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Preparedness Indicator System for Education 4.0 with FUCOM and Rough Sets

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Abstract: In view of the recent education sectoral transition to Education 4.0 (EDUC4), evaluating the preparedness of higher education institutions (HEIs) for EDUC4 implementation remains a gap in the current literature. Through a comprehensive review, seven criteria were evaluated, namely, human resources, infrastructure, financial, linkages, educational management, learners, and health and environment. This work offers two crucial contributions: (1) the development of an EDUC4 preparedness indicator system and (2) the design of a computational structure that evaluates each indicator and computes an aggregate preparedness level for an HEI. Using the full consistency method (FUCOM) to assign the priority weights of EDUC4 criteria and the rough set theory to capture the ambiguity and imprecision inherent in the measurement, this study offers an aggregate EDUC4 preparedness index to holistically capture the overall preparedness index of an HEI towards EDUC4. An actual case study is presented to demonstrate the applicability of the proposed indicator system. After a thorough evaluation, the results indicate that human resources were the most critical criterion, while health and environment ranked last. Insights obtained from the study provide HEIs with salient information necessary for decision making in various aspects, including the design of targeted policies and the allocation of resources conducive to implementing EDUC4 initiatives. The proposed indicator system can be a valuable tool to guide HEIs in pursuing EDUC4, resulting in a more effective and efficient implementation of this educational paradigm.

Keywords: Education 4.0; preparedness level; indicators; index; full consistency method; rough set theory

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1. Introduction

Higher education is crucial in adapting to new technology-based teaching and learning systems to address social concerns and transitions [1]. Education 4.0 (EDUC4) is considered the recent educational transition, which refers to the adaptation of innovative technologies to the current social environment [2]. The shift towards EDUC4 is being driven by technological progress and industrial growth, which has generated attention worldwide [3]. The primary goal of EDUC4 is to integrate information and communication technologies into university curricula to prepare students for the Fourth Industrial Revolution (4IR) [4], which is centered around smart technology, artificial intelligence (AI), and robotics. To achieve this, universities are developing systems for analyzing and adapting learning based on big data, machine learning, and artificial intelligence for improving and personalizing learning—a key component of EDUC4 [5]. With such advances in technology use, traditional school environments are insufficient for higher and vocational education, and integrating real-world challenges and work–life dynamics into the learning process of the future workforce is a critical agenda [6].

Given its nature, EDUC4 has become a desired learning approach that facilitates alignment with the 4IR to meet labor market demands for customized, flexible, accessible, and skill-based learning [7]. This approach transforms learning through innovative technologies such as immersive technologies, augmented reality, and simulation case studies [4,8]. Within this domain, digital strategies, digital security, and appropriate infrastructure are essential to EDUC4, an important pivot that effectively advances traditional education [9]. Due to the complexity inherent in EDUC4, the interconnectedness of knowledge, industry, and human resources forms its ecosystem [10]. As graduates become labor market responsive with the advent of EDUC4, universities play a pivotal role in promoting the social and cultural transitions required for the 4IR [11].

Various empirical evidence highlights the benefits of EDUC4 within the overarching ecosystem in which it operates. For instance, implementing EDUC4 benefits students' learning process, and is deemed more efficient than conventional learning approaches. It is particularly important in settings where students' learning is personalized, and specific attempts were reported to appropriately design a curriculum for student learning [12]. Due to its inevitability, several countries have sought to integrate EDUC4 into the higher education sector. For example, Malaysia revised its educational and instructional programs to accommodate the unmet 4IR requirements. With this, the Ministry of Higher Education launched an influential reference [13] that aims to develop and enhance individual potential and meet the nation's aspirations within the domain of EDUC4. Similarly, the Ministry of Education in Thailand launched Thailand 4.0, which seeks to promote economic prosperity, social well-being, raising human values, and environmental protection, which the education sector is instrumental in its implementation [14]. Additionally, Singapore started the "Smart Nation" initiative, which promotes the widespread adoption of digital and smart technology across the country [15]. Furthermore, the government of Ghana has enabled digitization as one of its primary policy goals and has recently unveiled several initiatives aiming to create a more digitally accessible public sector and promote efficiency, and the education sector serves as its driver [16]. According to Dzandza [17], seven of the nine libraries in Ghana's public universities have begun digitization efforts. In Korea, Srivani et al. [12] reviewed the impact of EDUC4 chatbots (i.e., bots designed to converse with humans) on Korean university students' foreign language learning. They found that EDUC4 chatbots positively affect Korean learners' learning of a foreign language.

In an attempt to fully embed EDUC4 in higher education institutions (HIEs), the emerging literature identifies some directions on how particular features of EDUC4 can be implemented in HEIs. These include opportunities to implement augmented reality/virtual reality (AR/VR) technologies in the classrooms [18], Internet of Things (IoT) in education with AI-enhanced biosensors and wearables [19,20], and preparing future engineers with the trends of cyber-physical systems [21]. Some works, including those by Stachová et al. [22], Giesenbauer and Müller-Christ [23], and Mourtzis et al. [24], offered a bird's eye view on insights to successfully overcome the challenges in the misalignment of the skill sets learned in schools and those skills needed in the industry. They argue that universities must adopt a multidimensional, multi-networked managerial model to successfully implement EDUC4 (e.g., business cooperation within universities, factory-to-classroom concepts, and external partnerships in the context of employee education). In managing its implementation, myriad policy directions for a successful implementation of EDUC4 have been put forward in various works (e.g., [2,7,23,25]). They contend that the re-alignment of the curriculum must be proactive, the transformation in higher education must be sustainable, and the assessment to overcome the implementation barriers should be consistent in order to gain the benefits of EDUC4.

Despite these advances, from a broader perspective, a clear evaluation tool to assess the preparedness of HEIs for EDUC4 implementation is missing in the current literature. Evaluating the preparedness of HEIs represents an important step in gaining insights into the following: (1) retrospectively assessing how the organization is collectively heading in view of EDUC4, (2) determining the current performance of the organization in the different facets of EDUC4 and building baseline conditions thereafter, (3) identifying critical "hotspots" in the organization for advancing its agenda regarding EDUC4, and (4) comparing the aggregate performance of different HEIs or units within HEIs in their efforts toward EDUC4 implementation. Numerous scholarly works delve into the discussion of the development of indicators and indices that assess the preparedness of HEIs in various contexts. They encompass a wide range of aspects, highlighting the following key areas: a framework for evaluating the long-term environmental sustainability of HEIs [10,26,27], examining preservice teacher preparedness for education for sustainable development [28], knowledge and attitude assessment in disaster preparedness in schools [29], measuring STEM teachers' instructional readiness [30], assessing e-learning platforms for blended learning [31], espousing a robust college readiness agenda [32], the data-driven decision making and big data analytics capability of HEIs [33], and service quality evaluation based on students' satisfaction [34]. The development of indicators or indices is popular due to its criticality in generating important holistic insights into the organization's performance in achieving a desired agenda. These insights offer organizations critical information for decision making regarding policy development, strategy formulation, and resource allocation in progressing toward a goal. In this particular focus in the literature on the EDUC4 agenda, Jamaludin et al. [10] reported initial low-resolution insights into the readiness of HEIs, at least in the ASEAN region. Their work identified 16 indicators spread over personal, curriculum, and pedagogical readiness, 7 for industry readiness, and 6 for humanity readiness. Their findings suggest the following: (1) high personal readiness among stakeholders (e.g., policymakers, lecturers, and students) for EDUC4, (2) high curriculum readiness, with areas attuned to the requirements of EDUC4, (3) low pedagogical readiness, (4) technical, management, and financial readiness of institutions are low, and (5) institutions are significantly not culturally ready for EDUC4. Although these insights provide an overview of the readiness of HEIs in the ASEAN, a number of limitations become apparent. First, having over 263 stakeholders from three groups (i.e., policymakers, lecturers, and students) to accomplish the task of describing HEIs from 10 ASEAN countries can be viewed as an overstretch to its objective and may not thoroughly provide a representative view of all HEIs in the region. Secondly, the limited number of indicators present in their evaluation fails to capture the overarching preparedness level of HEIs. Finally, their approach, as well as those described in other studies, could not provide HEIs with an overview of specific areas that require their attention to leapfrog to EDUC4.

Thus, this work advances on these limitations in the literature and offers a comprehensive evaluation approach by building an indicator system that holistically captures the overall preparedness index of an HEI in its route to EDUC4. It builds upon the prior work of Costan et al. [7] on seven areas HEIs need to examine in their implementation of EDUC4: human resources, infrastructure, financial, linkages, educational management, learners, and health and environment. With these areas, this current work attempts to determine the list of appropriate indicators, each with a measurement scale that decision makers in HEIs can efficiently measure. Subsequently, it offers a systematic approach that aggregates these indicators into a single-valued index that represents the preparedness level of an HEI in its EDUC4 implementation. In assigning the priority weights of EDUC4 areas necessary in the proposed computational framework, the full consistency method (FUCOM) proposed by Pamučar et al. [35] was adopted, as it augments the high cognitive workload requirement of its more popular counterparts, such as the analytic hierarchy process (AHP) and the best-worst method (BWM). Ocampo [36] demonstrated that the weights of attributes derived from FUCOM are highly consistent with those of the more prominent BWM. To capture the ambiguity and imprecision inherent in the measurements, we adopted the rough set theory introduced by Pawlak [37], with the basic concepts and operations presented in Pawlak [38]. While fuzzy set theory and its extensions (e.g., intuitionistic fuzzy sets, spherical fuzzy sets, and linear Diophantine fuzzy sets) are more popular in handling uncertainty in judgments, they require prior information (e.g., membership functions) and assumptions. Rough sets, on the other hand, overcome these limitations by representing imprecise judgments into a concept based on lower and upper approximations [38]. The applications of rough sets for performance evaluation are gaining prominence in the recent literature, including stroke indicators [39], predicting sustainability performance [40], assessing ecological environment sustainability of islands [41], and evaluating potential accidents on a mountain road [42], among others. Zhang et al. [43] reported a review of rough sets and their applications.

An actual case study in a Philippine HEI is presented to demonstrate the applicability of the proposed indicator system. To the best of our knowledge, this study is the first to offer such a system and its corresponding systematic computational framework to evaluate the preparedness of HEIs in their EDUC4 implementation. The main contribution of this work is the development of such an indicator system under a rough set environment that allows HEIs to assess their preparedness efforts in implementing EDUC4 and identifies specific actionable hotspots to leapfrog its progress towards EDUC4. The adoption of rough sets in this work is beneficial for handling uncertainty in the evaluation process while minimizing the cognitive workload of evaluators or decision makers by limiting additional information and assumptions required from them, such as the shape of the membership functions, as in fuzzy sets. The rest of the paper is arranged as follows. Section 2 presents some preliminary concepts of rough set theory and FUCOM. Section 3 illustrates the proposed indicator system for preparedness evaluation in EDUC4 implementation. Section 4 demonstrates an application of the indicator system in an actual case of a Philippine HEI. Some insights and limitations are identified in Section 5. It ends with concluding remarks in Section 6.

2. Preliminaries

This section details the preliminary concepts of rough set theory and the full consistency method.

2.1. Rough Set Theory

The rough set theory that Pawlak [37] put forward serves as a powerful mathematical technique for addressing information and knowledge that are imprecise, inconsistent, and incomplete without any assumptions and additional adjustments. Due to its innovative approach, distinct methodology, and straightforward operation, rough set theory has gained prominence in various fields such as intelligence information processing (e.g., [44,45]), pattern recognition (e.g., [46,47]), knowledge acquisition (e.g., [48]), and decision support analysis (e.g., [49]), among others. Note that this list is not intended to be comprehensive. A survey of the applications of rough set theory can be found elsewhere [43].

Rough set theory enables the representation of ambiguous concepts through a combination of precise concepts determined by two crisp numbers [37], defined as follows.

Definition 1. *Let U be the universe of discourse, Y be an arbitrary object of U, and $A = \{A_1, A_2, \ldots, A_t\}$ be a set of t classes ordered in a manner of $A_1 < A_2 < \ldots < A_t$. Then, $A_q \in A$, $\forall Y \in U$ and $1 \le q \le t$. The lower approximation, upper approximation, and boundary region of A_q, denoted as $\underline{Apr}(A_q)$, $\overline{Apr}(A_q)$, and $Bnd(A_q)$, respectively, are defined as follows.*

$$\underline{Apr}(A_q) = \bigcup\{Y \in U : A(Y) \le A_q\}, \tag{1}$$

$$\overline{Apr}(A_q) = \bigcup\{Y \in U : A(Y) \geq A_q\}, \tag{2}$$

$$Bnd(A_q) = \bigcup\{Y \in U : A(Y) \neq A_q\} = \{Y \in U : A(Y) < A_q\} \cup \{Y \in U : A(Y) > A_q\}. \tag{3}$$

Definition 2. *Any ambiguous class A_q of U can be represented by a rough number $RN(A_q)$ which is defined by its lower and upper limits, denoted as $\underline{Lim}(A_q)$ and $\overline{Lim}(A_q)$, respectively, and defined as follows.*

$$RN(A_q) = [\underline{Lim}(A_q), \overline{Lim}(A_q)], \tag{4}$$

$$\underline{Lim}(A_q) = \frac{1}{\underline{M}} \sum A(X) : X \in \underline{Apr}(A_q), \tag{5}$$

$$\overline{Lim}(A_q) = \frac{1}{\overline{M}} \sum A(X) : X \in \overline{Apr}(A_q). \tag{6}$$

where $\underline{M}$ and $\overline{M}$ are the number of objects included in $\underline{Apr}(A_q)$and $\overline{Apr}(A_q)$, respectively.

Definition 3. *Suppose $RN(A_q)$ and $RN(B_q)$ are two rough numbers, and μ is a nonzero constant; then, the interval arithmetic operations are carried out as follows:*

$$RN(A_q) + RN(B_q) = [\underline{Lim}(A_q) + \underline{Lim}(B_q), \overline{Lim}(A_q) + \overline{Lim}(B_q)] \tag{7}$$

$$RN(A_q) \div RN(B_q) = [\underline{Lim}(A_q) \div \underline{Lim}(B_q), \overline{Lim}(A_q) \div \overline{Lim}(B_q)] \tag{8}$$

$$RN(A_q) \times RN(B_q) = [\underline{Lim}(A_q) \times \underline{Lim}(B_q), \overline{Lim}(A_q) \times \overline{Lim}(B_q)] \tag{9}$$

$$\mu RN(A_q) = [\mu \underline{Lim}(A_q), \mu \overline{Lim}(A_q)] \tag{10}$$

Various aggregation methods for rough numbers are proposed in the literature. For instance, Stević et al. [50] provided a Rough Hamy aggregator for group decision making that simultaneously considers mutual correlations among multiple arguments.

Theorem 1. *Let $RN(\alpha_j) = [\underline{Lim}(\alpha_j), \overline{Lim}(\alpha_j)]$ $(j = 1, 2, \ldots, n)$ represent a set of rough numbers in R. The aggregate rough number can be determined as follows.*

$$\begin{aligned} RNHM\{RN(\alpha_1), RN(\alpha_2), \ldots, RN(\alpha_n)\} &= [\underline{Lim}(\alpha_{RNHM}), \overline{Lim}(\alpha_{RNHM})] \\ &= \left[\frac{\sum_{1 \leq i_1 < \ldots < i_k} \left(\prod_{j=1}^{k} \underline{Lim}(\alpha_{i_j}) \right)^{\frac{1}{k}}}{\binom{n}{k}}, \frac{\sum_{1 \leq i_1 < \ldots < i_k} \left(\prod_{j=1}^{k} \overline{Lim}(\alpha_{i_j}) \right)^{\frac{1}{k}}}{\binom{n}{k}} \right] \end{aligned} \tag{11}$$

where $(i_1, i_2, \ldots, i_k)$ includes all k-tuple combinations of $(1, 2, \ldots, n)$.

2.2. Full Consistency Method

To generate priority weights for a set of predefined attributes, Pamučar et al. [35] developed the FUCOM approach as a comparison-based multi-attribute decision making (MADM) method that incorporates some of the features of the AHP and BWM. Two well-known categories of constraints are used by FUCOM: (1) mathematical transitivity and (2) consistency in the relationships between attribute weights and the relative priorities of the attributes. The deviation from the full consistency (DFC) metric associated with these two constraint groups is optimized to establish the distribution of the priority weights of the attributes. Such metric measures the reliability of the resulting attribute weights.

The major takeaway of FUCOM over AHP and BWM is the minimal number of pairwise comparisons that decision makers must make, reducing their mental effort throughout the judgment–elicitation process. A classic MADM problem can be solved with FUCOM when the goal–criteria–alternative hierarchical structure is employed to produce the weights of the attributes and the priority weights of the alternatives for each attribute.

The integration of FUCOM has been widely used in prioritizing transportation demand management measures (e.g., [51,52]), public sector supply chain [53], evaluating the sustainability of farm tourism sites [36], determining drivers for investing in cryptocurrencies [54], and landfill site selection [55], among others. The computational step of FUCOM was introduced by Pamučar et al. [35]. Here, the word "criteria" refers to representational standards. They can be referred to as any collection of homogeneous elements in general (e.g., attributes, factors).

Step 1: Consider the collection $C = \{c_1, c_2, \ldots, c_n\}$ of decision criteria. Rank them in order of their level of importance. Based on this step, the following illustrates the ranking of the set of criteria based on their estimated weights:

$$c_{j(1)} > c_{j(2)} > \ldots > c_{j(s)} \quad (12)$$

where s denotes the rank of a criterion j, where $j \neq j'$ and $j, j' = 1, \ldots, n$. Whenever j and j' are perceived to have equal weights, then $c_{j(s)} = c_{j'(s)}$.

Step 2: Generate the comparative priorities $\left\{\varphi_{s/(s+1)}, s = 1, 2, \ldots, n\right\}$, such that the vector of relative priorities of the criteria, represented by Φ, is obtained as follows:

$$\Phi = \left(\varphi_{1/2}, \varphi_{2/3}, \ldots, \varphi_{s/(s+1)}\right) \quad (13)$$

where $\varphi_{s/(s+1)}$ denotes the priority ratio of the criterion $c_{j(s)}$ over the criterion $c_{j(s+1)}$. By construction, $\varphi_{s/(s+1)} \geq 1$.

Step 3: Obtain the final weight vector of the evaluation criteria, denoted as $\{w_j : j = 1, \ldots, n\}$. In generating the criteria weights, the following conditions must be satisfied: (1) the ratio of the weights of two criteria is equal to their comparative priority $\varphi_{s/(s+1)}$, specified in Step 2. Symbolically:

$$\frac{w_s}{w_{s+1}} = \varphi_{s/(s+1)} \quad (14)$$

In addition, (2) the final weight values must also meet the transitivity condition, i.e., $\varphi_{s/(s+1)} \times \varphi_{(s+1)/(s+2)} = \varphi_{s/(s+2)}$. Since $\varphi_{s/(s+1)} = \frac{w_s}{w_{s+1}}$ and $\varphi_{(s+1)/(s+2)} = \frac{w_{s+1}}{w_{s+2}}$, then $\frac{w_s}{w_{s+1}} \times \frac{w_{s+1}}{w_{s+2}} = \frac{w_s}{w_{s+2}}$. Thus, the following condition is required:

$$\frac{w_s}{w_{s+2}} = \varphi_{s/(s+1)} \times \varphi_{(s+1)/(s+2)} \quad (15)$$

To attain full consistency, these two conditions must be met. As such, the weight assignments $\{w_j : j = 1, \ldots, n\}$ must satisfy $\left|\frac{w_s}{w_{s+1}} - \varphi_{s/(s+1)}\right| \leq \chi$ and $\left|\frac{w_s}{w_{s+2}} - \varphi_{s/(s+1)} \times \varphi_{(s+1)/(s+2)}\right| \leq \chi$, where χ represents the DFC. Thus, obtaining the weight vector $\left(w_j : j = 1, \ldots, n\right)^T$ requires solving the following optimization problem:

$$\min \chi \quad (16)$$

subject to:

$$\left|\frac{w_s}{w_{s+1}} - \varphi_{s/(s+1)}\right| \leq \chi, \ \forall s$$

$$\left|\frac{w_s}{w_{s+2}} - \varphi_{s/(s+1)} \times \varphi_{(s+1)/(s+2)}\right| \leq \chi, \ \forall s$$

$$\sum_{j=1}^{n} w_j = 1\ w_j > 0,\ \forall j.$$

3. Development of the Proposed EDUC4 Preparedness Indicator System

The process of generating the set of indicators involves four distinct steps. Firstly, the areas or themes of EDUC4 implementation were identified based on a previously published systematic literature review by Costan et al. [7]. For convention, we treat these areas as the upper-level criteria in the proposed indicator system. These criteria, including human resources, infrastructure, financial, linkages, educational management, learners, and health and environment, are recognized by Costan et al. [7] as dimensions associated with known implementation barriers in operationalizing EDUC4 in HEIs. Secondly, preliminary indicators specific to each theme were formulated based on the results of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement outlined in Costan et al. [7]. Their systematic literature review identified 30 articles from which they established the themes of EDUC4 implementation. After obtaining the references, they were thoroughly examined with the intention of capturing possible indicators of a specific criterion. The initial inclusion rule is that an indicator must be quantifiable, such as those expressed through percentages, actual data, or espousing a minimum threshold requirement. They were systematically organized into different sub-criteria of the seven previously identified criteria.

In order to create a more robust identification of indicators in each criterion, the third step involved identifying the overlapping and irrelevant indicators based on the core components of EDUC4, as illustrated by Miranda et al. [2]. These components highlighted nine essential concepts, such as (A1) heutagogical, peeragogical, and cybergogical; (A2) mentorship, collaboration, and reference; (A3) active, independent, and trajectory designing; (A4) mostly student-centered education; (A5) training soft and hard key competencies; (A6) utilizing ICT tools and platforms powered by IoT; (A7) based on online sources, (A8) cyber and physical spaces, shared and individual; and (A9) connectivity, digitalization, and virtualization. This list forms the overarching agenda of EDUC4 that separates itself from the previous revolutions in education. This step ensures the relevance of all indicators in all components of EDUC4, an important direction to not over-generate the list of indicators in the proposed indicator system. Finally, the indicators were augmented and finalized through brainstorming and focus group discussions (FGDs) in the fourth and final step. This step was implemented with an expert group of eight members with extensive backgrounds in the education sector and university core processes. They all hold Ph.D. degrees in education, administration, governance, and research management. Their experiences range from 19 to 26 years, with an average of 22 years. The task of the expert group was to ensure the comprehensiveness and relevance of the indicators in each criterion. During the FGD, brainstorming, and augmentation efforts to establish a relevant indicator system, initially identified items were consolidated and evaluated based on redundancy and relevance. Figure 1 illustrates the steps in generating the list of final indicators relevant to EDUC4 implementation.

Results show that out of 129 identified indicators obtained from the review of the literature, 31 were considered redundant and irrelevant indicators to the core components of EDUC4 and were consequently removed from further analysis. At the same time, seven indicators were added during the augmentation process. The summary of the transitions of indicator lists across the steps in Figure 1 is found in Table 1. To provide a clear overview of the process, for instance, the indicators identified to measure the infrastructure for online learning (C22) and other infrastructure in line with the EDUC4 implementation (C23), internet connectivity was found to be redundant. Thus, the measurement derived from this indicator was revised to cut across both criteria. The final list of 105 indicators is presented in Table A1. By adopting these indicators and engaging key stakeholders, universities can better align their teaching and learning practices with the demands of the 4IR and EDUC4 framework.

Table 1. Generation of indicators per criterion.

Code	Criterion Description	No. of Indicators after Step 2 (A)	No. of Indicators after Step 3 (B)	No. of Indicators after Step 4 (C)	Final Indicators (A) − (B) + (C)
C1	Human resources	22	16	0	6
C2	Infrastructure				
C21	ICT infrastructure	6	0	0	6
C22	Infrastructure for online learning	7	0	0	7
C23	Other infrastructure relevant to EDUC4 implementation	5	0	0	5
C24	Science laboratories	6	0	0	6
C25	Library 4.0	13	0	0	13
C3	Financial				
C31	Faculty capability enhancement	2	0	0	2
C32	Technology and infrastructure alignment	3	0	0	3
C33	Physical facilities and supplies	2	0	1	3
C4	Linkages				
C41	Education and training	8	0	1	9
C42	Collaboration	7	1	0	6
C5	Educational management				
C51	Educational leaders' commitment	6	2	0	4
C52	Relationship with stakeholders	5	3	0	2
C53	Management support toward EDUC4 implementation	7	4	0	3
C6	Learners				
C61	Learners' experience	6	0	0	6
C62	Teaching and learning experience	5	0	0	5
C63	Students and curriculum design	4	0	1	5
C64	Technology-based monitoring of the system of student performance	3	1	0	2
C65	Student service	1	0	0	1
C7	Health and Environment				
C71	Screen viewing	1	0	0	1
C72	Physical risk	1	0	0	1
C73	Emotional risk	1	0	0	1
C74	Cognitive risk	1	0	0	1
C75	Time constraints for material preparation	1	0	0	1
C76	Classroom layout	6	4	0	2
C77	E-waste management	0	0	4	4
TOTAL		129	31	7	105

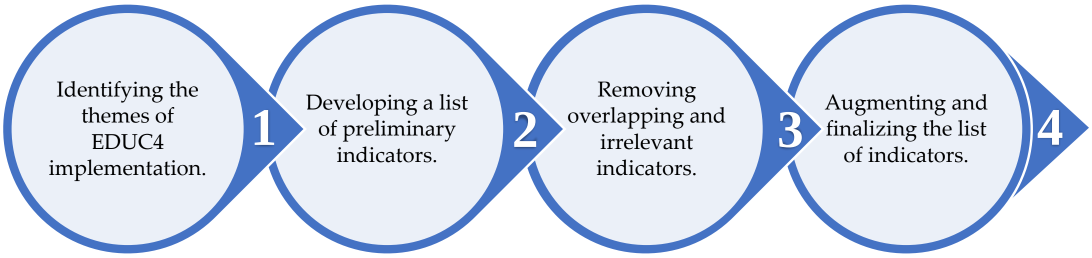

Figure 1. The process of generating the list of indicators.

3.1. Case Study Background

To demonstrate the applicability of the proposed indicator system, a case in a state university in the Philippines, i.e., Cebu Technological University (CTU), is presented in this work. Note that the case study considered only assumes one of the primary functions of the proposed indicator system, which is to evaluate the aggregate performance of an HEI and identify certain "hotspots". CTU is a state-funded HEI in central Philippines. The Board of Regents is the highest governing authority of CTU, chaired by a Commissioner of the Philippine Commission on Higher Education, and the university president sits as the Vice-Chair of the board. Five Vice Presidents assist the university president in carrying out the university's core functions, including instruction, research, extension, and production. The budget utilized by the university is mainly taken from the subsidies granted by the Philippine government through the annual release of the General Appropriations Act and from other incomes granted by several institutions, locally and internationally. Recently, CTU has strengthened its endeavor to become a premier university and forged various partnerships with universities abroad. It has nine external campuses, a main campus, and extension campuses. CTU-Danao is one of the external campuses of CTU, located in the northern part of Cebu. As a fast-growing institution, it has implemented massive improvements in its physical and technological infrastructure. The campus envisions leading the educational community by upgrading its facilities to improve the quality of instruction and thereby producing world-class graduates by adhering to the intricacies of EDUC4. Concerted efforts of various campus departments are underway toward a holistic approach to developing a campus that is EDUC4-ready. With its current EDUC4 trajectory, it is vital to determine its preparedness to realign efforts, human and financial resources, and development programs for full EDU4 implementation.

3.2. Application of the Proposed Methodology

This section details the application of the proposed methodology in the case of CTU-Danao. Figure 2 features the proposed methodology, which comprises two phases. Phase I utilizes rough FUCOM in obtaining the rough weight of each criterion, while Phase II obtains the index that describes the degree of preparedness of CTU-Danao in EDUC4 implementation.

Phase I. Generate criteria weights using rough-FUCOM.

Step 1. Establish the set of evaluation criteria $C = \left\{c_1, \ldots, c_f, \ldots, c_F\right\}$ to measure the preparedness of an institution for EDUC4 implementation. The evaluation criteria, namely, (1) human resources, (2) infrastructure, (3) financial, (4) linkages, (5) educational management, (6) learners, and (7) health and environment, were identified from Costan et al. [7]. In our work, a group of experts $(k = 1, 2, \ldots, K)$ was asked to elicit judgments on the evaluation criteria. The criteria were ranked according to their degree of significance to EDUC4 implementation.

Step 2. Construct the vector of the comparative priorities of the criteria for each expert. Arrange the evaluation criteria in decreasing level of importance. In our work, the expert group was again asked to elicit their judgments on the comparative priorities of the criteria set.

Step 3. Obtain the priority weights of the criteria. The priority weights of the evaluation criteria were obtained using Equation (16).

Step 4. Transform the priority weights into rough numbers. Assume that W is a set containing all the weight coefficients carried out by experts' evaluations, and w_x is an arbitrary object of W. A set of weight coefficients $\omega = \left(w_1^k, w_2^k, \ldots, w_F^k\right)$ are obtained from Step 1 to Step 3 and arranged in a manner $w_1^k < w_2^k < \ldots < w_F^k$; then, $w_j^k \in \omega, \forall w_x \in W$. The lower approximation $\underline{Apr}\left(w_j^k\right)$ and upper approximation $\overline{Apr}\left(w_j^k\right)$ are obtained using Equations (1) and (2), respectively. Then the rough number of $RN\left(w_j^k\right) = \left[\underline{Lim}\left(w_j^k\right), \overline{Lim}\left(w_j^k\right)\right]$ is determined following Equations (5) and (6). The optimal values of the rough weight coefficients of the criteria are calculated using Equation (17). The resulting rough weight coefficients are presented in Table 2.

$$RN(w_j) = \begin{cases} \underline{Lim}(w_j) = \frac{1}{K}\sum_{k=1}^{K} \underline{Lim}\left(w_j^k\right) \\ \overline{Lim}(w_j) = \frac{1}{K}\sum_{k=1}^{K} \overline{Lim}\left(w_j^k\right) \end{cases} \quad (17)$$

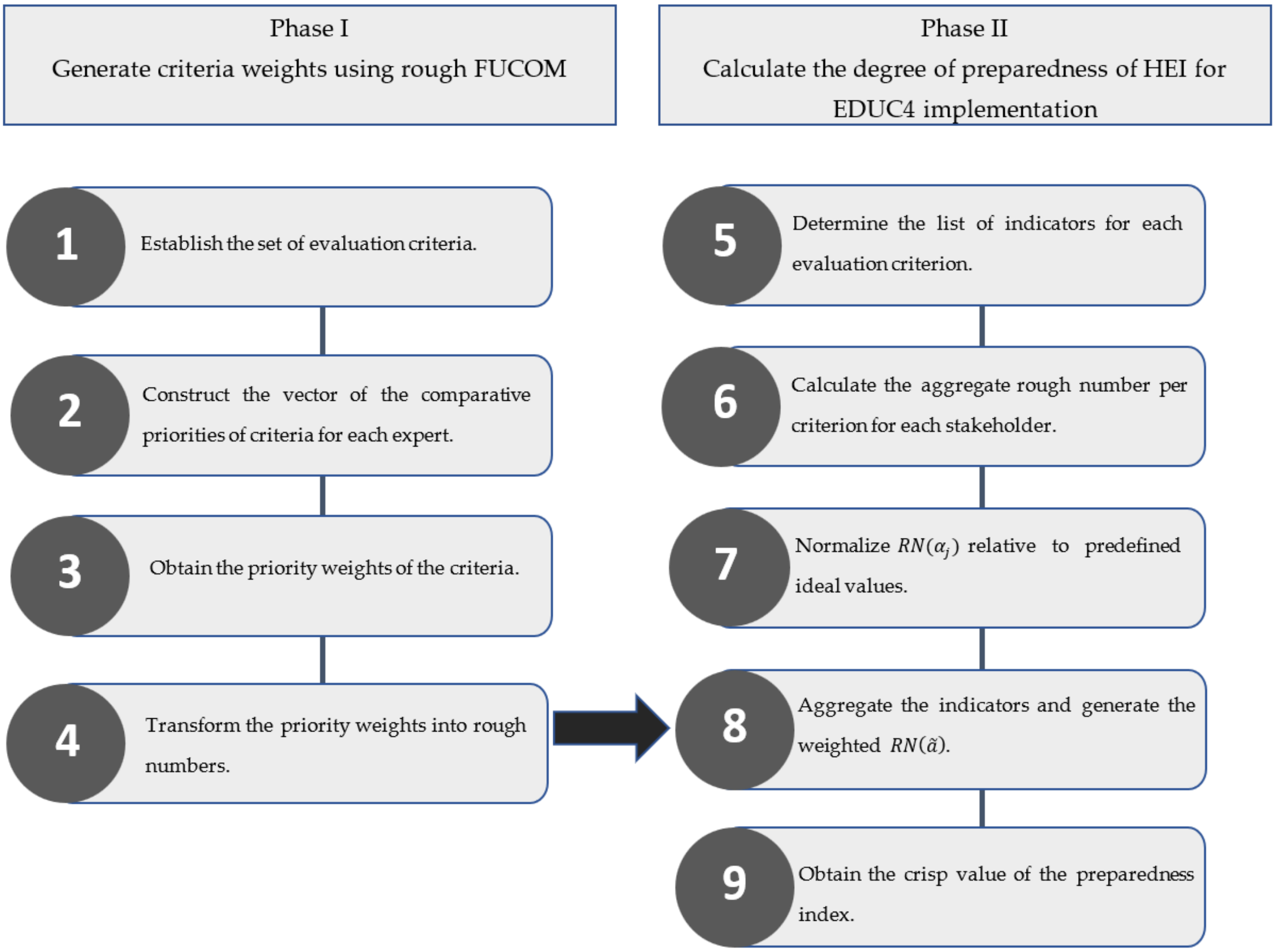

Figure 2. The proposed framework for adopting the proposed indicator system.

Phase II. Calculate the degree of preparedness of CTU-Danao for EDUC4 implementation.

Step 5. Determine the list of indicators for each evaluation criterion. A literature survey was conducted to gather the initial list of criterion indicators. The process described in Figure 1 was implemented to obtain a final set of indicators. The same group of experts who conducted Step 1 was involved in the discussion. The outcome of the discussion resulted in the list of indicators presented in Table A1. These indicators were then sorted according to the stakeholders associated with them. The following are the identified stakeholders that have a significant role in EDUC4 implementation: human resource office, faculty, dean, IT manager, registrar, Vice-President for Administration, librarian, finance office, OJT coordinators, Research and Development (R&D) office, internalization office, community extension office, student affairs office, educational leaders, Vice-President for Academics, secretary of the top management, campus administrator, evaluators, and students. Separate survey questionnaires were created for each stakeholder. Table A2 also shows each indicator and stakeholder's specific measurement scale and sampling plan.

Step 6. Calculate the aggregate rough number per criterion for each stakeholder. Let A be a set of all evaluations elicited by L $(l = 1, 2, \ldots, L)$ survey participants based on a set of n indicators characterizing fth criterion and α_x be an arbitrary object of A. A set of evaluations $\alpha = \left(\alpha_1^l,\ \alpha_2^l, \ldots, \alpha_n^l\right)$ elicited by lth respondent are arranged in a manner $\alpha_1^l < \alpha_2^l < \ldots < \alpha_n^l$ then $\alpha_j^l \in \omega, \forall \alpha_x \in A$. The lower approximations $\underline{Apr}\left(a_j^l\right)$ and upper approximation $\overline{Apr}\left(a_j^l\right)$ are obtained using Equations (1) and (2), respectively. Then, the rough number of $RN\left(a_n^l\right) = \left[\underline{Lim}\left(a_j^l\right), \overline{Lim}\left(a_j^l\right)\right]$ is determined following Equation (5) and Equation (6). Then the aggregate rough numbers $RN(\alpha_j)$ are obtained using the expression: $RN(\alpha_j) = \begin{cases} \underline{Lim}(\alpha_j) = \frac{1}{L}\sum_{l=1}^{L} \underline{Lim}\left(a_j^l\right) \\ \overline{Lim}(\alpha_j) = \frac{1}{L}\sum_{l=1}^{L} \overline{Lim}\left(a_j^l\right) \end{cases}$. The resulting aggregate rough numbers are presented in Table A2.

Step 7. Normalize $RN(\alpha_j)$ relative to predefined ideal values. A series of interviews with the concerned stakeholders were carried out to finalize quantifiable measures of the existing practices of the case university and the minimum standard based on statutory and regulatory requirements. Other standards were determined based on the emerging literature (e.g., [20,56,57]). The group of experts provided a set of ideal rough values per nth indicator, denoted as $RN\left(\alpha_j^*\right) = \left[\underline{Lim}\left(a_j^*\right), \overline{Lim}\left(a_j^*\right)\right]$ and defined as follows.

For maximization criteria:

$$RN(\widetilde{\alpha}_j) = \begin{cases} \underline{Lim}(\widetilde{\alpha}_j) = \underline{Lim}(\alpha_j) \div \overline{Lim}\left(a_j^*\right) \\ \overline{Lim}(\widetilde{\alpha}_j) = \overline{Lim}(\alpha_j) \div \underline{Lim}\left(a_j^*\right) \end{cases} \tag{18}$$

For minimization criteria:

$$RN(\widetilde{\alpha}_j) = \begin{cases} \underline{Lim}(\widetilde{\alpha}_j) = \underline{Lim}\left(a_j^*\right) \div \overline{Lim}(\alpha_j) \\ \overline{Lim}(\widetilde{\alpha}_j) = \overline{Lim}\left(a_j^*\right) \div \underline{Lim}(\alpha_j) \end{cases} \tag{19}$$

Step 8. Aggregate the indicators and generate the weighted $RN(\widetilde{\alpha})$. The $RN(\widetilde{\alpha}_j)$, where $j = (1,\ 2, \ldots,\ n)$, are aggregated using Equation (11). Then, the weighted $RN(\widetilde{\alpha}_j)$ is obtained through Equation (20).

$$RN(\hat{\alpha}_j) = RN(\widetilde{\alpha}_j) \times RN(w_j) = \begin{cases} \underline{Lim}(\widetilde{\alpha}_j) \times \underline{Lim}(w_j) \\ \overline{Lim}(\widetilde{\alpha}_j) \times \overline{Lim}(w_j) \end{cases} \tag{20}$$

where $RN(w_j)$ is the rough weight coefficients obtained from *Phase I*.

Step 9. Obtain the crisp value of the preparedness index. The weighted $RN(\hat{\alpha}_j)$ is transformed into crisp $\hat{\alpha}_j$ using Equation (21). The crisp scores are normalized using Equation (22). The results are presented in Table 3.

$$\hat{\alpha}_j = \frac{\underline{Lim}(\hat{\alpha}_j) \times (1 - \overline{Lim}(\hat{\alpha}_j)) + \overline{Lim}(\hat{\alpha}_j) \times \overline{Lim}(\hat{\alpha}_j)}{1 - \underline{Lim}(\hat{\alpha}_j) + Lim(\hat{\alpha}_j)} \tag{21}$$

$$\widetilde{a}_j = \frac{\hat{\alpha}_j}{\sum_{j=1}^{n} \hat{\alpha}_j} \tag{22}$$

Table 2. Rough priority weights of the criteria.

Criteria	Rough Weights
Human resources	[0.1167, 0.1545]
Infrastructure	[0.1545, 0.1684]
Financial	[0.1409, 0.1680]
Linkages	[0.1106, 0.1680]
Educational management	[0.1091, 0.1466]
Learners	[0.1191, 0.1540]
Health and environment	[0.1063, 0.1568]

Table 3. Rough and normalized crisp preparedness index per criterion.

Criteria	Rough Preparedness Index	Normalized Crisp Preparedness Index
Human resource	[0.6991, 0.8589]	0.2500
Infrastructure	[0.2654, 0.2667]	0.1169
Financial	[0.3434, 0.3545]	0.1393
Linkages	[0.4968, 0.7411]	0.1790
Educational management	[0.3515, 0.4011]	0.1122
Learners	[0.4976, 0.6891]	0.1817
Health and Environment	[0.0635, 0.1624]	0.0205

The single-valued aggregate EDUC4 preparedness index (EPI) for the case university is obtained as follows:

$$RN\left(\widetilde{\alpha}_j^w\right) = RN\left(w_j\right) \times RN\left(\hat{\alpha}_j\right) \tag{23}$$

$$a_j^w = \frac{\underline{Lim}\left(\widetilde{\alpha}_j^w\right) \times \left(1 - \overline{Lim}\left(\widetilde{\alpha}_j^w\right)\right) + \overline{Lim}\left(\widetilde{\alpha}_j^w\right) \times \overline{Lim}\left(\widetilde{\alpha}_j^w\right)}{1 - \underline{Lim}\left(\widetilde{\alpha}_j^w\right) + \overline{Lim}\left(\widetilde{\alpha}_j^w\right)} \tag{24}$$

$$w_j = \frac{\underline{Lim}\left(w_j\right) \times \left(1 - \overline{Lim}\left(w_j\right)\right) + \overline{Lim}\left(w_j\right) \times \overline{Lim}\left(w_j\right)}{1 - \underline{Lim}\left(w_j\right) + \overline{Lim}\left(w_j\right)} \tag{25}$$

$$EPI = \sum_{j=1}^{n} a_j^w / \sum_{j=1}^{n} w_j \tag{26}$$

Thus, the case university has an $EPI = 0.393$.

4. Sensitivity and Comparative Analysis

Sensitivity analysis was carried out to determine the extent to which the most influential criterion performance affects the ranking of the entire criteria set. The analysis was performed by changing the criteria weights to determine the model's sensitivity to weight changes. For this case, seven scenarios were formed in which the criteria weights were modeled. Scenarios were defined based on the weights, whereas the weights were assigned based on a certain criterion's domination. For instance, in the first scenario, human resources (C1) criterion dominates the ideal weights of (0.70, 0.70), and other criteria were assigned (0.05, 0.05). Table 4 presents the weights based on the domination of a certain criterion for seven scenarios.

Table 4. Sensitivity weights based on the domination of an identified criterion.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
C1	[0.7000, 0.7000]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]
C2	[0.0500, 0.0500]	[0.7000, 0.7000]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]
C3	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.7000, 0.7000]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]
C4	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.7000, 0.7000]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]
C5	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.7000, 0.7000]	[0.0500, 0.0500]	[0.0500, 0.0500]
C6	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.7000, 0.7000]	[0.0500, 0.0500]
C7	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.0500, 0.0500]	[0.7000, 0.7000]

Figure 3 presents the results of the comparative analysis after assigning priority weight to each criterion. It shows that the changes in the criteria ranking are observed to be directly dependent on the dominating criterion. For example, in the first scenario, assigning ideal weights on C1 generates an outcome that incurs utmost prioritization on the same criterion, with a notable increase of at least triple the original amount. The same behavior is evident in the succeeding scenarios where the dominating criterion takes the most priority in the ranking of the preparedness index. This remark is even observed with C7, originally having the lowest local preparedness index. Additionally, all the other criteria aside from the dominating criterion retain their order from the original hierarchy of the criteria. Figure 3 also shows that if all the weights of the dominating criteria from all the scenarios are to be collated, the result reflects the original ranking or index scores. This observation is consistent with the behavior of the remaining criteria, apart from the dominating criterion, which remain in the same order for all the scenarios. The findings in this analysis demonstrate that assigning priority criteria weights is crucial as it greatly influences the resulting aggregate index.

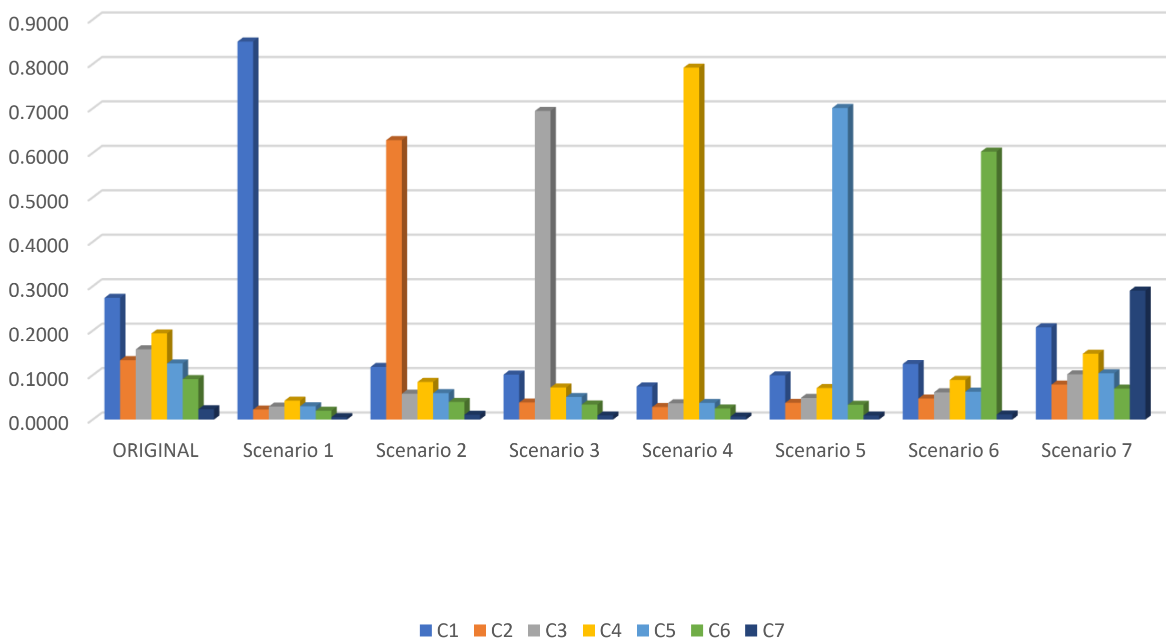

Figure 3. Ranking of results from the sensitivity analysis.

5. Results and Discussion

Given the overall results, an $EPI = 0.393$ out of 1.000 suggests that the case university still requires extensive effort to be prepared to implement EDUC4. This score indicates significant gaps in the university's current infrastructure, initiatives, and teaching–learning processes that must be addressed before it can fully embrace the intricacies of EDUC4. Regarding impact, the ranking of the identified criteria shows that infrastructure, financial resources, and learners emerge as the top three factors the case university must focus on to improve and implement EDUC4 effectively. These findings can be explained in parallel with the theoretical standpoint of the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2). This suggests that the adoption and use of new technologies (e.g., cyber-physical systems, smart classrooms, AR/VR) are influenced by several factors, including facilitating conditions, social influence, and motivation [58]. Infrastructure and financial resources can be seen as facilitating conditions that can influence the adoption and use of new educational technologies [9]. The lack of infrastructure and financial resources can limit the availability and accessibility of educational technologies, prompting barriers to their use [59]. Learners who perceive that other students are using and benefiting from new educational technologies and find them enjoyable and pleasurable are more likely to adopt and use them.

Several strategies can be considered to improve the implementation of EDUC4. For instance, the university can secure funding to support infrastructure development and facilities improvement through various sources, such as government grants, industry partnerships, and international collaborations [60]. More attention must be paid to ensure that the infrastructure and technology systems are in place, which can be achieved through proper planning, implementation, and continuous evaluation. Furthermore, the university can adopt learner-centered approaches to improve the degree of use of EDUC4 tools such as cloud computing, AI, and IoT, among others. This direction is highly relevant, especially since the results show that learners, although affected by the health and environment factor, have high screen time, indicating that if addressed, the utilization of EDUC4 technologies would help optimize the implementation. Hence, providing personalized and interactive learning experiences that engage the students using adaptive learning technologies and project-based learning approaches could facilitate the rapid adoption of EDUC4. On the other hand, faculty development and training programs can be established to equip the university faculty with the skills and knowledge needed to use these new technologies and practices effectively.

In light of these findings, it could be deduced that improving infrastructure, accessing financial resources, and employing learner-centered approaches are critical directions to successfully implement EDUC4. These initiatives require careful planning, implementation, and evaluation, which can be supported through funding, partnerships, and collaborations with other institutions and stakeholders. By implementing them, the case university can effectively embrace the benefits of EDUC4 and contribute to advancing education, especially in the developing economy. Overall, the proposed preparedness indicator system can effectively measure in an encompassing view the preparedness of HEIs in their direction of implementing the EDUC4 as a disruptive paradigm in education. The proposed system considers the overarching scope of EDUC4, and the computational procedure allows a measurable metric that can determine the overall preparedness level of a university. The system offers two general uses: (1) it can be used to compare the overall individual EDUC4 preparedness levels of universities or units within a university, and (2) it can be used to identify hotspots or areas within the university that require greater attention and investment. The first function allows the ranking of universities or their units for the performance evaluation or inputs to reward systems. The second function provides information for resource allocation decisions and long-range planning of universities.

6. Conclusions

This work offers a comprehensive evaluation approach that aims to capture the overall preparedness index of an HEI in its implementation of EDUC4. The proposed indicator system considers a range of criteria that impact an HEI's preparedness, which allows for a more accurate and in-depth assessment of its readiness for EDUC4. This comprehensive approach can help HEIs identify areas where they need to improve, thus facilitating the development of targeted strategies for the successful implementation of EDUC4. Seven criteria became benchmarks in the proposed indicator system: human resources, infrastructure, financial, linkages, educational management, learners, and health and environment.

In each criterion, a set of indicators were identified through a rigorous four-step process. A total of 105 indicators were identified, each with a quantifiable measure designed to be accessible by HEIs. To capture the relative importance of the seven criteria and the inherent uncertainty of the evaluation process, FUCOM and rough set theory were used. FUCOM assigns the priority weights of the criteria, while rough sets handle the uncertainty of the computational process. To demonstrate its application, an actual case study in a state university in the Philippines was implemented.

After a rigorous evaluation of the indicator system within the proposed computational framework, results indicate that human resources are considered top tier, while infrastructure, financial resources, and learners are among the top three that need re-evaluation for EDUC4 implementation. It is noteworthy that technological processes and industrial growth drive EDUC4; however, it is not apparent from the findings. This may imply that the case university is unprepared to implement the educational paradigm. Inadequate infrastructure and financial resources can act as barriers to using educational technologies, limiting their availability and accessibility. Educational technologies may not function optimally without proper infrastructure, such as reliable Internet connectivity and access to appropriate hardware and software. Moreover, the scarcity of financial resources makes it difficult for institutions to acquire and maintain the necessary technologies. These barriers can impact the quality of education, particularly in areas with limited educational resources. Thus, addressing these infrastructure and financial limitations is crucial in ensuring equitable access to educational technologies and ultimately improving educational outcomes, especially during the transition.

This study has limitations that require future consideration. First, the domain literature on EDUC4 is evolving, and some criteria and their indicators may not be identifiable at present. However, future real-life conditions and scenarios require additional consideration of future criteria that are not yet straightforward. At present, the nexus between disaster risk management and EDUC4 is not yet fully understood. Future work may consider other criteria and indicators in the computational framework of the indicator system in order to provide a more holistic overview of EDUC4. Secondly, the measurement for each indicator may be enhanced to translate subjective 7-point scale measures to more measurable indicators. This agenda is a rich resource for future work. Identifying the ideal values for indicators may contain idiosyncrasies in view of the background of the expert group. Thus, future research may consider re-evaluation of indicator measures. Lastly, other emerging priority allocation tools aside from FUCOM may be used to assign the priority weights of the criteria. In addition, the use of fuzzy sets and their extensions may be considered a framework for handling uncertainty in decision making within the computational structure of the EDUC4 preparedness indicator system.

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Appendix A

Table A1. List of indicators per criterion.

			Criterion	Mapping of Components A1	A2	A3	A4	A5	A6	A7	A8	A9
C1			**Human resources**									
	C11		Percentage of educators who attended relevant EDUC4 training and seminars	X	X		X	X	X	X		X
	C12		Degree of educators' utilization of innovative pedagogical approaches (e.g., problem-based, project-based, game-based, and action-oriented)	X	X	X	X	X	X	X	X	X
	C13		Degree of educators' utilization of innovative assessment methods	X	X	X	X	X	X	X	X	X
	C14		Percentage of educators who utilize digital technologies for effective teaching and learning process	X	X	X	X	X	X	X	X	X
	C15		Degree of the utilization of hybrid teaching modality	X	X	X	X	X	X	X	X	X
	C16		Degree of educators' competence in designing digital educational materials (e.g., audio clips, video content/presentations, digital portfolios, social networking, and websites) for learning enhancement	X	X	X	X	X	X	X	X	X
C2			**Infrastructure**									
	C21		ICT Infrastructure									
		C211	Computer units to student ratio	X		X	X	X	X	X	X	X
		C212	Peripherals: number of printers, document scanners, opaque projectors, projectors, or smart TVs	X		X	X		X	X	X	X
		C213	Availability of a Local Area Network (LAN)	X		X	X	X	X	X	X	X
		C214	Availability of a university website	X			X		X	X	X	X
		C215	Number of teleconferencing and videoconferencing equipment	X	X	X	X	X	X	X	X	X
		C216	Number of 3D printers	X		X	X	X	X	X	X	X
	C22		Infrastructure for online learning									
		C221	Internet connectivity on the campus									
		C2211	Average Internet speed	X	X	X	X	X	X	X	X	X
		C2212	Availability of free Wi-Fi	X	X	X	X	X	X	X	X	X
		C222	Internet connectivity at home									
		C2221	Provision of connectivity kits to students	X	X	X	X	X	X	X	X	X
		C2222	Average Internet speed	X	X	X	X	X	X	X	X	X

Table A1. *Cont.*

			Criterion	Mapping of Components A1	A2	A3	A4	A5	A6	A7	A8	A9
C2			**Infrastructure**									
		C2223	University subscriptions to web conference platforms (e.g., Zoom, MS Teams, etc.)	X	X	X	X	X	X	X	X	X
		C2224	Existence of learning management systems	X	X	X	X	X	X	X	X	X
		C2225	Percentage of programs utilizing massive open online courses (MOOCs)	X	X	X	X	X	X	X	X	X
	C23		Other infrastructure relevant to EDUC4 implementation									
		C231	Number of educational technology laboratories supportive of a flipped classroom approach, hybrid learning format, augmented and virtual reality learning spaces, etc.	X	X	X	X	X	X	X	X	X
		C232	Number of 21st-century cyber-physical systems for education (e.g., student monitoring devices embedded with sensors that communicate with smartphones and servers, smart classrooms (example: RFID-based door access control, interactive boards, AI service chatbot, etc.), and communication systems for emergencies)	X	X	X	X	X	X	X	X	X
		C233	Number of campus-learning centers to provide global exposure and partnership development for learners (e.g., fabrication laboratory, discussion rooms, etc.)	X	X	X	X	X	X	X	X	X
		C234	Number of interactive whiteboards	X	X	X	X	X	X	X	X	X
		C235	Number of infrastructures for connected classrooms (e.g., touchscreen devices, bring your own device such as smartphones, etc.)	X	X	X	X	X	X	X	X	X
	C24		Science Laboratories									
		C241	Physics-related laboratories towards EDUC4									
		C2411	Number of AR–VR systems in physics-related laboratories	X	X	X	X	X	X	X	X	X
		C2412	Number of software subscriptions in physics-related laboratories	X	X	X	X	X	X	X	X	X
		C242	Chemistry-related laboratory towards EDUC4 implementation									
		C2421	Number of AR–VR systems in chemistry-related laboratories	X	X	X	X	X	X	X	X	X
		C2422	Number of software subscriptions to chemistry-related laboratories	X	X	X	X	X	X	X	X	X
		C243	Biology-related laboratory towards EDUC4 implementation									
		C2431	Number of AR–VR systems in biology-related laboratories	X	X	X	X	X	X	X	X	X
		C2432	Number of software subscriptions to biology-related laboratories	X	X	X	X	X	X	X	X	X

Table A1. *Cont.*

			Criterion	Mapping of Components A1	A2	A3	A4	A5	A6	A7	A8	A9
C2			**Infrastructure**									
	C25		Library 4.0									
		C251	Number of computers in the physical library	X	X	X	X	X	X	X	X	X
		C252	Library automation software									
		C2521	Availability of computerized cataloguing and classification	X		X	X	X	X	X	X	X
		C2522	Availability of Book to Desk (B2D) or desk booking utility	X		X	X	X	X	X	X	X
		C2523	Availability of mobile work list alerts and push information for academics	X	X	X	X	X	X	X	X	X
		C253	Number of library consortia			X	X	X	X	X	X	X
		C254	Availability of library website	X		X	X	X	X	X	X	X
		C255	Library e-resources									
		C2551	Degree of ease of access to library e-resources	X		X	X	X	X	X	X	X
		C2552	Degree of ease of finding relevant information	X		X	X	X	X	X	X	X
		C2553	Number of titles available	X		X	X	X	X	X	X	X
		C2554	Availability of full access to back issues	X		X	X	X	X	X	X	X
		C2555	Download speed	X		X	X	X	X	X	X	X
		C2556	Availability of access from home	X		X	X	X	X	X	X	X
		C256	Free Wi-Fi	X	X	X	X	X	X	X	X	X
C3			**Financial**									
	C31		Faculty capability enhancement									
		C311	Budget allocated for educators to attend relevant training and seminars for EDUC4	X	X		X	X	X	X		X
		C312	Budget allocated for necessary equipment and materials (e.g., laptop) to be used by faculty	X	X			X	X	X	X	X
	C32		Technology and infrastructure alignment									
		C321	Proportion of annual budget allocated for equipment (e.g., hardware and software) supportive of EDUC4 implementation	X	X	X	X	X	X	X	X	X
		C322	Proportion of annual budget allocated for maintenance on a per-student basis	X		X	X	X	X	X	X	X

Table A1. *Cont.*

				Mapping of Components								
			Criterion	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**
C3			**Financial**									
		C323	Proportion of annual budget allocated for data protection and safety on a per-student basis	X		X	X	X	X	X	X	X
	C33		Physical facilities and supplies									
		C331	Proportion of annual budget allocated for facility construction and conversion (e.g., rooms, laboratories) to comply with EDUC4 standards	X	X	X	X	X	X	X	X	X
		C332	Proportion of annual budget allocated for office supplies and teaching materials necessary for EDUC4	X	X	X	X	X	X	X	X	X
		C333	Proportion of annual budget allocated for maintaining EDUC4 facilities (e.g., rooms, laboratories)	X	X	X	X	X	X	X	X	X
C4			**Linkages**									
	C41		Education and training									
		C411	Average number of hours required for on-the-job training		X	X	X	X				
		C412	Number of training, seminars, and conferences conducted by guest lecturers from the industry	X	X	X	X	X	X	X		X
		C413	Number of university–industry collaborations/partnerships for the on-the-job training	X	X	X	X	X	X	X		X
		C414	Number of part-time lecturers from industry teaching at the university		X	X	X	X		X	X	
		C415	Number of educators working in consultancy for industry		X		X			X	X	X
		C416	Number of cooperative research projects with industry	X	X	X	X	X	X	X	X	X
		C417	Percentage of industry's involvement in the system of determining the final proficiency rating of interns		X	X	X	X		X		
		C418	Percentage of interns hired by the partner industries/institutions		X	X	X	X				
		C419	Number of industry-funded laboratories in the university	X	X	X	X	X	X	X	X	X
	C42		Collaboration									
		C421	Degree of partnerships with the local community across all aspects of education—from curricula and academics to infrastructure, research, study experience, and practicum	X	X	X	X	X	X	X	X	X
		C422	Availability of initiatives for developing curriculum and faculty partnerships with international universities	X	X	X	X	X	X	X	X	X
		C423	Existence of an internationalization office that fosters partnerships with international students and alumni	X	X	X	X	X		X	X	X
		C424	Existence of a community extension office		X	X	X	X		X	X	X
		C425	Degree of partnerships with industry across all aspects of education—from curricula and academics to infrastructure, research, study experience, and practicum	X	X	X	X	X	X	X	X	X
		C426	Number of endorsement requests from industries intended for employment		X	X	X	X		X		X

Table A1. *Cont.*

				Mapping of Components								
			Criterion	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**
C5			**Educational management**									
	C51		Educational leaders' commitment									
		C511	Degree of involvement of the educational leaders (i.e., University President, Deans, and area chairpersons) in implementing EDUC4 activities	X	X		X	X	X	X		X
		C512	Existence of a policy for the evaluation of the EDUC4 implementation	X	X	X	X	X	X	X		X
		C513	Number of EDUC4-related "quality issues" reviewed in educational leaders' meetings	X	X	X	X	X	X	X	X	X
		C514	Number of EDUC4 strategic plans implemented by the top management	X	X	X	X	X	X	X	X	X
	C52		Relationship with stakeholders									
		C521	Availability of the annual conduct of stakeholders' meeting		X	X	X	X				
		C522	Amount of stakeholders' feedback used as a basis for improving EDUC4-related services in the university	X	X	X	X	X				
		C53	Management support toward EDUC4 implementation									
		C531	Inclusion of EDUC4 concepts in the university's Vision, Mission, Goals, and Objectives	X	X	X	X	X	X	X	X	X
		C532	Existence of an office that monitors and evaluates EDUC4 integration in the delivery of the university core functions	X	X	X	X	X	X	X	X	X
		C533	Existence of a policy regarding hybrid teaching modality	X	X	X	X	X	X	X	X	X
C6			**Learners**									
	C61		Learners' experience									
		C611	Degree of the curriculum showing a strong linkage to real-world learning methods	X	X	X	X	X	X	X	X	X
		C612	Availability of flexible learning programs as options for students with various needs	X	X	X	X	X	X	X	X	X
		C613	Existence of a technology-driven feedback system so students can participate in the curriculum design	X	X	X	X	X	X	X	X	X
		C614	Extent of utilization of digital media-based collaboration and peer-to-peer learning tools for social learning and life development in the instructional delivery	X	X	X	X	X	X	X	X	X
		C615	Extent of learning opportunities that cater to varied levels of students' capabilities until mastery of competency is attained	X	X	X	X	X	X	X	X	X
		C616	Degree of students' utilization of digital technologies in interpreting and analyzing data	X	X	X	X	X	X	X	X	X
	C62		Teaching and learning experiences									
		C621	Extent to which the delivery of instruction is through varied strategies, including individualized teaching, gamification and simulation, problem- and inquiry-based teaching and learning, and augmented and virtual reality	X	X	X	X	X	X	X	X	X
		C622	Availability of digital enablers (e.g., 3D printing and robotics) to enrich students' creativity	X	X	X	X	X	X	X	X	X
		C623	Percentage of students exposed to participatory learning through field experiences	X	X	X	X	X	X	X	X	X
		C624	Utilization of flexible assignments to accommodate multiple learning styles	X	X	X	X	X	X	X	X	X

Table A1. *Cont.*

			Criterion	Mapping of Components A1	A2	A3	A4	A5	A6	A7	A8	A9
C6			**Learners**									
		C625	Availability of resources that make learning available at any time in any place	X	X	X	X	X	X	X	X	X
	C63		Students and curriculum design									
		C631	Extent of the curriculum promoting the development of soft skills such as adaptability, learn-to-learn communication, social and cultural awareness, creativity, curiosity, empathy, initiative, leadership, critical thinking and analytical thinking, persistence, responsibility, problem solving, and teamwork	X	X	X	X	X	X	X	X	X
		C632	Extent of the curriculum promoting the development of hard skills such as digital technologies design, people management, quality management, technological resource management, risk management, time management, financial management, computational thinking, and creative problem solving	X	X	X	X	X	X	X	X	X
		C633	Extent of the design of the curriculum reflecting the use of the following technological drivers utilized in the delivery of instruction: cloud computing, artificial intelligence, Internet of Things, digital games, augmented reality, 5G networks, social networks, and other educational software	X	X	X	X	X	X	X	X	X
		C634	Degree of students' use of the following EDUC4 tools in the teaching–learning process: cloud computing, artificial intelligence, Internet of Things, digital games, augmented reality, 5G networks, social networks, and other educational software	X	X	X	X	X	X	X	X	X
		C635	Extent of the curriculum emphasizing teaching digital citizenship (e.g., technology ethics, social, ethical, and legal responsibilities in the utilization of technological tools and resources, etc.)	X	X	X	X	X	X	X	X	X
	C64		Technology-based monitoring system of students' performance									
		C641	Extent of use of technology-based assessment tools (e.g., Kahoot, Quizlet) in checking content attainment	X	X	X	X	X	X	X	X	X
		C642	Availability of a digital media board for students to view individual feedback on performance in the industry	X	X	X	X	X	X	X	X	X
	C65		Student services									
		C651	Availability of an online system booking for school services such as health, guidance counseling, and library use, among others	X	X	X	X	X	X	X	X	X
C7			**Health and environment**									
	C71		Screen viewing									
		C711	Average number of screen-viewing hours daily			X	X	X	X	X	X	X
	C72		Physical risk									

Table A1. *Cont.*

				Mapping of Components								
			Criterion	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**
C7			**Health and environment**									
		C721	Frequency of health-related effects experienced due to prolonged screen viewing for the last two (2) months (i.e., dry eyes, digital eye strain, fatigue, posture, etc.).			X	X	X	X	X	X	X
	C73		Emotional risk									
		C731	Did you feel any of the following (e.g., stress, loneliness, depression, anxiety, and impaired socializing skills) in relation to prolonged screen viewing?			X	X	X	X	X	X	X
	C74		Cognitive risk									
		C741	Did you feel any of the following (e.g., weakened emotional judgment, delayed learning, lower score in thinking and language tests) in relation to prolonged screen viewing?			X	X	X	X	X	X	X
	C75		Time constraint for material preparation									
		C751	Average amount of time needed to prepare digital educational materials per topic in a course	X	X			X	X	X	X	X
	C76		Classroom layout									
		C761	Percentage of physical classrooms with flexible seating arrangements that allow both independent and collaborative workstations	X	X	X	X	X	X	X	X	X
		C762	Degree of learning conduciveness of physical classrooms	X	X	X	X	X	X		X	
	C77		**E-waste management**									
		C771	Existence of policy on e-waste management					X	X		X	
		C772	Degree of implementation of the policy related to e-waste management					X	X		X	
		C773	Annual volume of e-waste generated						X		X	
		C774	Annual volume of e-waste under circularity initiatives (e.g., reuse, reduce, recycle, recovery, redesign, and remanufacturing)						X		X	

Note: **A1**—heutagogical, peeragogical, and cybergogical; **A2**—mentorship, collaboration, and reference; **A3**—active, independent, and trajectory designing; **A4**—mostly student-centered education; **A5**—training soft and hard key competencies; **A6**—utilizing ICT tools and platforms powered by IoT; **A7**—based on online sources; **A8**—cyber and physical spaces shared and individual; **A9**—connectivity, digitalization, and virtualization.

Table A2. Aggregate performance of indicators in rough numbers.

	Measurement Scale	Sampling Plan	Stakeholder	Ideal Value	Actual Score	Normalized Score
C11	%	Actual data	Human resource office	[1.0000, 1.0000]	[0.9000, 0.9000]	[0.9000, 0.9000]
C12	7-point Likert scale	At least 30% of the faculty members, randomly selected	Faculty	[7.0000, 7.0000]	[5.1132, 5.7347]	[0.7305, 0.8192]
C13	7-point Likert scale	At least 30% of the faculty members, randomly selected	Faculty	[7.0000, 7.0000]	[4.8478, 5.6295]	[0.6925, 0.8042]
C14	%	Actual data	Deans	[1.0000, 1.0000]	[0.5719, 0.9534]	[0.5719, 0.9534]
C15	7-point Likert scale	At least 30% of the faculty members, randomly selected	Faculty	[7.0000, 7.0000]	[4.7111, 5.6821]	[0.6730, 0.8117]
C16	7-point Likert scale	At least 30% of the faculty members, randomly selected	Faculty	[7.0000, 7.0000]	[4.5590, 6.0973]	[0.6513, 0.8710]
C21	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C211	ratio (%)	Actual data	Deans	[0.2000, 0.2000]	[0.0063, 0.0184]	[0.0316, 0.0922]
C212	units per 100 students	Actual data	Deans	[1.3013, 1.3013]	[0.1650, 0.3651]	[0.1268, 0.2806]
	units per 100 students	Actual data	Deans	[1.3013, 1.3013]	[0.0875, 0.2876]	[0.0673, 0.2210]
	units per 100 students	Actual data	Deans	[1.3013, 1.3013]	[0.0132, 0.0821]	[0.0101, 0.0631]
	units per 100 students	Actual data	Deans	[1.3013, 1.3013]	[0.1069, 0.2742]	[0.0821, 0.2107]
	units per 100 students	Actual data	Deans	[1.3013, 1.3013]	[0.7689, 1.2466]	[0.5909, 0.9579]
C213	0 = No, 1 = Yes	Actual data	IT manager	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C214	0 = No, 1 = Yes	Actual data	IT manager	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C215	units per 100 students	Actual data	Deans	[18.0000, 18.0000]	[0.0449, 0.3594]	[0.0025, 0.0200]
C216	units per 100 students	Actual data	Deans	[1.1774, 1.1774]	[0.0310, 0.2789]	[0.0263, 0.2368]
C22	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C221	average of the section component ratings	Actual data		[10.5000, 25.5000]	[6.5000, 10.5000]	[0.2549, 1.0000]
C2211	Mbps	Actual data	IT manager	[20.0000, 50.0000]	[12.0000, 20.0000]	[0.2400, 1.0000]
C2212	0 = Not available, 1 = Available	Actual data	IT manager	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C222	average of the section component ratings	Actual data				
C2221	0 = No, 1 = Yes	Actual data	IT manager	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C2222	Mbps	Actual data	IT manager	[20.0000, 50.0000]	[8.0000, 15.0000]	[0.1600, 0.7500]
C223	0 = No, 1 = Yes	Actual data	IT manager	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C224	0 = No, 1 = Yes	Actual data	IT manager	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C225	%	Actual data	Registrar	[0.2000, 0.2000]	[0.0000, 0.0000]	[0.0000, 0.0000]

Table A2. *Cont.*

C23	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C231	actual count	Actual data	Deans	[18.0000, 18.0000]	[0.4967, 2.4267]	[0.0276, 0.1348]
C232	actual count	Actual data	Deans	[12.0000, 12.0000]	[0.1700, 1.0600]	[0.0142, 0.0883]
C233	actual count	Actual data	Vice-President for Administration	[10.0000, 10.0000]	[4.0000, 4.0000]	[0.4000, 0.4000]
C234	actual count per classroom	Actual data	Deans	[1.0000, 1.0000]	[0.4359, 0.5000]	[0.4359, 0.5000]
C235	actual count per student	Actual data	Deans	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C24	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C2411	actual count per laboratory	Actual data	Deans	[26.0000, 26.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C2412	actual count per laboratory	Actual data	Deans	[1.0000, 1.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C2421	actual count per laboratory	Actual data	Deans	[26.0000, 26.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C2422	actual count per laboratory	Actual data	Deans	[1.0000, 1.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C2431	actual count per laboratory	Actual data	Deans	[26.0000, 26.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C2432	actual count per laboratory	Actual data	Deans	[1.0000, 1.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C25	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C251	actual count	Actual data	Librarians	[645.5000, 645.5000]	[48.0000, 48.0000]	[0.0744, 0.0744]
C2521	0 = No, 1 = Yes	Actual data	Librarians	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C2522	0 = No, 1 = Yes	Actual data	Librarians	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C2523	0 = No, 1 = Yes	Actual data	Librarians	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C253	actual count	Actual data	Librarians	[15.0000, 15.0000]	[1.0000, 1.0000]	[0.0667, 0.0667]
C254	0 = No, 1 = Yes	Actual data	Librarians	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C2551	range of values within [0,10], where 0 represents an absence	Actual data	Librarians	[10.0000, 10.0000]	[6.0000, 6.0000]	[0.6000, 0.6000]
C2552	range of values within [0,10], where 0 represents an absence	Actual data	Librarians	[10.0000, 10.0000]	[6.0000, 6.0000]	[0.6000, 0.6000]
C2553	actual count	Actual data	Librarians	[96,825.0000, 96,825.0000]	[16,335.0000, 16,335.0000]	[0.1687, 0.1687]

Table A2. *Cont.*

C25	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C2554	range of values within [0,10], where 0 represents an absence	Actual data	Librarians	[10.0000, 10.0000]	[7.0000, 7.0000]	[0.7000, 0.7000]
C2555	Mbps	Actual data	IT manager	[25.0000, 50.0000]	[15.0000, 40.0000]	[0.3000, 1.6000]
C2556	range of values within [0,10], where 0 represents an absence	Actual data	IT manager	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C256	0 = No, 1 = Yes	Actual data	IT manager	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C31	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C311	Php per faculty member	Actual data	Accounting/Finance office	[70,000, 70,000]	15,000, 20,000	[0.2143, 0.2857]
C312	Php per faculty member	Actual data	Accounting/Finance office	[30,000, 30,000]	30,000, 30,000	[1.0000, 1.0000]
C32	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C321	Php per student	Actual data	Accounting/Finance office	[1549.19, 1549.19]	[464.7560, 464.7560]	[0.3000, 0.3000]
C322	Php per student	Actual data	Accounting/Finance office	[774.59, 774.59]	[77.4593, 77.4593]	[0.1000, 0.1000]
C323	Php per student	Actual data	Accounting/Finance office	[100.000, 100.000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C33	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C331	Php per student	Actual data	Accounting/Finance office	[500.000, 500.000]	[309.8373, 309.8373]	[0.6197, 0.6197]
C332	Php per student	Actual data	Accounting/Finance office	[100.000, 100.000]	[77.4593, 77.4593]	[0.7746, 0.7746]
C333	Php per student	Actual data	Accounting/Finance office	[250.000, 250.000]	[154.9187, 154.9187]	[0.6197, 0.6197]

Table A2. *Cont.*

C41	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C411	no. of hours	Actual data	OJT coordinators	[1000, 1000]	720, 1440	[0.7200, 1.4400]
C412	actual count	Actual data	Deans	[3.0000, 5.0000]	[1.3600, 2.2533]	[0.2720, 0.7511]
C413	actual count	Actual data	OJT coordinators	[30.000, 100.000]	[21.5000, 62.5000]	[0.2150, 2.0833]
C414	actual count	Actual data	Human resource office	[50.0000, 50.0000]	[40.0000, 50.0000]	[0.8000, 1.0000]
C415	actual count	Actual data	Faculty	[60.0000, 60.0000]	[2.2133, 9.2967]	[0.0369, 0.1549]
C416	actual count	Actual data	R&D office/research centers	[25.0000, 25.0000]	[0.5000, 1.5000]	[0.0200, 0.0600]
C417	%	Actual data	OJT coordinators	[0.5000, 0.5000]	[0.5000, 0.5000]	[1.0000, 1.0000]
C418	%	Actual data	Human resource office	[0.3000, 0.3000]	[0.8000, 0.8000]	[2.6667, 2.6667]
C419	actual count	Actual data	R&D office	[5.0000, 5.0000]	[0.5000, 1.5000]	[0.1000, 0.3000]
C42	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C421	7-point Likert scale	Actual data	Deans	[7.0000, 7.0000]	[5.0400, 5.3600]	[0.7200, 0.7657]
C422	0 = No, 1 = Yes	Actual data	Deans	[1.0000, 1.0000]	[0.0640, 0.3760]	[0.0640, 0.3760]
C423	0 = No, 1 = Yes	Actual data	Internationalization office	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C424	0 = No, 1 = Yes	Actual data	Community extension office	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C425	7-point Likert scale	Actual data	SAO & OJT coordinators	[7.0000, 7.0000]	[5.2600, 6.0000]	[0.7514, 0.8571]
C426	actual count	Actual data	Human resource office	[60.0000, 60.0000]	[30.0000, 30.0000]	[0.5000, 0.5000]
C51	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C511	7-point Likert scale	At least 60% of educational leaders	Educational leaders (e.g., Presidents, Vice-Presidents, Campus directors, Deans)	[7.0000, 7.0000]	[5.0000, 5.0000]	[0.7143, 0.7143]
C512	0 = No, 1 = Yes	Actual data	Vice-President for Academics	[1.0000, 1.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C513	actual count	Actual data	Secretary of the top management	[12.000, 20.000]	[4.0000, 4.0000]	[0.2000, 0.3333]
C514	actual count	Actual data	Vice-President for Academics	[8.0000, 16.0000]	[2.0000, 2.0000]	[0.1250, 0.2500]
C52	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C521	0 = No, 1 = Yes	Actual data	Campus administrator	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C522	percentage	Actual data	Campus administrator	[1.0000, 1.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]

Table A2. *Cont.*

C53	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C531	7-point Likert scale	Actual data	Evaluator	[7.0000, 7.0000]	[4.8889, 5.7778]	[0.6984, 0.8254]
C532	0 = No, 1 = Yes	Actual data	Vice-President for Academics	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C533	0 = No, 1 = Yes	Actual data	Vice-President for Academics	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C61	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C611	7-point Likert scale	Actual data	Deans	[7.0000, 7.0000]	[4.7467, 5.6400]	[0.6781, 0.8057]
C612	0 = No, 1 = Yes	Actual data	Deans	[1.0000, 1.0000]	[0.6400, 0.9600]	[0.6400, 0.9600]
C613	0 = No, 1 = Yes	Actual data	Deans	[1.0000, 1.0000]	[0.1600, 0.6400]	[0.1600, 0.6400]
C614	7-point Likert scale	Actual data	Deans	[7.0000, 7.0000]	[3.6400, 3.9600]	[0.5200, 0.5657]
C615	7-point Likert scale	Actual data	Deans	[7.0000, 7.0000]	[3.6400, 3.9600]	[0.5200, 0.5657]
C616	7-point Likert scale	At least 100 students (randomly selected)	Students	[7.0000, 7.0000]	[3.6031, 5.2566]	[0.5147, 0.7509]
C62	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C621	0 = No, 1 = Yes	Actual data	Deans	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C622	0 = No, 1 = Yes	Actual data	Deans	[1.0000, 1.0000]	[0.1600, 0.6400]	[0.1600, 0.6400]
C623	%	At least 100 students (randomly selected)	Students	[0.0000, 0.0000]		
C624	0 = No, 1 = Yes	Actual data	Deans	[1.0000, 1.0000]	[1.0000, 1.0000]	[1.0000, 1.0000]
C625	0 = No, 1 = Yes	Actual data	Students	[1.0000, 1.0000]	[0.8051, 0.9894]	[0.8051, 0.9894]
C63	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C631	7-point Likert scale	Actual data	Deans	[7.0000, 7.0000]	[5.3600, 5.8400]	[0.7657, 0.8343]
C632	7-point Likert scale	Actual data	Deans	[7.0000, 7.0000]	[4.6500, 5.3800]	[0.6643, 0.7686]
C633	7-point Likert scale	Actual data	Deans	[7.0000, 7.0000]	[3.9200, 5.2533]	[0.5600, 0.7505]
C634	7-point Likert scale	At least 100 students (randomly selected)	Students	[7.0000, 7.0000]	[3.1612, 5.1524]	[0.4516, 0.7361]
C635	7-point Likert scale	At least 100 students (randomly selected)	Students	[7.0000, 7.0000]	[4.0401, 5.8469]	[0.5772, 0.8353]
C64	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C641	7-point Likert scale	At least 30% of the faculty members, randomly selected	Faculty	[7.0000, 7.0000]	[3.1119, 5.7462]	[0.4446, 0.8209]
C642	0 = No, 1 = Yes	Actual data	College deans	[1.0000, 1.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C65	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C651	7-point Likert scale	At least 100 students (randomly selected)	Students	[7.0000, 7.0000]	[3.6364, 5.5601]	[0.5195, 0.7943]
C71	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C711	no. of hours	At least 100 students (randomly selected)	Students	[3.0000, 5.0000]	[4.0633, 9.6543]	[0.3107, 1.2305]

Table A2. *Cont.*

C72	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C721	no. of occurrence	At least 100 students (randomly selected)	Students	[0.0000, 0.0000]	[1.4437, 15.9766]	[0.0000, 0.0000]
C73	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C731	0 = No, 1 = Yes	At least 100 students (randomly selected)	Students	[0.0000, 0.0000]	[0.5574, 0.9613]	[0.0000, 0.0000]
C74	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C741	0 = No, 1 = Yes	At least 100 students (randomly selected)	Students	[0.0000, 0.0000]	[0.5574, 9.6543]	[0.0000, 0.0000]
C75	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C751	no. of hours	At least 30% of the faculty members, randomly selected	Faculty	[3.0000, 3.0000]	[2.5680, 16.2045]	[0.1851, 1.1682]
C76	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C761	%	At least 30% of the faculty members, randomly selected	Faculty	[0.6000, 0.6000]	[0.4770, 0.9218]	[0.7950, 1.5364]
C762	7-point Likert scale	At least 30% of the faculty members, randomly selected	Faculty	[7.0000, 7.0000]	[4.9295, 6.4249]	[0.7042, 0.9178]
C77	Measurement scale	Sampling plan	Stakeholder	Ideal value	Actual score	Normalized score
C771	0 = No, 1 = Yes	Actual data	Campus administrator	[1.0000, 1.0000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C772	7-point Likert scale	Actual data	Campus administrator	[7.000, 7.000]	[0.0000, 0.0000]	[0.0000, 0.0000]
C773	kilogram	Actual data	Campus administrator	[30.000, 50.000]	[320.00, 350.00]	[0.0857, 0.1563]
C774	kilogram	Actual data	Campus administrator	[250.000, 270.000]	[0.0000, 0.0000]	[0.0000, 0.0000]

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