Research Article

Factors Influencing Teaching Quality in Universities: Analyzing Causal Relationships Based on Neutrosophic DEMATEL

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While teaching quality has been widely studied, this work advances the domain literature by evaluating the factors influencing teaching quality in order to determine their causal relationships and eventually identify those crucial factors. With ten factors obtained from a comprehensive review of literature, the neutrosophic decision-making trial and evaluation laboratory (DEMATEL) method is used to model these factors in the case of public universities in the Philippines. The DEMATEL handles the causal relationships among factors of teaching quality, while the vagueness associated with domain experts eliciting judgments within the DEMATEL is modeled in single-valued neutrosophic numbers. Findings reveal that individual characteristics, psychological characteristics, and institutional culture are key factors of teaching quality, while institutional resources and student composition are minor key factors. Higher education institutions (HEIs) must pay more attention to these factors in designing different initiatives, as they are crucial in shaping teaching quality. These findings offer important insights for HEIs in their recruitment and hiring decisions, strategic road mapping for building an institutional culture that values teaching quality, establishing student composition schemes, and resource allocation decisions for promoting institutional resources that drive teaching quality initiatives. Some policy takeaways and avenues for future works are also discussed.

1. Introduction

Good education combines sensitivity to context, history, culture, and socioeconomic conditions ([1], p. 4). The knowledge obtained from education is not only necessary in achieving social welfare and freedom but also in improving the quality of life ([2, 3], p. 229). Accordingly, education plays an essential role in the global initiatives relating to human equality, opportunity, and technological innovation ([4], p. 181). Thus, higher education institutions (HEIs) aim to promote a mode of learning that ensures lifelong education, which guarantees work stability and relevance

([1], p. 4). The domain literature (e.g., [5–7]) emphasizes that teaching quality is deemed the most important factor in achieving educational goals (e.g., high literacy). Teaching quality is embodied as an integration of both teacher characteristics (e.g., professional qualifications, experience, place of residence, and in-service training) and actions (e.g., teaching practices, attitudes, and content knowledge) [8]. It has a significant impact on student learning which HEIs have greater control over. Accordingly, how teachers manage class learning and interaction significantly affects student motivation and engagement [9, 10].

Due to teaching quality's significant impact on students' learning curve, what constitutes high-quality instruction has drawn attention from researchers and practitioners for the past few decades [6]. Thus, various studies (e.g., [11, 12]) have identified factors that have a significant impact on the teaching quality in HEIs. These factors include individual characteristics of the instructors [12, 13], psychological characteristics [14], self-efficacy [14, 15], teaching motivation [16, 17], teaching experience [18, 19], professional development [20, 21], student composition [22, 23], student's feedback [11, 24, 25], institutional culture [26, 27], and institutional resources [28, 29]. However, despite teaching quality being a popular domain in literature, a holistic assessment of the factors that influence it remains unexplored. Several teaching quality frameworks (e.g., [30, 31]) differ in focus, level of abstraction, and subject-relatedness [6]. These frameworks merely identify the different factors that influence teaching quality in HEIs without investigating the interdependencies between these factors. The insights gained from understanding the overall structure of teaching quality with the consideration of the interrelationships between its factors would provide significant insights for policymakers in HEIs for optimal resource allocation, planning, and decision-making. For instance, factors such as institutional resources and institutional culture may impact professional development in a way HEIs must prioritize resources for the provision of training that would improve the capability of teachers in the delivery of courses. Thus, understanding these complex relationships would offer insights on more priority factors of teaching quality that would aid HEIs in the design of their response initiatives.

This work advances such a gap by determining the relationships of the factors of teaching quality through an analytical evaluation that captures both complexity and uncertainty under a systems perspective. In this work, a list of factors that have a significant impact on teaching quality is identified through a literature survey. Since the identified factors include subjective characteristics which need expert judgments in evaluating whether a specific factor influences another, including the extent of such influence, a decision-making trial and evaluation laboratory (DEMATEL) approach is adopted. DEMATEL is part of the family of problem structuring techniques first introduced in the 1970s [32, 33]. This technique offers an approach that systematically structures problems in different domains by considering experts' judgments in view of knowledge and experience; wherein subjectivity is inherent. It is beneficial for analyzing causal relationships among the factors of a complex system [34, 35] and visualizing the structure of these relationships in an attempt to determine those factors that have significant roles in the system. Since its development, DEMATEL has been widely used in various fields such as safety management [36], supply chain [37], education management [38], online learning [39], educational innovation [40], healthcare [41, 42], and sustainable urban development [43]. A review of its applications can be found in Si et al. [44].

To this date, various extensions of the DEMATEL method in addressing structuring problems have been offered. It is important to note that the DEMATEL approach is expert-oriented, and thus inherent uncertainties, particularly in the judgments elicited by the human experts, are prevalent. Since these judgments reflect the experts' knowledge and experience, they are vague and imprecise to some extent. To address this vagueness and uncertainty, various researchers (e.g., [45, 46]) offer the integration of the DEMATEL approach and the fuzzy set theory introduced by Zadeh [47]. However, the fuzzy set theory is only limited to introducing a single membership function, failing to capture other types of uncertainty. Thus, Atanassov [48] proposed the intuitionistic fuzzy set theory, which introduces a nonmembership and hesitancy function. This has led to the introduction of the intuitionistic fuzzy DEMATEL [49, 50]. However, unsureness, which is a type of judgment uncertainty inherent in expert judgment, is outside the scope of the intuitionistic fuzzy set theory. To address this limitation, Smarandache [51] introduced the concept of neutrosophy. Within this notion, the neutrosophic set is a generalization of the intuitionistic fuzzy set, which represents real-world problems effectively by considering all aspects of a decision situation, i.e., truthiness, indeterminacy, and falsity [52]. Integrating the DEMATEL approach and the neutrosophic set has become popular in the literature. Some of its applications include developing supplier selection criteria [53], addressing problems in coastal erosion [54], evaluating e-commerce websites [55], selecting transport service providers [56], prioritizing the components of e-learning system [57], and determining factors for the adoption of cloud computing in the educational sector [58]. This list is not intended to be comprehensive.

Thus, in this work, the neutrosophic set theory is used to express the preferences of the decision-makers in the context of the DEMATEL, particularly in determining the interdependences among the factors of teaching quality. The use of the DEMATEL has been gaining attention in the education sector, including applications in flipped learning (e.g., [59]), e-learning (e.g., [39, 57]), mobile environments (e.g., [60]), strategy development (e.g., [61]), sustainability management (e.g., [38]). However, its application in understanding the factors of teaching quality remains unexplored in the domain literature. To demonstrate the integration of neutrosophic set theory within the DEMATEL, hereby denoted as neutrosophic DEMATEL, a case study was conducted in the public universities of the Philippines, wherein a purposive survey of domain experts was facilitated to extract the relationships of the identified factors of teaching quality. The significant changes of the Philippine education landscape (e.g., shift

to the K to 12 Basic Education Curriculum) have encouraged HEIs to consistently pursue teaching quality reforms [62]. The agenda this study offers helps in designing effective initiatives of HEIs that promote teaching quality in a rigorous and systematic manner. Hence, the contribution of this work is the holistic assessment of the interrelationships of factors of teaching quality to identify the most relevant factors which may be input in designing initiatives to advance teaching quality in HEIs. This paper is organized as follows: Section 2 discusses the factors of teaching quality and their relationships, based on a literature review. Section 3 provides the relevant background of neutrosophic set theory and the DEMATEL approach, while Section 4 presents the application of the neutrosophic DEMATEL. Section 5 discusses the results and their implications, and Section 6 highlights the policy insights. This paper ends with the conclusion and discussion of future work in Section 7.

2. Literature Review

This section presents the factors that significantly impact teaching quality in HEIs based on a thorough literature review. The keywords "teaching quality" AND "higher educational institution" OR "university" are used in the Google Scholar database to generate the journal articles to be considered for the literature survey. A filter for the year of publication was also considered, wherein only journal articles published within the year 2000-2020 were obtained. Afterward, the journal articles were assessed whether the identified factors of teaching quality are in an HEI setting. Content analysis was performed on the qualified journal articles to determine the factors. The final list of ten (10) factors generated from the literature survey is discussed in this section.

2.1. Individual Characteristics. The importance of considering the effects of the teacher's demographic characteristics such as gender, age, and marital status on teaching quality was emphasized by Reid [63]. Various works in the literature (e.g., [64, 65]) studied the psychological empowerment effect of these demographic characteristics towards teaching quality. Specifically, the effect of gender differences was notable in student relationships wherein female teachers show more significant concern towards female students than males [66]. On the other hand, a study conducted by Saleem et al. [66] shows that teachers aged 46 and above show more significant work commitment than young teachers. Aside from the demographic characteristics, Ting [67] also identified the teacher's intellectual capacity, class management, and communication as essential components of quality teaching.

2.2. Psychological Characteristics. Psychological traits of teachers include an enduring, relatively stable trait or set of traits with a possible neuropsychological basis [14, 68]. Since the early 1950s, some traits have long been thought to influence teaching quality but revealed minimal evidence of a predicted association between instructors' attitudes, personality traits, and teaching performance, despite a broad perception that teachers' personalities were linked to teaching success. However, Klassen and Tze [14] revealed a strong link between the psychological traits of the teacher and teaching quality. Specifically, conscientiousness and emotional stability, among all other psychological traits a teacher can have, have a significant relation to teaching quality.

2.3. Self-Efficacy. According to Holzberger et al. [15], most researchers studying teachers' self-efficacy beliefs see the construct as a determinant of successful educational outcomes (e.g., teaching quality). Teachers with high efficacy beliefs are thought to work harder, be more involved in informal learning activities, and be more persistent and less stressed [69]. Teachers' self-efficacy has been demonstrated to influence the teachers' instructional practices, passion, commitment, teaching behaviors, and persistence in engaging with challenging students (e.g., [70]). Various studies (e.g., [71]) revealed that teachers' self-efficacy is linked to job satisfaction and stress management, but its relationship to teaching quality is unclear. However, a further investigation conducted by Klassen et al. [72] concluded that there is empirical evidence that teachers' self-efficacy influences teaching quality. This relationship is worthy of further investigation for self-efficacy interventions and training.

2.4. Teaching Motivation. Various studies (e.g., [73]) in the literature explore the positive relationship between teaching motivation and teaching characteristics (e.g., autonomy support). Accordingly, teaching motivation is linked to a teacher's professional competence and influences teachers' instructional behaviors and practices as well as teaching quality [17]. Praetorius et al. [16] pointed out that understanding the relationships between aspects of teaching motivation and teaching quality has implications for teacher training and professional development. Teachers with high teaching motivation invest more effort in teaching, goal setting, showing high persistence and attention in their instruction (e.g., [74, 75]), and are more likely to engage in professional development activities [76, 77].

2.5. Teaching Experience. Teaching experience, as demonstrated by various research (e.g., [19]) and public discourse, is considered as one of the many factors influencing the quality of teaching [78]. The evidence for associations between teaching experience and teaching quality using indirect measures (i.e., standardized assessment of student performance) is prominent in the literature (e.g., [79]). Furthermore, Podolsky et al. [19] emphasized that as the teachers gain experience, the more they are able to foster effective student learning. Their findings pointed out the importance of creating collaborative environments where teachers continue to grow.

2.6. Professional Development. Professional development refers to structured professional learning that results in improvements in teacher practices and student learning outcomes [20]. Since research has shown that teaching quality and school leadership are the most critical factors in raising student achievement, teachers, school, and district leaders must effectively continue to expand their knowledge and

skills to implement the best educational practices ([80], p. 3). Thus, various scholars and practitioners have devoted their time and effort to construct a professional training and development structure that consequently improves teachers' teaching quality [21].

2.7. Student Composition. Adapting the educational instructions based on the need of the students is one of the necessary skills teachers should have [81]. However, from a teacher's perspective, addressing every need of each student in a given time on a daily basis has its difficulty. As a result, teachers utilized the method of creating a learning environment based on the composition of each class. Significantly, Fauth et al. [22] emphasized that the quality of teaching received by a particular student depends on the composition of the class. Several studies identified the different factors teachers usually base to classify student composition: sociocultural background (e.g., [82]), student achievement and general cognitive abilities (e.g., [83]), and motivational composition (e.g., [22]).

2.8. Student's Feedback. Feedback is a type of information provided by an individual (e.g., teacher, student, peer, self, and experience) in relation to the different aspects of the recipient's performance [84], which has a substantial performance-enhancing effect [11]. As a result, numerous studies on feedback research in education proving the positive relationship between student feedback and teaching quality emerged (i.e., [24, 25]). In particular, student feedback drives improvement-oriented actions towards the teaching quality of teachers [11].

2.9. Institutional Culture. Institutional culture refers to an educational institution's established patterns, behaviors, common values, beliefs, and ideologies [26]. Reports in the literature (i.e., [27, 85, 86]) clearly show the significant impact of institutional culture on quality teaching. For example, Cox et al. [85] found that teaching-centered and learning-centered policies implemented by an institution have a positive effect on teacher-student interaction, thus, improving quality teaching in the classroom. As a result, they emphasized that culture with improved teaching quality is likely to lead to improved student engagement and learning.

2.10. Institutional Resources. Hill et al. [29] identified institutional resources as any resources that an institution provides for utilization by students and teachers in the classroom, such as textbooks, guides, and curricula. The impact of these standards-aligned curriculum materials on instructional outcomes enables high-quality teaching in the institution [28]. Aside from material resources provided by the institution, teachers' colleagues can also serve as a resource for teachers to improve the quality of their teaching [29]. Ronfeldt et al. [87] supported the claim and proved that teacher collaboration engrossed in instructional planning and enactment improves student outcomes.

3. Preliminaries

3.1. Neutrosophic Sets

Definition 1. (see [51]). Let X be a space of points (objects) with generic elements in X denoted by x. A neutrosophic set A in X is characterized by a truth membership function $T_A(x)$, indeterminacy membership function $I_A(x)$, and falsity membership function $F_A(x)$. The functions $T_A(x)$, $I_A(x)$, and $F_A(x)$ are actual standard or non-standard subsets of $]0^-, 1^+[$. That is, $T_A(x): X \longrightarrow]0^-, 1^+[$, $I_A(x): X \longrightarrow]0^-, 1^+[$, and $F_A(x): X \longrightarrow]0^-, 1^+[$. Thus, there is no restriction on the sum of $T_A(x)$, $I_A(x)$, and $F_A(x)$, so $0^- \le \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \le 3^+$.

On this basis, Wang et al. [52] introduced the concept of a single-valued neutrosophic set (SVNS).

Definition 2. (see [52]). Let X be a space of points (objects) with generic elements in X denoted by x. A single-valued neutrosophic set (SVNS) $\tilde{A}$ in X is given as

$$\tilde{A} = \{\langle x, T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\rangle: x \in X\}, \tag{1}$$

where $T_{\tilde{A}}(x)$ is the truth membership function, $I_{\tilde{A}}(x)$ is the indeterminacy membership function, and $F_{\tilde{A}}(x)$ is the falsity membership function. For every $x \in X$, $T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x) \in [0, 1]$, and $0 \le T_{\tilde{A}}(x) + I_{\tilde{A}}(x) + F_{\tilde{A}}(x) \le 3$.

We refer to $x \in \tilde{A}$ as a single-valued neutrosophic number (SVNN) and is written conveniently as $x = \langle T_x, I_x, F_x\rangle$.

Definition 3. (see [52]). Let $u = \langle T_u, I_u, F_u\rangle$ and $v = \langle T_v, I_v, F_v\rangle$ be any two SVNNs, and $\lambda > 0$. The operations are defined as follows:

$$u \oplus v = \langle T_u + T_v - T_u T_v, I_u I_v, F_u F_v\rangle,$$
$$u \otimes v = \langle T_u T_v, I_u + I_v - I_u I_v, F_u + F_v - F_u F_v\rangle,$$
$$\lambda u = \left\langle 1 - (1 - T_u)^\lambda, I_u^\lambda, F_u^\lambda\right\rangle, \tag{2}$$
$$u^\lambda = \left\langle T_u^\lambda, 1 - (1 - I_u)^\lambda, 1 - (1 - F_u)^\lambda\right\rangle.$$

Definition 4. (see [88]). Let $\tilde{A}_j = \langle T_{\tilde{A}_j}, I_{\tilde{A}_j}, F_{\tilde{A}_j}\rangle (j = 1, 2, \cdots, n)$ be a collection of SVNNs. The single-valued neutrosophic weighted aggregation (SVNWA) of $\tilde{A}_j$ is

$$\text{SVNWA}\left(\tilde{A}_1, \tilde{A}_2, \cdots, \tilde{A}_n\right)$$
$$= \left\langle 1 - \prod_{j=1}^n \left(1 - T_{\tilde{A}_j}\right)^{w_j}, \prod_{j=1}^n \left(I_{\tilde{A}_j}\right)^{w_j}, \prod_{j=1}^n \left(F_{\tilde{A}_j}\right)^{w_j}\right\rangle, \tag{3}$$

wherein, $w_j = (w_1, w_2, \cdots, w_n)^T$ be the weight vector of $\tilde{A}_j$ and $w_j > 0$, $\sum_{j=1}^n w_j = 1$.

Definition 5. (see [89]). Let $\tilde{A} = \{\langle x, T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\rangle : x \in X\}$ be an SVNN, then the deneutrosophication of $\tilde{A}$ that maps $\tilde{A}$ onto $\mathbb{R}$, defined by a function $f : \tilde{A} \longrightarrow \mathbb{R}$, is as follows,

$$E\left(\tilde{A}\right) = \frac{(3 + T_{\tilde{A}} - 2I_{\tilde{A}} - F_{\tilde{A}})}{4}. \tag{4}$$

3.2. The DEMATEL Method. The DEMATEL, developed in the 1970s by the Battelle Memorial Institute of Geneva for a Science and Human Affairs Program, is a graph theoretical tool for analyzing a structural model or system characterized by elements (as vertices) and causal relationships among elements (as edges). Following the direct relationships among elements and their resulting indirect relationships via transitivities, the DEMATEL intends to categorize all elements into two groups (i.e., net cause and net effect). This categorization leads to a better understanding and realization of the elements of the system, which may offer solutions to complex problems ([33] [32]). Using concepts of graph theory and linear algebra, the following describes the computational process of the DEMATEL. Note that some notations are consistent with Gonzales et al. [40].

Step 1. Determine the components of the system.

This process can be obtained via different approaches, including a literature review on the domain topic, focus group discussion on the practical problem, and expert decisions. Let $i = 1, \cdots, n$ be the elements.

Step 2. Generate the direct-relation matrix.

An expert group of K members performs pairwise comparisons of the causal relationships between n elements. This generates a direct-relation matrix $X^k = (x_{ij}^k)_{n \times n}$ where x_{ij}^k represents the causal influence of the element i on element j as perceived by the kth member, $k = 1, 2, \cdots, K$, of the group. A predefined evaluation scale will be used to represent the severity of the causal influence.

Step 3. Aggregate the direct-relation matrices X^k, $k = 1, 2, \cdots, K$.

Considering that $w_k > 0 (\sum_k w_k = 1)$ is assigned to the importance of the kth member, Equation (5) describes the aggregate direct-relation X.

$$X = (x_{ij})_{n \times n} = \left(\sum_k w_k x_{ij}^k\right)_{n \times n}. \tag{5}$$

Step 4. Normalize the aggregate direct-relation matrix.

The normalized direct-relation matrix is calculated using Equations (6) and (7).

$$G = g^{-1} X, \tag{6}$$

$$g = \max\left(\max_{1 \le i \le n} \sum_{j=1}^{n} x_{ij}, \max_{1 \le j \le n} \sum_{i=1}^{n} x_{ij}\right). \tag{7}$$

Step 5. Calculate the total relation matrix.

Once G is obtained, a continuous decrease in the system's indirect effects along with the powers of G (i.e., $G + G^2 + G^3 + \dots$) guarantees convergent solutions to the matrix inversion. The total relation matrix $T = (t_{ij})_{n \times n}$ is computed using Equation (8), where I is an identity matrix.

$$T = G \left(I - G\right)^{-1}. \tag{8}$$

Step 6. Categorize the elements into the net cause and net effect.

Compute for D and R vectors using Equations (9) and (10), respectively.

$$D = \left(\sum_{j=1}^{n} t_{ij}\right)_{n \times 1} = (t_i)_{n \times 1}, \tag{9}$$

$$R = \left(\sum_{i=1}^{n} t_{ij}\right)_{1 \times n} = (t_j)_{1 \times n}. \tag{10}$$

The $(D + R^T)$ vector (i.e., also known as the "prominence" vector) represents the relative importance of each element. Those elements in the $(D - R^T)$ (i.e., also known as the "relation" vector) having $t_i - t_j > 0$, $i = j$ belong to the net cause group, while those elements with $t_i - t_j < 0$, $i = j$ belong to the net effect group.

Step 7. Create a prominence-relation map. This map illustrates the $(D + R^T, D - R^T)$ mapping of the elements, as shown in Figure 1. The directed relationship of the elements of the prominence-relation map is defined by t_{ij}. However, some of these total relationships are insignificant, either in theory or practice. To filter out these insignificant relations, a threshold value λ is set. For $t_{ij} > \lambda$, then a directed edge from element i to element j is drawn in the prominence-relation map. Otherwise, such a directed edge does not exist. The calculation for λ is critical since having a low value implies that most of the relationship is significant, while having a high value implies that only a few relationships are significant. A handful of approaches have been put forward in determining λ within the context of the DEMATEL. One systematic approach is the MMDE algorithm proposed by Li and Tzeng [90], which has been demonstrated in some recent works, e.g., Gonzales et al. [40].

3.3. Maximum Mean Deentropy Algorithm. The MMDE algorithm is influenced by the concept of entropy to identify the effective information of the influence matrix and draws a threshold to filter the unnecessary information in the influence matrix [90]. Entropy is a physical measurement of thermal dynamics and has become an essential concept in the social sciences [91, 92]. In information theory, entropy is used to measure the expected information content of certain messages and is a criterion for the amount of 'uncertainty' represented by a discrete probability distribution. Entropy is affected by the probabilities of the elements in a system, where the larger the entropy is, the more uncertainty of single events is, which implies that the system is more unstable.
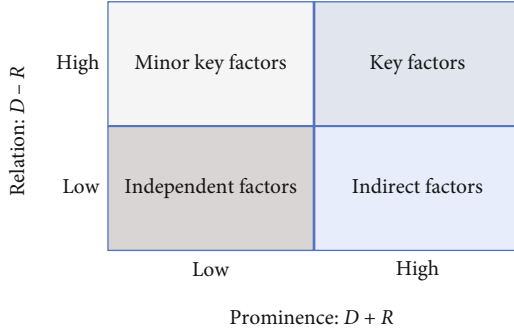
FIGURE 1: The prominence-relation map.

Three basic definitions featured by Li and Tzeng [90] are addressed as follows. Note that the notations adopted in this section are mostly lifted from Li and Tzeng [90].

Definition 6. Let a random variable with n elements be denoted as $X = (x_1, x_2, \cdots, x_n)$ with a corresponding probability $P = (p_1, p_2, \cdots, p_n)$, then, we define the entropy, $H(X)$ as follows

$$H(p_1, p_2, \cdots, p_n) = -\sum p_i \log p_i, \qquad (11)$$

where $\sum_{i=1}^{n} p_i = 1$ and $p_i \log p_i = 0$ if $p_i = 0$.

By Definition 6, $H(p_1, p_2, \cdots, p_n)$ is the largest when $p_1 = p_2 = \cdots = p_n$ and the largest entropy is denoted as $H(1/n, 1/n, \cdots, 1/n)$.

Definition 7. For a given finite discrete scheme of X, the deentropy of X is denoted as H^D and defined as

$$H^D = H\left(\frac{1}{n}, \frac{1}{n}, \cdots, \frac{1}{n}\right) - H(p_1, p_2, \cdots, p_n). \qquad (12)$$

Definition 8. The $t_{ij} \in T$ refers to a directed influence relation from element i to element j. For each t_{ij}, the element i is defined as a dispatch node and the element j as a receiving node.

Thus, the total relation matrix T can be considered as a set (set T) with n^2 pair ordered elements. There are ordered dispatch-node set T^{Di} and ordered receive-node set T^{Re} in the set T. If the number of the variables in T^{Di} or T^{Re} is m, the frequency of variables i or j is k, the probability of the variable is $p_i = k/m$. Thus, the probability of each variable can be defined and conform with Definition 6 for $\sum_{i=1}^{n} p_i = 1$. In the following description, $C(T^{Di})$ or $C(T^{Re})$ represents the cardinality of set T and $N(T^{Di})$ or $N(T^{Re})$ represents the cardinality of the different elements in set T. With the total relation matrix T of the DEMATEL and the Definitions mentioned above, the steps of finding the threshold value λ using the MMDE are described as follows.

Step 1. Transform T into ordered triplets T^*.

Transform the $n \times n$ total relation matrix T into an ordered set $T = \{t_{11}, t_{12}, \cdots, t_{21} t_{22}, \cdots, t_{nn}\}$, rearrange the ele-ment order in set T from large to small, and then transform to a corresponding ordered triplets set (t_{ij}, i, j) denoted as T^*.

Step 2. Construct the dispatch-node set (T^{Di}) and receive-node set (T^{Re}).

Take the second and third element from the ordered triplets of the set T and then obtain a new ordered dispatch-node set (T^{Di}) and receive-node set (T^{Re}). These two sets can be defined as follows:

$$\begin{aligned} T^{Di} &= \{i : i \in \{1, \cdots, n\}\}, \\ T^{Re} &= \{j : j \in \{1, \cdots, n\}\}. \end{aligned} \qquad (13)$$

Step 3. Calculate the MDE_t^{Di} and MDE_t^{Re} of T^{Di} and T^{Re}.

Take the first t elements of T^{Di} and T^{Re} as a new set T_t^{Di} and T_t^{Re} where $t = 1, 2, \cdots, C(T_t^{Di})$ or $C(T_t^{Re})$. Owing to the dispatch node and receive node appearing one time, $N(T^{Di})$ or $N(T^{Re})$ should be used to calculate the probabilities of different elements and calculate the H^{Di} and H^{Re} of the set T_t^{Di} and T_t^{Re}. Then, H_t^{Di}, H_t^{Re}, MDE^{Di}, and MDE_t^{Re} can be calculated by the following equations:

$$\begin{aligned} H_t^{Di} = H&\left[\frac{1}{C(T_t^{Di})}, \frac{1}{C(T_t^{Di})}, \cdots, \frac{1}{C(T_t^{Di})}\right] \\ &- H\left[\frac{k_1}{N(T_t^{Di})}, \frac{k_2}{N(T_t^{Di})}, \cdots, \frac{k_t}{N(T_t^{Di})}\right], \end{aligned}$$

$$\begin{aligned} H_t^{Re} = H&\left[\frac{1}{C(T_t^{Re})}, \frac{1}{C(T_t^{Re})}, \cdots, \frac{1}{C(T_t^{Re})}\right] \\ &- H\left[\frac{k_1}{N(T_t^{Re})}, \frac{k_2}{N(T_t^{Re})}, \cdots, \frac{k_t}{N(T_t^{Re})}\right], \end{aligned}$$

$$\text{MDE}_t^{Di} = \frac{H_t^{Di}}{N(T_t^{Di})},$$

$$\text{MDE}_t^{Re} = \frac{H_t^{Re}}{N(T_t^{Re})}. \qquad (14)$$

Step 4. Find the $T_{\max}^{Di}$ and $T_{\max}^{Re}$ with the MMDE.

Select the maximum MDE_t^{Di} and MDE_t^{Di} and their corresponding T_t^{Di} and T_t^{Re}. These are denoted as $T_{\max}^{Di}$ and $T_{\max}^{Re}$ and defined as

$$\begin{aligned} T_{\max}^{Di} &= \max\left(\text{MDE}_t^{Di}\right) = \{1, 2, \cdots, t^{\max}\}, \\ T_{\max}^{Re} &= \max\left(\text{MDE}_t^{Re}\right) = \{1, 2, \cdots, t^{\max}\}. \end{aligned} \qquad (15)$$

Step 5. Construct the maximum information set and identify the threshold value.

Union set T^* is formed by taking all elements of $T_{\max}^{Di}$ in the dispatch-node and $T_{\max}^{Re}$ in the receive-node. The minimum value in T^* is the threshold value denoted as T^{Th}.

4. Methodology

This section presents the application of DEMATEL under a neutrosophic environment along with the MMDE algorithm in determining the interrelationships of the factors affecting teaching quality in HEIs in the case environment (i.e., Philippines).

4.1. Case Study Information. The Philippines ranked 48th in the global talent ranking conducted by the Institute for Management Development (IMD), wherein one of the factors affecting the country's economic underperformance is underinvestment and underdevelopment in the education sector [93]. Moreover, out of 2,393 HEIs in the Philippines, only two (2) managed to grab a spot in the World University Rankings 2021 [94]. As a response to the state of quality education in the Philippines, the Commission on Higher Education (CHED) mandates HEIs to adapt learning competency-based standards and outcome-based systems to assure quality in Philippine educational institutions [95]. The government sector has also been championing the increase in teaching quality pursuant to K-12 curricula adaption, wherein HEIs have redesigned their curricula to cater to the changes brought by the transition [96]. However, despite the best intentions of the educational reform, certain challenges have been brought upon by the major overhaul in the country's educational system. The readiness of the HEIs for the implementation of the K-12 program was insufficient, wherein teaching requalification, realignment of curriculum, and workforce surplus management were some of the problems encountered [97]. These difficulties have brought in a significant impact on the quality of education associated with the transition. For instance, Almerino et al. [98] reported that Filipino students in some K-12 tracks have a generally below-average performance, implying unpreparedness for higher education.

Aside from the K-12 transition, Philippine higher education has also been challenged by the changes brought by the prominence of the 4th Industrial Revolution (4IR). The shift has encouraged HEIs to adopt technology-based approaches in teaching pedagogy, popularly branded as Education 4.0, which prompted the need to redesign the teaching curricula and techniques [99]. Technological competitiveness has been crucial to cope with the pace of Education 4.0 [99], wherein the Philippines is falling behind [100], especially the public universities. Aside from the challenges brought by the K-12 and Education 4.0 transition, the quality of education in the Philippines has long been known to have a poor global reputation [101]. The educational sector of the Philippine government has been acting to address this issue. However, since the quality of teaching is governed by various factors, certain aspects of the pedagogy may be overlooked. Furthermore, the enormity of the actors playing a significant role in HEIs contributed to the complexity of the educational system. Investments for the improvements in the education system can also be expensive, wherein financial resources may not be accessible to other countries. Moreover, according to Wang and Cui [102], achieving good teaching results that provide technical support for advancing the capabilities of the workforce, innovation, and reforms become crucial policy points. With the implementation of quality education, HEIs are now converging a more considerable emphasis on boosting quality requirements and classifying new breakthrough points to overcome critical challenges [103]. Thus, it is essential to determine the interrelationships among the factors of teaching quality in HEIs to identify the most relevant factors under uncertain environments. Hence, the application of neutrosophic DEMATEL to assess the factors of teaching quality is demonstrated in this work.

4.2. Application of Neutrosophic DEMATEL. The methodological framework for the neutrosophic DEMATEL procedure in assessing the factors affecting teaching quality in Philippine public universities is illustrated in Figure 2.

Step 1. Identify the factors affecting teaching quality in public universities. A list of factors can be constructed using a standardized list, literature survey, or focus group discussion of a given decision problem. In this work, a literature survey (i.e., described in Section 2) is conducted to determine the list of factors affecting teaching quality (see Table 1) in HEIs.

Step 2. Set up the initial direct-relation matrices in neutrosophic sets. Twenty-three (23) decision-makers affiliated with public HEIs in the Philippines are identified to respond to the survey conducted. Each of them is asked to assess the degree of the causal relationship of each factor to other factors of teaching quality using a predefined 5-point scale. The responses are extracted to construct 23 initial direct-relation matrices. To capture the vagueness and uncertainty within the dataset, these matrices were then transformed to their corresponding neutrosophic values using the linguistic evaluation scale shown in Table 2. The scale used was adopted and modified from the work of Yörükoğlu and Aydın [104].

Step 3. Aggregate the initial direct-relation matrices in the neutrosophic set. The initial direct-relation matrices in SVNNs were aggregated using Equation (3), and the resulting matrix is shown in Table 3.

Step 4. Construct a corresponding crisp of the aggregate direct-relation matrix. The corresponding crisp values of the aggregate initial-direct relation matrix in SVNNs were obtained using Equation (4). The resulting matrix is presented in Table 4.

Step 5. Generate the normalized direct-relation matrix. Equations (6) and (7) were utilized to construct the normalized direct-relation matrix shown in Table 5.

Step 6. Obtain the total relation matrix. The total relation matrix was generated using Equation (8), and the resulting matrix is featured in Table 6.

Step 7. Calculate the threshold value. The MMDE algorithm was utilized to determine the threshold value $\rho = 1.5525$ in this study. The results in the corresponding steps of the MMDE algorithm discussed in Section 3.3 are shown in Table 7.
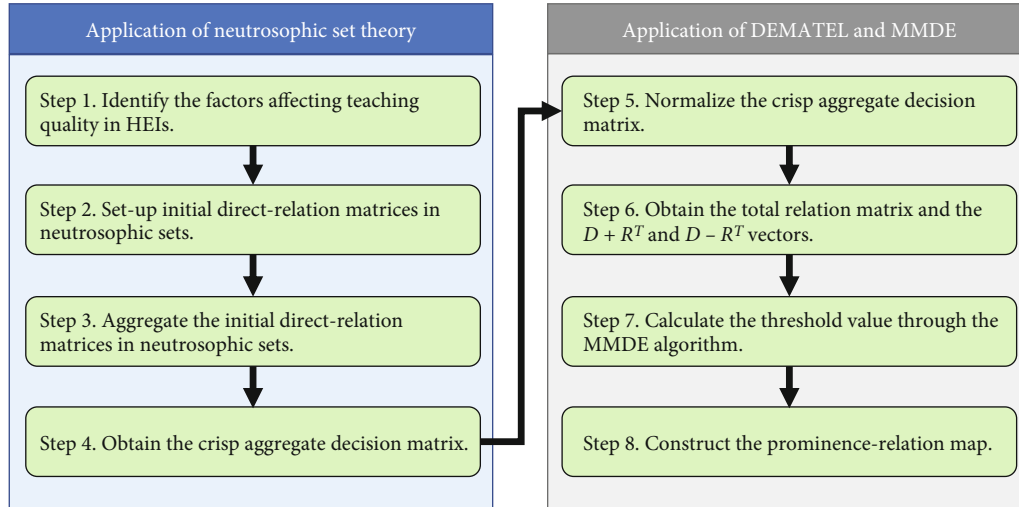
Figure 2: Methodological framework.

Table 1: Factors affecting teaching quality in public universities.

Code	Construct	Description	References
IC	Individual characteristics	Associated with the characteristics of individual teachers, which include age, gender, and position	Feldman [13]; Cho and Baek [12]
PC	Psychological characteristics	An enduring, relatively stable trait or set of traits, with a possible neuropsychological basis	Klassen and Tze [14]
SE	Self-efficacy	Beliefs in the capability to carry out desired courses of action in the service of valued goals	Klassen and Tze [14]; Holzberger et al. [15]
TM	Teaching motivation	Encouragement, motivation, and adaptive attributes of teachers in conducting their profession	Zee and Koomen, [17]; Praetorius et al. [16]
TE	Teaching experience	The number of years the teacher practices his or her profession.	Podolsky et al. [19]; Graham et al. [18]
PD	Professional development	A set of structured professional learning conducted by the institution that results in changes in teacher practices	Gore et al. [21]; Darling-Hammond et al. [20]
SC	Student composition	Sociocultural, cognitive, and motivational characteristics of the students	Fauth et al. [22]; Rjosk et al. [23]
SF	Student's feedback	Student's perception and assessment of teaching quality in the form of feedbacking	Bijlsma et al. [11]; Gaertner and Brunner, [24]; Hammonds et al. [25]
IS	Institutional culture	Embedded patterns, behaviors, shared values, beliefs, and ideologies of the educational institution	Kezar and Eckel [26]; Kustra et al. [27]
IR	Institutional resources	Instructional materials, curriculum, and other resources provided or created by the institution	Hill and Charalambous [28]; Hill et al. [29]

Table 2: Linguistic evaluation scale [104].

Linguistic variables	Influence scores	Equivalent SVNNs
No influence (NO)	0	$\langle 0.10, 0.80, 0.90 \rangle$
Very low (VL)	1	$\langle 0.35, 0.60, 0.70 \rangle$
Low (L)	2	$\langle 0.50, 0.40, 0.45 \rangle$
High (H)	3	$\langle 0.80, 0.20, 0.15 \rangle$
Very high (VH)	4	$\langle 0.90, 0.10, 0.10 \rangle$

Step 8. Construct the prominence-relation map. To construct the prominence-relation map shown in Figure 3, the $(D + R^T, D - R^T)$ coordinates were used. The values of the coordinates, presented in Table 8, were obtained using Step 6 and Step 7 in Section 3.2. Using the calculated threshold value ($\rho = 1.5525$), the significant relationships of the factors of teaching quality are represented by the directed edge drawn in the prominence-relation map.

5. Results and Discussion

Teaching quality is viewed as a collaborative and context-dependent construct influenced by interactions between teachers, students, and learning content [6, 105–107], thus, making it a prevalent topic in the literature. However, understanding the interdependences of its factors remains unexplored. The insights gained from understanding the

Table 3: Aggregate neutrosophic initial direct-relation matrix.

	IC	PC	SE	TM	TE
IC	<0.10, 0.80, 0.90>	<0.83, 0.16, 0.15>	<0.83, 0.16, 0.15>	<0.83, 0.17, 0.16>	<0.82, 0.18, 0.17>
PC	<0.82, 0.17, 0.16>	<0.10, 0.80, 0.90>	<0.85, 0.15, 0.14>	<0.83, 0.16, 0.15>	<0.78, 0.21, 0.20>
SE	<0.81, 0.18, 0.16>	<0.80, 0.19, 0.18>	<0.10, 0.80, 0.90>	<0.83, 0.17, 0.15>	<0.77, 0.22, 0.21>
TM	<0.77, 0.22, 0.21>	<0.77, 0.22, 0.21>	<0.83, 0.17, 0.16>	<0.10, 0.80, 0.90>	<0.83, 0.17, 0.16>
TE	<0.80, 0.19, 0.18>	<0.80, 0.19, 0.18>	<0.82, 0.17, 0.16>	<0.84, 0.15, 0.14>	<0.10, 0.80, 0.90>
PD	<0.81, 0.18, 0.16>	<0.78, 0.21, 0.19>	<0.83, 0.17, 0.15>	<0.84, 0.15, 0.14>	<0.82, 0.18, 0.17>
SC	<0.66, 0.31, 0.31>	<0.71, 0.28, 0.26>	<0.76, 0.22, 0.21>	<0.81, 0.18, 0.16>	<0.69, 0.29, 0.28>
SF	<0.74, 0.24, 0.24>	<0.75, 0.24, 0.23>	<0.78, 0.21, 0.20>	<0.84, 0.16, 0.15>	<0.74, 0.25, 0.25>
IS	<0.67, 0.31, 0.31>	<0.70, 0.28, 0.27>	<0.74, 0.25, 0.23>	<0.82, 0.18, 0.16>	<0.79, 0.20, 0.19>
IR	<0.61, 0.37, 0.36>	<0.65, 0.32, 0.32>	<0.75, 0.24, 0.22>	<0.83, 0.17, 0.15>	<0.81, 0.18, 0.17>
	PD	SC	SF	IS	IR
IC	<0.85, 0.14, 0.13>	<0.63, 0.33, 0.33>	<0.83, 0.17, 0.15>	<0.73, 0.25, 0.24>	<0.71, 0.28, 0.26>
PC	<0.83, 0.17, 0.16>	<0.65, 0.32, 0.31>	<0.83, 0.16, 0.15>	<0.74, 0.24, 0.22>	<0.61, 0.35, 0.35>
SE	<0.81, 0.18, 0.16>	<0.69, 0.30, 0.28>	<0.78, 0.21, 0.19>	<0.74, 0.25, 0.23>	<0.72, 0.27, 0.25>
TM	<0.83, 0.16, 0.15>	<0.68, 0.30, 0.30>	<0.85, 0.14, 0.14>	<0.77, 0.22, 0.21>	<0.65, 0.32, 0.32>
TE	<0.83, 0.17, 0.15>	<0.64, 0.33, 0.33>	<0.81, 0.19, 0.17>	<0.71, 0.27, 0.25>	<0.70, 0.29, 0.27>
PD	<0.10, 0.80, 0.90>	<0.67, 0.30, 0.29>	<0.81, 0.19, 0.17>	<0.76, 0.23, 0.21>	<0.74, 0.25, 0.24>
SC	<0.70, 0.28, 0.26>	<0.10, 0.80, 0.90>	<0.81, 0.18, 0.16>	<0.74, 0.24, 0.23>	<0.71, 0.26, 0.26>
SF	<0.78, 0.21, 0.20>	<0.76, 0.22, 0.22>	<0.10, 0.80, 0.90>	<0.77, 0.22, 0.20>	<0.76, 0.23, 0.21>
IS	<0.86, 0.14, 0.13>	<0.76, 0.23, 0.22>	<0.82, 0.18, 0.16>	<0.10, 0.80, 0.90>	<0.79, 0.21, 0.18>
IR	<0.84, 0.16, 0.14>	<0.79, 0.20, 0.19>	<0.81, 0.18, 0.17>	<0.82, 0.17, 0.15>	<0.10, 0.80, 0.90>

Table 4: Corresponding crisp values.

	IC	PC	SE	TM	TE	PD	SC	SF	IS	IR
IC	0.1500	0.8393	0.8408	0.8345	0.8221	0.8586	0.6597	0.8348	0.7494	0.7219
PC	0.8300	0.1500	0.8547	0.8408	0.7879	0.8332	0.6741	0.8410	0.7612	0.6394
SE	0.8221	0.8064	0.1500	0.8361	0.7813	0.8205	0.7030	0.7919	0.7492	0.7320
TM	0.7781	0.7817	0.8318	0.1500	0.8345	0.8405	0.6965	0.8572	0.7772	0.6708
TE	0.8064	0.8083	0.8300	0.8492	0.1500	0.8348	0.6618	0.8175	0.7281	0.7142
PD	0.8207	0.7940	0.8348	0.8480	0.8236	0.1500	0.6924	0.8152	0.7711	0.7510
SC	0.6802	0.7249	0.7782	0.8207	0.7086	0.7224	0.1500	0.8207	0.7585	0.7328
SF	0.7541	0.7611	0.7906	0.8425	0.7475	0.7923	0.7741	0.1500	0.7848	0.7724
IC	0.6854	0.7194	0.7537	0.8272	0.7978	0.8617	0.7702	0.8244	0.1500	0.7975
IR	0.6282	0.6714	0.7588	0.8348	0.8187	0.8468	0.8020	0.8187	0.8316	0.1500

overall structure of the factors of teaching quality with the consideration of their interdependences would provide significant insights for policymakers in HEIs to inform resource allocation decisions. With the steps provided in Section 3, the neutrosophic DEMATEL was performed in order to identify the critical causal relationships among factors and classify them as "net cause" or "net effect" factors. Results show that the most prominent factors of teaching quality are teaching motivation (TM), professional development (PD), and student feedback (SF). Prominence factors refer to those who have a high measure of $D + R^T$. A high measure of $D + R^T$ only implies relative significance but does not necessarily mean that the prominent factors are the most significant ones. They are deemed popular factors, with roles being a

cause or an effect. Accordingly, the ranking of factors based on their prominence is as follows: TM ≻ PD ≻ SF ≻ SE ≻ TE ≻ IC ≻ PC ≻ IS ≻ IR ≻ SC.

The relationship of the factors of teaching quality to the most prominent factor (i.e., teaching motivation) should also be highlighted. As illustrated in Figure 3, teaching motivation (TM) is significantly influenced by individual characteristics (IC), psychological characteristics (PC), teaching experience (TE), and professional development (PD). This result is consistent in a study conducted by Zee and Koomen [17] and Praetorius et al. [16], wherein they emphasized the linkage that exists between the teacher's competence, character, and professional development engagement. Based on this result, establishing initiatives to support professional

Table 5: Normalized direct-relation matrix.

	IC	PC	SE	TM	TE	PD	SC	SF	IS	IR
IC	0.0195	0.1092	0.1094	0.1086	0.1070	0.1117	0.0859	0.1086	0.0975	0.0940
PC	0.1080	0.0195	0.1112	0.1094	0.1025	0.1084	0.0877	0.1095	0.0991	0.0832
SE	0.1070	0.1049	0.0195	0.1088	0.1017	0.1068	0.0915	0.1031	0.0975	0.0953
TM	0.1013	0.1017	0.1083	0.0195	0.1086	0.1094	0.0906	0.1116	0.1012	0.0873
TE	0.1049	0.1052	0.1080	0.1105	0.0195	0.1086	0.0861	0.1064	0.0948	0.0930
PD	0.1068	0.1033	0.1086	0.1104	0.1072	0.0195	0.0901	0.1061	0.1004	0.0977
SC	0.0885	0.0943	0.1013	0.1068	0.0922	0.0940	0.0195	0.1068	0.0987	0.0954
SF	0.0981	0.0991	0.1029	0.1096	0.0973	0.1031	0.1007	0.0195	0.1021	0.1005
IC	0.0892	0.0936	0.0981	0.1076	0.1038	0.1121	0.1002	0.1073	0.0195	0.1038
IR	0.0818	0.0874	0.0988	0.1086	0.1066	0.1102	0.1044	0.1066	0.1082	0.0195

Table 6: Total relation matrix.

	IC	PC	SE	TM	TE	PD	SC	SF	IS	IR
IC	1.3651	1.4638	1.5283	1.5726	1.4991	1.5540	1.3555	1.5525	1.4520	1.3811
PC	1.4297	1.3645	1.5120	1.5549	1.4778	1.5330	1.3411	1.5350	1.4362	1.3558
SE	1.4249	1.4394	1.4240	1.5504	1.4733	1.5277	1.3410	1.5257	1.4313	1.3626
TM	1.4245	1.4411	1.5101	1.4732	1.4837	1.5345	1.3444	1.5376	1.4388	1.3601
TE	1.4249	1.4413	1.5071	1.5536	1.3991	1.5310	1.3379	1.5302	1.4305	1.3621
PD	1.4432	1.4566	1.5254	1.5718	1.4971	1.4673	1.3573	1.5481	1.4523	1.3824
SC	1.3573	1.3779	1.4448	1.4923	1.4115	1.4611	1.2254	1.4733	1.3803	1.3133
SF	1.4124	1.4294	1.4959	1.5459	1.4646	1.5194	1.3447	1.4436	1.4306	1.3627
IC	1.4077	1.4277	1.4949	1.5475	1.4733	1.5302	1.3472	1.5274	1.3573	1.3685
IR	1.3964	1.4174	1.4902	1.5431	1.4705	1.5233	1.3463	1.5216	1.4339	1.2862

Table 7: Results from the MMDE algorithm.

| Item	Data
Step 1. The ordered triplet set, T^*	$\left\{ \begin{array}{l} (1.5726,1,4), (1.5718,6,4), (1.5549,2,4), (1.5540,1,6), (1.5536,5,4), \\ (1.5525,1,8), (1.5504,3,4), (1.5481,6,8), (1.5475,9,4), \cdots, (1.2254,7,7) \end{array} \right\}$
Step 2. Dispatch-node set, T^{Di}	$\{1, 6, 2, 1, 5, 1, 3, 6, 4, \cdots, 7\}$
Step 3.1. T_i^{Di} sets and MDE_i^{Di} values	$T_1^{Di} = \{1\}$, $\text{MDE}_1^{Di} = 0$; $T_2^{Di} = \{1, 6\}$, $\text{MDE}_2^{Di} = 0$; $T_3^{Di} = \{1, 6, 2\}$, $\text{MDE}_3^{Di} = 0$; $T_4^{Di} = \{1, 6, 2, 1\}$, $\text{MDE}_4^{Di} = 0.0085$; $\cdots$
Step 3.2. Set of MDE_i^{Di} values	$\{0, 0, 0, 0.0085, 0.0059, 0.0156, 0.0117, 0.0100, 0.0083, \cdots, 0\}$
Step 4.1. Maximum MDE_i^{Di}	0.00156
Step 4.2. Dispatch-node set of maximum MDE_i^{Di}	$\{1, 6, 2, 1, 5, 1\} \Longrightarrow \{1, 6, 2, 5\}$
Step 5.1. Receive-node set, T^{Re}	$\{4, 4, 4, 6, 4, 8, 4, 8, 4, \cdots, 7\}$
Step 5.2. Set of MDE_i^{Re} values	$\{0, 0, 0, 0.0284, 0.0419, 0.0334, 0.0438, 0.0287, 0.0362, \cdots, 0\}$
Step 5.3. Maximum MDE_i^{Re}	0.0491
Step 5.4. Receive-node set of maximum MDE_i^{Re}	$\{4, 4, 4, 6, 4, 8, 4, 8, 4, 4, 4\} \Longrightarrow \{4, 6, 8\}$
Step 6.1. $T_{\max}^{Di}$	$\{(1.5726,5,11), (1.5718,6,4), (1.5549,2,4), (1.5536,5,4)\}$
Step 6.2. $T_{\max}^{Re}$	$\{(1.5726,5,11), (1.5540,1,6), (1.5525,1,8)\}$
Step 6.3. T^{Th}	$\{(1.5726,5,11), (1.5718,6,4), (1.5549,2,4), (1.5536,5,4), (1.5540,1,6), (1.5525,1,8)\}$
Step 6.3. Threshold value	1.5525
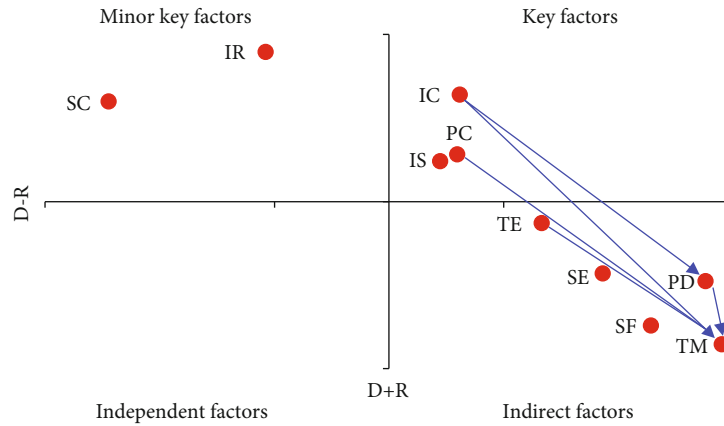
Figure 3: Prominence-relation map of the factors of teaching quality.

Table 8: Prominence-relation vectors.

Code	Factors	D	R^T	$D + R^T$	Rank	$D - R^T$	Category
IC	Individual characteristics	14.7240	14.0863	28.8103	6	0.6377	Net cause
PC	Psychological characteristics	14.5400	14.2592	28.7992	7	0.2808	Net cause
SE	Self-efficacy	14.5002	14.9326	29.4328	4	-0.4324	Net effect
TM	Teaching motivation	14.5480	15.4052	29.9532	1	-0.8571	Net effect
TE	Teaching experience	14.5177	14.6499	29.1676	5	-0.1323	Net effect
PD	Professional development	14.7016	15.1815	29.8830	2	-0.4799	Net effect
SC	Student composition	13.9374	13.3409	27.2783	10	0.5965	Net cause
SF	Student's feedback	14.4492	15.1951	29.6443	3	-0.7459	Net effect
IS	Institutional culture	14.4818	14.2433	28.7251	8	0.0000	Net effect
IR	Institutional resources	14.4289	13.5348	27.9637	9	0.8941	Net cause

development, help gain professional experience, and improve the psychological capacity of the human resources can significantly improve the teaching quality in an institution. Such initiatives may include teaching seminars, collaboration with other institutions, industry linkages, and research immersion.

Due to the interdependences of the factors of teaching quality, factors categorized as "net effect" (i.e., receivers) are consequently improved once the factors categorized as "net cause" (i.e., dispatchers) are addressed. Thus, decision-makers should focus more on the dispatchers in developing initiatives. Based on the results (see Table 8), the dispatchers are individual characteristics (IC), psychological characteristics (PC), student composition (SC), and institutional resources (IR). On the other hand, the receivers are self-efficacy (SE), teaching motivation (TM), teaching experience (TE), professional development (PD), student feedback (SF), and institutional culture (IS). Hence, policymakers should invest in adequate instructional, infrastructural, technological, and technical resources to ensure teaching quality. Every teacher is anticipated to employ tools to boost student learning, and the function of technology in schools is garnering a great deal of attention [108]. Aside from that, initiatives on personnel recruitment and character development should also be implemented by HEIs body to establish a pool of teachers with high competence and good character.

For identifying the significant factors of teaching quality, the $D + R^T$ and $D - R^T$ vectors must be simultaneously considered. Moreover, these vectors are utilized in constructing the prominence-relation map (see Figure 3). Findings suggest that the key factors (high prominence, high relation) are individual characteristics (IC), psychological characteristics (PC), and institutional culture (IS). On the other hand, institutional resources (IR) and student composition (SC) are considered as the minor key factors (low prominence, high relation) while teaching experience (TE), self-efficacy (SE), professional development (PD), student's feedback (SF), and teaching motivation (TM) are the indirect factors (high prominence, low relation). The focus should be on the key factors wherein individual characteristics (IC) are the most influential. It is essential to note that individual characteristics (IC) and psychological characteristics are categorized as a "net cause" factor, signifying its significance on the majority of factors of teaching quality. Thus, designing initiatives to improve this factor would significantly affect other factors of teaching quality.

We now direct our discussion to the key factors and minor key factors to establish policy takeaways that decision-makers in the HEIs, particularly in the Philippines, might explore to improve teaching quality. First, individual and psychological characteristics are internal to the teachers,

and HEIs have limited control once the teachers become part of the teaching faculty of the organization. It is then crucial to revisit and establish hiring and recruitment guidelines to ensure that candidates possess the necessary characteristics to effectively carry out teaching duties at the desired standard. Hiring decisions that would outline the characteristics of the candidates that HEIs will then consider must be guided by the latest empirical findings of the domain literature. The design of hiring standards must consider insights, for instance, regarding gender, age, marital status, intellectual capacity, class management, and communication (e.g., [63–67]). In addition, the standards must be integrated with mechanisms that can evaluate personalities, psychological traits, conscientiousness, and emotional stability, among an array of positive psychological characteristics of teachers. These insights are elaborated in some validated reports in the literature (e.g., [14, 68]). Nevertheless, careful examination of these individual and psychological characteristics requires attention so that existing laws are observed during the recruitment process. Second, institutional culture affects teaching quality, as implied in this work. This finding is supported by domain scholars, including Umbach [86], Cox et al. [85], and Kustra et al. [27]. HEIs must collectively promote a culture that emphasizes and recognizes learning excellence. The complexity of such an agenda, however, is overwhelming and requires a sustained collaboration of various actors for an extended period of time. Its overarching scope integrates planning and control measures associated with infrastructure spending, employee hiring, promotion, compensation and benefits, recognition schemes, resource allocation, and student admission policies, among other aspects. The repeated behavior of the HEI management in these areas would set the culture on how an organization views teaching quality. Managers of HEIs must carefully create a long-term roadmap that leverages their capabilities and seizes external opportunities in establishing a culture that puts a premium on the quality of teaching.

On the other hand, minor key factors of teaching quality include student composition and institutional resources. First, establishing a student composition scheme must be part of the strategic direction of HEIs. The findings of this work suggest that such a scheme influences teaching quality, which is supported by some reports (e.g., [22, 82, 83]). Extreme nonhomogeneity of a given class based on students' IQ, for example, confuses the learning environment that a teacher creates for the students. Consequently, students on both ends of the class spectrum may not capture the desired learning outcomes of the course. One best practice that some Philippine universities may exercise is the platform long established by the University of the Philippines (i.e., the Philippine flagship university) through the University of the Philippines College Admission Test (UPCAT), which categorizes students' intellectual capacity upon admission to a program. Such a platform regulates student composition in a class, which in consequence, helps facilitate a homogeneous learning environment that teachers can establish during the delivery of the course. Finally, the role of institutional resources could not be undervalued in improving teaching quality in HEIs. The capacity of an organization to support

crucial initiatives for upgrading laboratory facilities, purchasing cutting edge laboratory tools and equipment, building learning commons, improving libraries, enhancing internet infrastructure, providing support in carrying out faculty and student development programs, and constructing facilities that further promote teaching-learning process is key to keep teaching quality at desired levels. These insights are documented in the literature (e.g., [28, 29, 87]). Without those resources, especially financial resources, it would be difficult, if not impossible, for HEIs to realize their goals directed at achieving target teaching quality. Since both key factors and minor key factors of teaching quality exhibit interdependences, it is essential that HEIs effectively communicate them with their stakeholders to better define their collective roles [109]. Nevertheless, exploring these factors creates ripple effects for teachers and other stakeholders.

6. Conclusion and Future Agenda

This study combines neutrosophic set theory and the DEMATEL approach in systematically assessing the causal relationships among the factors of teaching quality. With factors obtained from a comprehensive review of the literature, the neutrosophic DEMATEL attempts to determine the critical interrelationships of these factors in ultimately identifying those factors that are net cause and net effect, based on expert assessments that take subjectivity into account. Applied in a case study of public universities in the Philippines, results suggest that individual characteristics, psychological characteristics, student composition, and institutional resources are part of the net cause group, which implies that they impact the rest of the factors, including self-efficacy, teaching motivation, teaching experience, professional development, student's feedback, and institutional culture. Those in the net cause group are influential in achieving teaching quality in HEIs. Findings also reveal three factors must be given more attention as they are deemed key in improving teaching quality. They include individual characteristics, psychological characteristics, and institutional culture. Meanwhile, supporting these key factors are the minor key factors which consist of institutional resources and student composition. Through its various initiatives, the HEI management must ensure that the key and minor key factors must be part of its strategic direction to achieve desired teaching quality. Decision-makers must revisit recruitment and hiring decisions to highlight individual and psychological characteristics that better support the quality of teaching and eventually develop a pool of teachers with high competence and strong character. Also, a roadmap of sustained and consistent decisions on different organizational aspects impacting teaching quality is necessary to build an institutional culture that prioritizes excellent teaching quality.

The results of this work contribute significantly to the current literature, as they provide meaningful insights on the overall structure of the factors affecting teaching quality. These results would aid decision-makers, especially HEIs, in resource allocation, human resource pooling, and strategy development. However, this work has its limitations. Since

the focus of this study is public universities, to some extent, the results do not hold the same grounds in the private setting. There may be factors of teaching quality present in private institutions that were not considered in this work. Moreover, countries outside the case environment (i.e., Philippines) have different cultures, resources, bureaucracy, and educational systems that the result of this study could not represent. For further agenda, the results of this work could be validated through statistical modeling (e.g., structural equation modeling), which would provide a valuable empirical scaffolding of the exploratory work demonstrated in this paper. Future work could also explore the use of other problem structuring methods, such as interpretive structural modeling, fuzzy cognitive mapping, fuzzy decision maps, and the weighted influence nonlinear gauge system (WINGS) in modeling the factors of teaching quality. Finally, other DEMATEL extensions that capture uncertainty (e.g., grey system theory, hesitant fuzzy sets, type-2 fuzzy sets, Pythagorean fuzzy sets, and Fermatean fuzzy sets) could be adopted, and the findings could be compared with the insights of this work.

Data Availability

The data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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