j=1}^{n} w_i x_{ij} \tag{5}$$

Table 6. Elements weights' combination for the sensitivity-analysis.

Implementation	Science-Education	Sustainable-Development	Flipped-E-Learning	Technology-Infrastructure
I. Equal weights to elements	0.250	0.250	0.250	0.250
II. Priority to science-education	0.500	0.167	0.167	0.167
III. Priority to sustainable-development	0.167	0.500	0.167	0.167
IV. Priority to flipped-e-learning	0.167	0.167	0.500	0.167
V. Priority to technology-infrastructure	0.167	0.167	0.167	0.500
VI. Priority to decision-makers	0.120	0.540	0.070	0.250

3. Results and Discussion

Through MCDA-FDEMATEL method, the final results attained were presented in terms of by means of WLC and sensitivity-analysis test. As the indicator-based model, the results were taken from the sixteen influences, which were classified into four elements to validate the most important criteria of flipped e-learning systems in sustainable science education for a more long-term learning scheme. Here, the most significant elements are acquired after employing WLC and then are gauged the likelihood for six implementations' sensitivity-analysis (I to VI) and their sub-elements. Therefore, the results reproduced the main patterns and paradigms to reveal a flipped e-learning system through a science education for sustainable development.

3.1. Elements' and Sub-Elements' Results

Figure 4 confirms that their layers of each sub-elements with normalized and standardized values recognized as the suitability index 0 to 1. Together with Tables 1–4, it represents sixteen different sub-elements analysis taking a substantial effect on the entire evaluation procedure tangled with the weighting procedure for this application. Then, the selected elements are sorted into four key elements together with sub-elements, viz. science-education, sustainable-development, flipped-e-learning and technology-infrastructure elements. Sixteen sub-elements are related with the multiplication process, more precisely (1) University program contents; (2) University course contents; (3) University system updates; (4) University professors; (5) Environmental contents; (6) Physical contents; (7) Social contents; (8) Economic contents; (9) Interactivity & help; (10) User interface; (11) ICTs arrangement; (12) Application distribution; (13) Students motivation; (14) Students evaluation; (15)

Distinct programs; and (16) Technology usage. The weighting indices of the intermediate suitability elements are as the follow: 0.120 for science-education; 0.540 for sustainable-development; 0.250 for technology-infrastructure; and 0.070 for flipped-e-learning. Examination on MCDA-FDEMATEL concludes the most important elements of flipped e-learning systems in science education for sustainable development are sustainable-development element and, among them, environmental contents is the most affected variable as a sub-element.

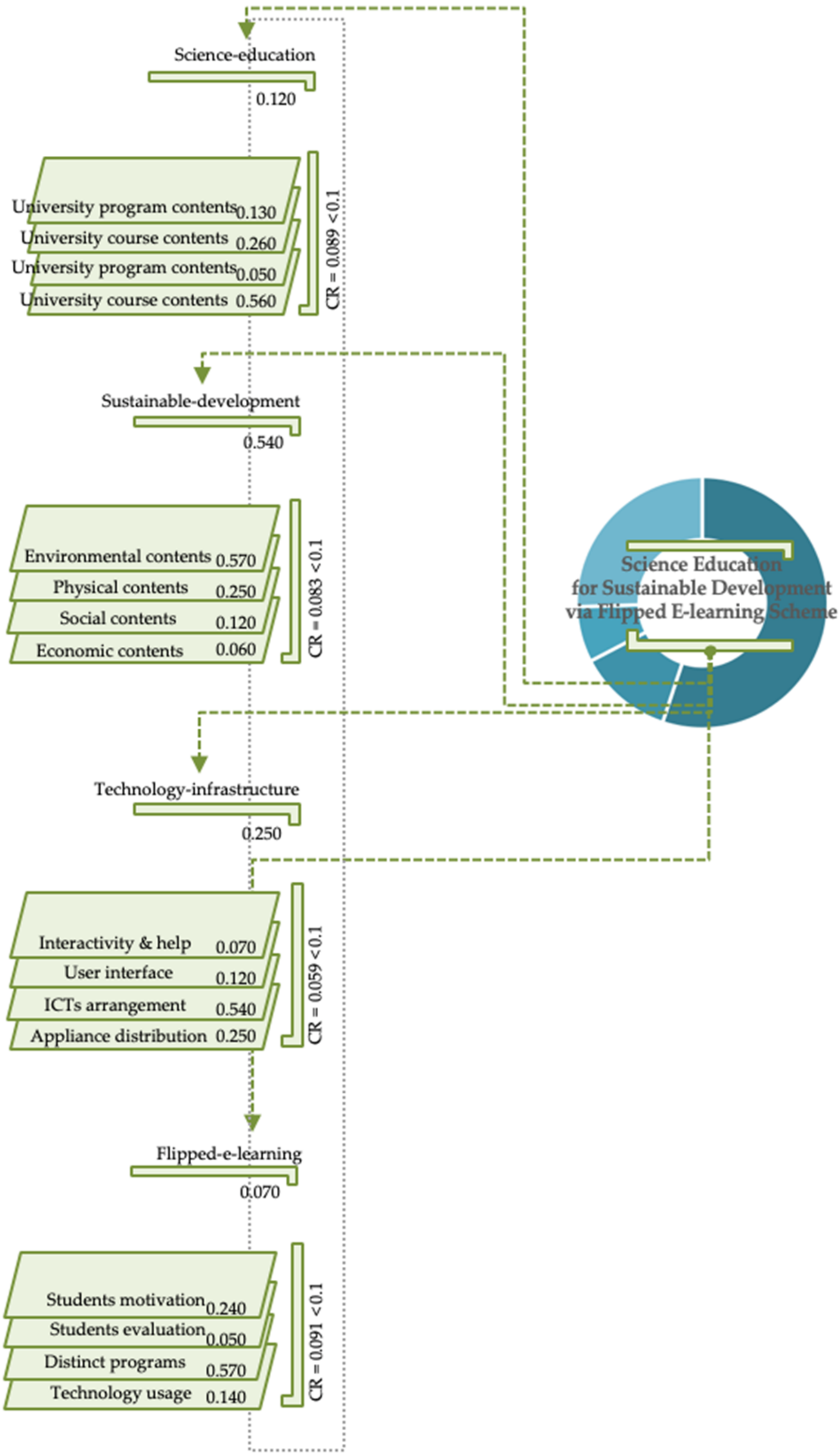

Figure 4. Results of flipped e-learning scheme in sustainability science education.

3.2. Sensitivity-Analysis with WLC and Results

Then, six different implementations, I to VI, produced by the sensitivity-analysis with different weights, were applied to the four elements of a network structure in clusters as shown in Figure 5. Specifically, the six different implementations I to VI indicate the following: I is equal weights for all elements (0.250 for all elements); II is priority to science-education element (0.500, 0.167, 0.167 and 0.167 for four elements science-education, sustainable-development, flipped-e-learning and technology-infrastructure, respectively); III is priority to sustainable-development element (0.167, 0.500, 0.167 and 0.167 for four elements science-education, sustainable-development, flipped-e-learning and technology-infrastructure, respectively); IV is priority to flipped-e-learning element (0.167, 0.167, 0.500 and 0.167 for four elements science-education, sustainable-development, flipped-e-learning and technology-infrastructure, respectively); V is priority to technology-infrastructure element (0167, 0.167, 0.167 and 0.500 for four elements science-education, sustainable-development, flipped-e-learning and technology-infrastructure, respectively); VI is the most important elements on the basis of the decision makers' weightings with professionals discussion (0,120, 0.540, 0.250 and 0.070 for four elements science-education, sustainable-development, flipped-e-learning and technology-infrastructure, respectively) as shown in Table 6. Analysis on MCDA-FDEMATEL produces corresponding results for every influence regardless of the indicators' number used for the evaluation. For most important elements in flipped e-learning systems in sustainable science education, implementation VI was selected (sustainable-development, an element, as 0.540 in the index suitability scale used of 0 to 1) and environmental contents (as a sub-element) with 0.570 index. Moreover, the results of the sensitivity-analysis established the paradigm and pattern shaped by WLC had high dependability and appropriateness.

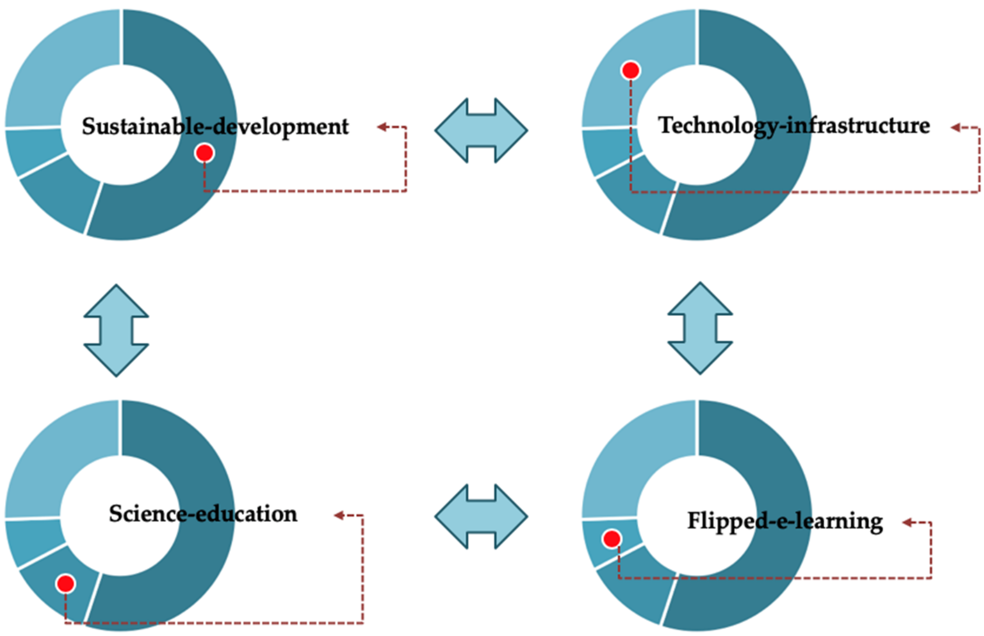

Figure 5. The network structure in clusters of sustainable science education through flipped e-learning system.

3.3. Discussion

The results demonstrate the novel information on the important elements and sub-elements selection of diverse possible impacts in science education for sustainable development through flipped e-learning system. This study specifies an exclusive decision-support method for flipped e-learning system for sustainability science education and various implementations with input from decision-makers, and fills a niche of multi-criteria analyses and for decision-making methods in science e-learning systems behind decision-makers' objective.

The methodology proposed and the results obtained can be used to validate most important elements of science education for sustainable development through flipped e-learning teaching (RQ 1). They can be also achieved with parallel education conditions and existing data required. The results summarize feasible drawbacks and glitches devised from traditional education, with options and activities for science education for sustainable development through flipped e-learning scheme that have not yet been satisfactorily used. The key conclusion conveyed that this method could show the most favorable component in flipped sustainable science e-learning systems for long-term learning programs, as well as specify their initial ranking. Using WLC method, the results display a component method and the highest consistency among them (RQ 2). Also, different patterns and likelihoods generated by WLC and sensitivity-analysis results supported sixteen possible impacts and four elements. Here, we can discover that elements' and sub-elements' ranking is an indicator-based model for the adaptation of flipped e-learning system in sustainability science education and the possibility of the efficient six different implementations (I to VI), which recompensing for their flexible facts (RQ 3). Thus, this method can be a much more seamless and holistic decision-making.

Currently, sustainable science education in a higher education is still an early stage and scarce application exists although they have acted many roles and parts in transforming societies by educating decision-makers. In these demanding and challenging situations, science education in life-long cycle can create a chance of pedagogical niche for flipped e-learning teaching [13–15]. Regardless of previous attempts in flipped e-learning teaching, the lack of literature is still difficult to identify and analyze the elements and sub-elements of flipped e-learning systems in sustainable science education [23–25]. Thus, these operational methods are necessary to adjust sustainable science education of flipped e-learning system with various decision-makers on multiple criteria [26,37,38]. In particular, these operational techniques and methods are barely used in the topic of neither sustainability education nor flipped e-learning systems. Therefore, there are no specific studies to deal with these aspects all together that will give a novel approach as the study proposed.

Consequently, this methodology could be employed in various works to certify most important elements of science education for sustainable development though flipped e-learning scheme with parallel education circumstances and available data necessary. Similarly, it can be used to explain decision problems due to the flexible feature of methodology. In the context of mathematical speaking, professors do not have to apply the mathematical equations by themselves to find out own suitable criteria, but simply they can reflect these suggestions into their programs or university management can integrate some insights from final considerations into staff management and curriculum design. For someone who wants to participate more actively, we are on the way to develop a web-based model that users can introduce their own criteria and weights without knowing the operational and mathematical techniques. Until then, users can reference these elements and sub-elements proposed first and can apply the most suitable criteria for each different aspect and whole aspect for sustainable science education though flipped e-learning systems. Together with the prototype, we also are working on first-hand experiences ourselves and also students and therefore believe this would give more useful information and enhance the interest of more uses.

4. Conclusions

A combined and operational approach was presented to identify and analyze elements for science education for sustainable development with MCDA-FDEMATEL method by flipped e-learning system. The combination of MCDA methods with FDEMATEL technique is applied in an introductory science course, entitled "teaching in matter and energy" that is a compulsory subject of the bachelor degree in Primary Education, Teacher Training College (Spain). With the method proposed, the main elements are collected as science-education, sustainable-development, technology-infrastructure and flipped-e-learning. With WLC and sensitivity-analysis on grading scale of 0 to 1, from less important to more important elements, the final results' analyses with sixteen sub-elements are determined (I to VI implementations) in the context of MCDA-FDEMATEL method. The most important element and sub-element for science education for sustainable development through flipped e-learning scheme are sustainable-development (as an element), VI implementation with 0.540 index, and environmental contents (as a sub-element) with 0.570 index. Moreover, the results of the sensitivity-analysis validated that the paradigm and pattern shaped by WLC had high dependability and appropriateness. Hence, this approach could be used in various works to certify most important science education aspects for sustainable development through flipped e-learning teaching elements and sub-elements with equivalent and comparable education environments.

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