Neutrosophic Sets and Systems {Special Issue: NeutroGeometry, NeutroAlgebra, and Their Applications}, Vol. 71, 2024

University of New Mexico

Factors Affecting Educational Quality: A Study Using Neutrosophic Likert Scales and Fuzzy Set Qualitative Comparative Analysis

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Abstract. This study investigates the educational quality of graduate programs at public universities by employing neutrosophic set theory and fuzzy-set Qualitative Comparative Analysis (fsQCA). The analysis centers on three crucial factors: Teacher Training and Education (TTE), Educational and Technological Resources (ETR), and School Environment and Academic Climate (SEA). The results demonstrate that the combination of ETR (Educational Technology Readiness) and SEA (Student Engagement and Achievement) is the most reliable indicator of educational quality, with the highest overall metric of 0.826292. Although the ETR alone demonstrates substantial coverage, highlighting its wide-ranging significance, the study emphasizes the importance of considering both individual factors and their combinations in comprehending educational outcomes. The research offers crucial insights for enhancing educational quality by implementing focused strategies in resource allocation and improving the environment. Subsequent research should investigate these discoveries in various educational environments and consider supplementary variables such as socio-economic impacts and teaching methods. Another area of future research is to enhance the support of set-theoretic research methods based on neutrosophic sets.

Keywords: Educational Quality, Neutrosophic Likert Scales, Fuzzy Set Qualitative Comparative Analysis, fsQCA.

1 Introduction

Educational quality in graduate programs in public universities is a crucial issue that directly affects the professional and academic development of students and, therefore, the general quality of the educational system [1]. The research focuses on analyzing this quality using methods based on neutrosophic set theory, an innovative approach that allows us to capture the complexity and ambiguity inherent to the educational experience. The importance of the study lies in its potential to improve understanding of the multiple and often subjective dimensions of educational quality, offering a more complete and accurate perspective compared to traditional methods [2]. Historically, the evaluation of educational quality has evolved from approaches based on simple metrics to more sophisticated methods that consider qualitative and quantitative aspects. However, despite advances, many studies still do not adequately address the complexity of students' experiences in the context of graduate programs [3,4]. Neutrosophic set theory, which integrates indeterminacy and uncertainty into analysis, represents a significant advance in this field. This theory has proven to be useful in other research domains, but its application in the analysis of educational quality in graduate programs remains an emerging and underexplored area [5, 6].

Educational quality is a complex concept that involves not only measuring student learning but also evaluating the efficiency of educational processes and ensuring equity in access to education. Traditional methods of assessment, such as standardized tests, often fall short in capturing the richness of educational experiences, as they reduce quality to mere figures and percentages. This has led to a call for more holistic and multifactorial approaches that consider the broader socioeconomic context, curricular structure, and pedagogical practices that influence education. In this context, the application of neutrosophic set theory emerges as a promising alternative, offering a more adaptable evaluation method that can handle the uncertainty, indeterminacy, and inconsistency present in educational environments [7,8,9].

The neutrosophic approach offers a nuanced and inclusive understanding of educational quality by incorporating diverse perspectives and often-overlooked variables. It emphasizes the significance of both academic outcomes and the contexts in which they occur, such as motivation, the school environment, and pedagogical methods. Fuzzy Set Qualitative Comparative Analysis (fsQCA) enhances this by identifying combinations of factors that lead to varying levels of educational quality [10]. This study integrates neutrosophic Likert scales [11] with fsQCA to analyze the complex causality between factors and educational quality, a method recently proposed for more comprehensive evaluation.

2 Preliminaries

2.1 fsQCA and neutrosophic sets.

The relationships between variables are not always simple and often manifest through complex and non-linear patterns, as postulated by complexity theory [12, 13, 14]. This implies that the same cause can trigger different effects depending on the context in which occurs. Three fundamental principles stand out in this theory, conjunction, equifinality and causal asymmetry [15]:

- The concept of conjunction is based on the collaboration between antecedent conditions that function collectively to produce a result, rather than operating individually to account for variation.
- Equifinality refers to the concept that a system can achieve the same result despite starting from various initial conditions and following different paths.
- Causal asymmetry, however, asserts that although certain conditions can cause a result to occur, the absence of those conditions does not necessarily ensure the absence of the result.

Fuzzy Set Qualitative Comparative Analysis (fsQCA) [16, 17] is a modeling technique that incorporates the principles of conjunction, equifinality, and causal asymmetry to capture the complexity of relationships between conditions and outcomes. It identifies the conjunction of antecedent conditions that collectively contribute to the production of an outcome, acknowledging that various initial conditions can lead to the same result. Furthermore, fsQCA demonstrates the notion of causal asymmetry by illustrating that although specific conditions may be required for a particular result, the absence of these conditions does not necessarily hinder the occurrence of that result. This highlights the complex and non-linear nature of causality in intricate systems.

Moreover, the concept of neutrosophy can enhance the comprehension of intricate causality by introducing the inherent qualities of indeterminacy and uncertainty in social phenomena [18, 19]. The application of neutrosophic set theory, which can effectively deal with indeterminacy, provides a more sophisticated perspective for comprehending these intricate relationships [20].

2.2 Neutrosophic Liker Scales

Surveys that utilize neutrosophic Likert scales [21] are efficient in assessing the range of opinions and their impact on public policy and social discourse. These surveys accurately capture areas of agreement, disagreement, and uncertainty.

Here, we provide the essential definitions and concepts pertaining to neutrosophic sets and single-valued neutrosophic sets.

Definition 1 ([22]). Let U be a universe of discourse. $N=\{(x, T(x), I(x), F(x)): x \in U\}$ is a neutrosophic set, denoted by a truth membership function, $TN: U \rightarrow]0^-, 1^+[$; an indeterminacy membership function, $IN: U \rightarrow]0^-, 1^+[$; and a falsity membership function, $FN: U \rightarrow]0^-, 1^+[$.

Single-valued neutrosophic sets provide a way to represent and analyze possible elements in the universe of discourse U

Definition 2 ([23]). Let U be a universe of discourse. A single-valued neutrosophic set is defined as $N=\{(x, T(x), I(x), F(x)): x \in U\}$, which is identified by a truth membership function, $TN: U \rightarrow [0, 1]$; indeterminacy membership function, $IN: U \rightarrow [0, 1]$; and falsity membership function, $FN: U \rightarrow [0, 1]$, with $0 \leq TN(x) + IN(x) + FN(x) \leq 3$

Using neutrosophic scales with single value neutrosophic sets, responses are classified according to the total of the True, Indeterminate and False components as follows:

- T+I+F=1: Complete
- T+I+F<1: Incomplete
- T+I+F>1: Contradictory

These values are derived from situations where opinions are often incomplete or contradictory. The categorization mentioned here is a notable benefit of employing neutrosophic methods, as it enables a more intricate comprehension of the varying levels of accuracy, uncertainty, and falsehood in responses [24].

For integrating neutrosophic Likert scales into the fsQCA framework is necessary to develop a fuzzification process. Given $AN = \{x, (TA(x), IA(x), FA(x)) : x \in X\}$ a NS. Its equivalent fuzzy membership set is defined as $AF = \{(x, \mu A(x)) : x \in X\}$,where $\mu A(x) = s\left((TA(x), IA(x), FA(x)), (1,0,0)\right)$. So, using the similarity equation proposed in [25],

$$\mu A(x) = 1 - \frac{1}{2}[(1 - T_A(x)) + \max\{I_A(x), F_A(x)\}] \quad (1)$$

The range of the similarity measure function is in the unit interval [0,1], μA (x) ∈ [0,1] for all x ∈ X. Therefore, the membership function of the derived fuzzy set belongs to [0, 1] and satisfies the property of a membership function of a fuzzy set [26].

3 Proposed framework

Each stage of the proposed framework is accompanied by a brief explanation, which makes it easier to understand the process in its entirety.

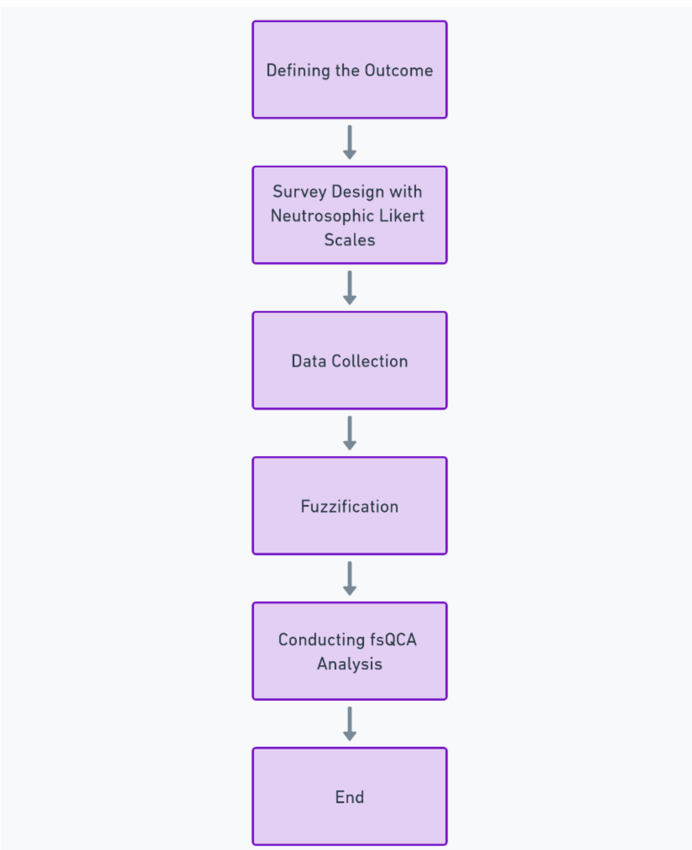

Figure 1. Process Flowchart for Analysis with Neutrosophic Likert Scales and fsQCA

Defining the outcome: Begin by identifying and accurately describing the specific phenomenon, event, or condition you want to investigate. This stage is crucial, as it establishes the focus and frame of reference for the entire analysis.

Survey Design with Neutrosophic Likert Scales: Next, design neutrosophic Likert scales that will be used to measure both the outcome and the associated variables. Unlike conventional Likert scales, which use a fixed scale (such as 1 to 5), neutrosophic scales introduce elements of truth, indeterminacy, and falsehood. Each option on the scale is represented by a triplet (T, I, F), where T indicates the degree of truth, I the degree of indeterminacy, and F the degree of falsehood. This approach allows for a more detailed interpretation of participants' responses and attitudes.

Data Collection: Data collection is conducted through surveys that utilize Neutrosophic Likert scales. These scales allow for the capture of more nuanced and complex opinions and attitudes of respondents, enhancing the richness of the data set. This approach ensures that the collected data is comprehensive and accurately reflects the variables under study, using various indicators or measures related to the defined outcomes. and attitudes.

Fuzzification: the neutrosophic sets obtained are transformed into equivalent fuzzy sets, following the procedure described in Equation 1.

Conducting fsQCA Analysis: Perform fsQCA to identify which combinations of factors or conditions are associated with the presence or degree of the outcome. The fsQCA program for Windows is used for data processing [18, 19].

The validity of the configuration is evaluated by measuring the consistency and coverage values. Consistency is the measure of the reliability with which the set of pathways produces the desired result. Coverage refers to the degree to which the result is clarified by this arrangement of pathways [20]:

$$Consistency\ (Y_i \leq X_i) = \frac{\sum \min (X_i, Y_i)}{\sum Y_i} \quad (2)$$

$$Coverage\ (Y_i \leq X_i) = \frac{\sum \min (X_i, Y_i)}{\sum X_i} \quad (3)$$

where:
X_i is the membership value of case i in the set of causal conditions.
Y_i is the membership value of case i in the result set.

Both metrics are used in comparative analysis to evaluate the relationships established between individual conditions, combinations of conditions, path configurations, and the final result. Generally, values greater than 0.8 are considered indicators of a strong relationship [20].

4 Results.

The defined result is the perception of the **Quality of education (QE)** . A Likert scale is developed, represented as single-valued neutrosophic sets. The study also considers the following variables:

Teacher training and education (TTE): The level of preparation and quality of continuous training that teachers receive are essential to guarantee high-quality education.

Educational and technological resources (ETR): The availability and access to teaching materials, educational technologies and learning tools directly impact the quality of the educational process.

School environment and academic climate (SEA): A safe, inclusive and stimulating school environment promotes effective learning and improves the quality of education.

A survey was conducted with a group of 12 university professors from Ecuador (see Table 1).

Table 1. Survey data

No	Teacher training and training	Educational and technological resources	School environment and academic climate	Quality of Education
1	(0.9, 0.8, 0.1)	(0.6, 1, 0.6)	(0.3, 0.7, 0.3)	(0.8, 0.6, 0.7)

No	Teacher training and training	Educational and technological resources	School environment and academic climate	Quality of Education
2	(0.6, 0.6,0.6)	(1,1,1)	(0.6,0.1,0.6)	(0.6, 0.6, 0.7)
3	(0.8, 0.7, 0,4)	(0.7, 0.9, 0.6)	(0.8, 0.6, 0.6)	(0.9, 0.5, 0.3)
4	(1,1,0)	(0.8,0.8,0)	(1,0.9,0.3)	(0.7, 1, 0.9)
5	(1,0.6,0)	(1,0.6,0.4)	(0.8,0.5,0.2)	(0,9, 0,6, 0,1)
6	(0.9, 0.8, 0.7)	(0.8, 0.6, 0.4)	(0.7, 0.6, 0.5)	(0.8, 0.6, 0.6)
7	(0.1, 0.6, 0.8)	(1,0,0)	(0.6, 0.6, 0.6)	(0.8, 0.6, 0.1)
8	(1, 0.9, 0.1)	(0.8, 0.7, 0.1)	(0.8, 0.8, 0.1)	(0,9, 0,9, 0,1)
9	(1,1,0)	(0.8, 0.7, 0.1)	(1,0,0)	(0.9, 0, 0)
10	(0.7, 1, 0.1)	(0.9, 0.4, 0)	(0.6, 0.9, 0.1)	(1,0,0)
11	(0.4, 0.7, 0.1)	(0.3, 0.9, 0.4)	(0.8, 0.4, 0.6)	(0.4, 0.8, 0.3)
12	(0.6, 1, 0.6)	(0.6, 0.6, 0.1)	(0.1, 0.6, 0.7)	(1,0,0.8)

The fuzzification process is developed using Equation 1. (Table 2)

Table 2. Fuzzy values

No	Teacher training and training	Educational and technological resources	School environment and academic climate	Quality of Education
1	0.55	0.30	0.30	0.55
2	0.50	0.50	0.50	0.45
3	0.55	0.40	0.60	0.70
4	0.50	0.50	0.55	0.35
5	0.70	0.70	0.65	0.65
6	0.55	0.60	0.55	0.60
7	0.15	1.00	0.50	0.60
8	0.55	0.55	0.50	0.50
9	0.50	0.55	1.00	0.95
10	0.35	0.75	0.35	1.00
11	0.35	0.20	0.60	0.30
12	0.30	0.50	0.20	0.60

A necessary condition analysis is performed to test consistency and coverage (Table 3).

Table 3. Analysis of necessary conditions

Tested conditions	Consistency	Coverage
Teacher training and education (TTE)	0.717241	0.936937
Educational and technological resources (ETR)	0.806897	0.893130
School environment and academic climate (SEA)	0.786207	0.904762

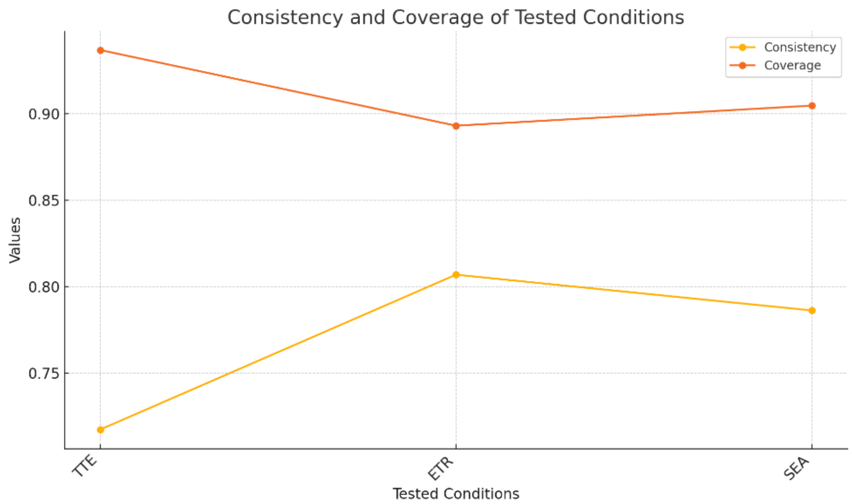

Figure 2. Analysis of necessary conditions (consistency and coverage)

The analysis of necessary conditions using consistency and coverage values for the three evaluated categories (Teacher training and development - FCA, Educational and technological resources - RET, and School environment and academic climate - TCA) reveals key insights within the context of fuzzy-set Qualitative Comparative Analysis (fsQCA). The highest consistency is observed for "Educational and technological resources (RET)," indicating it as the most consistently necessary condition. However, "Teacher training and development (FCA)" exhibits the highest coverage, suggesting it explains a significant proportion of the cases where the outcome occurs. "School environment and academic climate (TCA)" also plays an important role with high values in both consistency and coverage. Overall, while all conditions are crucial, RET stands out as the most necessary condition, and FCA is key in most cases where the outcome is achieved. These findings are essential for understanding the dynamics influencing the outcome and can inform educational policy and strategic planning.

The results of the superset analysis are shown in Table 4.

Table 4. Results of the subset/ superset analysis

Terms	Consistency	Coverage	Combined
TTE*ETR*SEA	0.958333	0.634483	0.792552
ETR*SEA	0.961538	0.689655	0.826292
TTE*ETR	0.940000	0.648276	0.797064
TTE*SEA	0.950980	0.668966	0.809683
ETR	0.893130	0.806897	0.875529
SEA	0.904762	0.786207	0.868768
TTE	0.936937	0.71724	0.838389

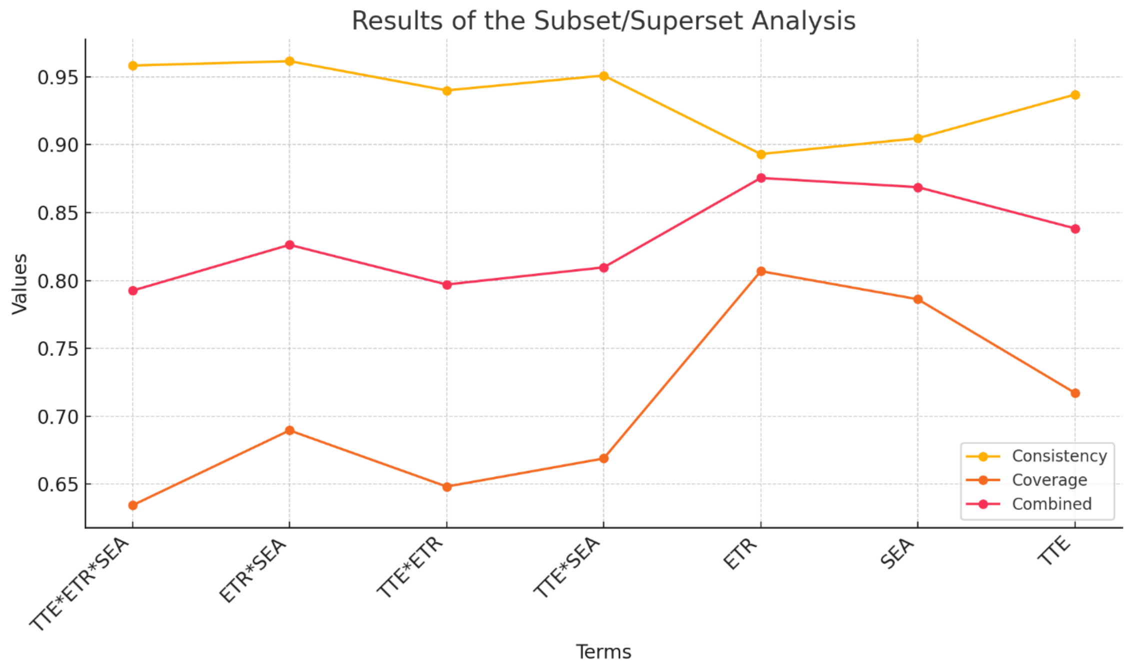

Figure 3. Results of the Subset/Superset Analysis

The subset/superset analysis reveals that the combination "ETR*SEA" (Educational and Technological Resources combined with School Environment and Academic Climate) is the most robust predictor of the outcome, with the highest combined metric of 0.826292, indicating strong consistency and good coverage. While this combination is highly consistent, individual conditions like "ETR" (Educational and Technological Resources) exhibit the highest coverage at 0.806897, suggesting they explain a significant proportion of cases where the outcome occurs. Overall, the analysis highlights the importance of both specific combinations of conditions and individual factors in predicting the desired outcome, providing valuable insights for strategic decision-making and policy development.

Conclusions

The study's conclusions highlight the critical role that Educational and Technological Resources (ETR) and the School Environment and Academic Climate (SEA) play in determining the quality of education in graduate programs. The superset analysis identifies the combination of ETR and SEA as the most robust predictor of educational quality, with the highest combined metric of 0.826292, underscoring the importance of these factors when considered together. While the ETR condition alone also shows significant coverage, indicating its broad applicability, the analysis emphasizes that both individual factors and their combinations are crucial for understanding and improving educational outcomes in public university graduate programs. This nuanced understanding of educational quality is essential for developing targeted strategies that enhance both the resources available to students and the environments in which they learn.

For future research, it is suggested that the application of neutrosophic set theory and fuzzy-set Qualitative Comparative Analysis (fsQCA) be expanded to include a more diverse range of educational settings and larger sample sizes. Further exploration into other combinations of conditions, such as the inclusion of socio-economic factors or variations in pedagogical practices, could provide a deeper understanding of the complexities influencing educational quality. Additionally, longitudinal studies could assess the long-term impact of these identified factors on student outcomes, helping to refine and validate the findings over time. Such research would contribute significantly to the ongoing effort to optimize educational quality across different contexts. Another area of future research is to enhance the support of set-theoretic research methods based on neutrosophic sets.

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Received: June 17, 2024. Accepted: August 7, 2024