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TEC 21 Model and Critical Thinking: An NCM-based Neutrosophic Analysis in Higher Education

Mohd Anas Wajid[1], Claudia Camacho-Zuñiga[2], Florentin Smarandache[3], Hugo Terashima-Marin[4], Mohammad Saif Wajid[5], and Mohammad Kaif Wajid[6]

[1]Institute For the Future of Education, Tecnologico de Monterrey, Monterrey, Mexico.
E-mail: anaswajid.bbk@gmail.com
[2]Institute For the Future of Education, Tecnologico de Monterrey, Monterrey, Mexico.
E-mail claudia.camacho@tec.mx
[3]University of New Mexico, 705 Gurley Ave., Gallup, NM 87301, USA. E-mail: smarand@unm.edu
[4]Department of Computer Science, School of Engineering and Sciences, Tecnológico de Monterrey, Monterrey, Mexico. E-mail: terashima@tec.mx
[5]Department of Computer Science, School of Engineering and Sciences, Tecnológico de Monterrey, Monterrey, Mexico. E-mail: mohdsaif06@gmail.com
[6]Institute of Management Sciences, Lucknow University, India.

Abstract: With a growing emphasis on developing transverse competencies in students, many educational institutions are trying to revolutionize the traditional system of education. One among others is TEC de Monterrey in Mexico which refines its educational models so that the students can be nourished with the skills that prepare them not only for the present but for years to come. Among skill development transverse competencies are considered a key to the successful career development of a student that emphasizes on critical thinking aspect. So mainly the the educational models try to inculcate or enhance the critical thinking of students. Towards this goal, TEC introduced the TEC21 model that is oriented towards critical thinking skill development of the students. The current work in this regard utilizes real-time student data collected using the eOpen instrument and takes into consideration experts' opinions to analyze the TEC21 model. The determinate factors are taken from the TEC21 model and indeterminate factors are identified from the literature. As real-time data especially educational data contain much uncertain, indeterminate, and unknown information, therefore this research introduces the use of Neutrosophic Logic to address the uncertainty of the data. Through the use of neutrosophy, we have shown how indeterminate factors when considered for analysis give a better representation of information. We have also compared neutrosophic cognitive maps with used earlier fuzzy cognitive maps to show their effectiveness in this regard. Overall system developed using NCM gives a better analysis of educational models like TEC21. This is the only work now that has utilized neutrosophy to understand and analyze the TEC21 model.

Keywords: Educational Innovation, Higher Education, TEC21 Model, Neutrosophy, Data Science, Critical Thinking

1. Introduction

The need of society pushes towards the development of not only physical infrastructure but also a lot of development is needed towards the development of the human mind for efficient and effective utilization of resources. Keeping this in mind prominent educational institution TEC de Monterrey keeps on enhancing its educational models to better prepare its students for a better tomorrow. In light of this TEC has proposed an educational model TEC21 which is mainly focused on developing transverse competencies among students [8]. Though this model is in its development phase, here in the present work we try to analyze the model through a very popular approach of neutrosophic cognitive maps (NCMs) [9] [17]. NCMs are the extension of Fuzzy Cognitive Maps with an addition that allows us to quantify the uncertainty that holds a very important position when it comes to modeling uncertain, unknown, and indeterminate factors. Neutrosophy is a branch of philosophy that deals with indeterminacy, contradiction, and incomplete information. The neutrosophic set theory allows for the representation of indeterminate, imprecise, and inconsistent information, which can be useful in situations where traditional binary logic and crisp sets may not fully capture the complexities of the analysis. In a nutshell, we can say that NCM analysis explicitly considers the degree of indeterminacy or ambiguity associated with each factor whereas traditional FCM analysis typically treats factors as either present or absent, without explicitly accounting for degrees of uncertainty. Overall, NCM analysis provides a more flexible and nuanced approach to analyzing the external environment, particularly in situations where information is incomplete or uncertain.

It can help decision-makers better understand the complexities of the external environment and make more informed decisions in response to changes in these factors. Therefore in the present work we have used NCMs to analyze the effect of uncertain and indeterminate factors on the currently running TEC21 model in Tecnologico de Monterrey, Monterrey, Mexico to show how we can take into consideration unknown factors in analyzing any situation. We'll use neutrosophic numbers to represent the degrees of truth, indeterminacy, and falsehood for each factor.

The motivation for employing NCMs for analyzing the TEC 21 model lies in its ability to handle the uncertainties and complexities of the model's external environment. The TEC 21 model operates within a dynamic educational landscape where factors such as technology, policies, and societal trends are constantly evolving. NCM offers a more comprehensive approach by not only considering the presence or absence of these factors but also their degrees of truth, indeterminacy, and falsehood. This nuanced analysis can help in identifying potential risks and opportunities related to the TEC 21 model, enabling organizations to make more informed decisions and develop adaptive strategies. Furthermore, employing a novel approach like NCM can contribute to research and innovation in the field of educational technology, leading to new insights and methodologies for analyzing and improving educational models.

1.1. TEC 21 Model

TEC de Monterrey has always focussed on nourishing young minds to make them aware of what the current world requires. It has always focussed on training our young people and future professionals to have a strong emphasis on addressing the current problems that society demands to address. Tecnologico de Monterrey is known for leading in educational models and innovations. Their new model focuses on practical education, blending theory with skills. Starting in 2019, this model is being gradually implemented in all courses, aligning with Education 4.0. It offers students engaging projects that develop new skills, competencies, and knowledge. The TEC21 Educational Model, implemented on 26 campuses, aims to enhance student´s competitiveness through comprehensive training and active learning activities. It fosters entrepreneurship, leadership, and innovation competencies, with dedicated spaces like libraries, learning commons, and InnovAction Gym for collaborative work. Challenge-based learning is central to the TEC21 model, addressing industry needs and developing digital-based solutions. This model emphasizes the importance of incentives and proper distribution channels for industry collaboration. Academic institutions need to immerse students in real challenges to achieve better results. The TEC21 model focuses on developing competencies for work and lifelong learning, including disciplinary and transversal competencies necessary for professional practice in various sectors. This goal of TEC has enabled it from time to time to come up with different strategies to refine its education models. In light of this TEC has generated a differentiating strategy in its new TEC21 Educational Model. The new model has its focus on building transverse competencies that future professionals must develop in both the disciplinary and personal aspects. The model's main aim is towards the development of these competencies through four major pillars that promote student transformation. These major pillars are: A) Challenging and interactive learning experiences, B) Flexibility in the teaching-learning process, C) The building of a memorable university experience, and, D) Inspiring innovative teachers [8]. The TEC21 Educational Model integrates the purposes of the vision, defines and links the actors and components that participate in the teaching-learning process and takes advantage of opportunities to offer students a comprehensive education of international quality. Its objective is to provide comprehensive training and improve the competitiveness of students in their professional field by enhancing the skills of future generations to develop the competencies required to enable them to become leaders who will face the challenges and opportunities of the 21st century. In August 2019, the Tecnologico de Monterrey (Tec Mty) began to implement the Tec21 Educational Model [6] [7]. Since its inception, many studies have been conducted to ascertain the objectives of this model. The present work in this regard has focused mainly on the influence of uncertainties and indeterminacy on the successful implementation of this model in TEC de Monterrey. The TEC21 model at Tecnológico de Monterrey is an innovative educational model focused on developing competencies through challenge-based learning. The model emphasizes the following key factors and these are the well-defined and measurable aspects of the TEC21 model. For the current study, they are considered as determinate factors throughout this paper.

These are as follows [8].

- Critical Thinking Skills (C1)
- Problem-Solving Ability (C2)
- Creativity (C3)
- Collaboration (C4)
- Communication Skills (C5)
- Self-Regulation (C6)
- Reflective Thinking (C7)

The rest of the paper is divided into 5 sections. Section 2 and Section 3 present extensive literature surveys and methodology respectively. Section 4 is focused on results and discussion whereas Section 5 presents the conclusion of the present work.

2. Literature Survey

With the growing need to bring evolution to education, there have always been efforts to propose new methodologies for refining the education systems across the globe. These efforts are put not only by the academicians but also a lot more is done by the researchers who continuously study the scenarios and come up with different strategies to propose new methods to refine the education system by taking insights from the real-time data. In light of this many researchers have studied the newly introduced TEC21 model in TEC de Monterrey, Monterrey, Mexico. Hugo A López et al. [10] studied the model and provided a way to integrate Education 4.0 with the present model to prepare students for the needs of Industry 4.0. Their research presented a case study of a Capstone project developed with undergraduate engineering students. Through this, they contributed towards showing that a suitable educational framework is needed for making students capable of addressing the demands of Industry 4.0. Guillermo Gándara Fierro et al. [11] have analyzed this model by taking a case study based on the first semester results. Through this work, they proposed the possibility of helping the community's transformations. Under the new Tec21 Educational Model, Cintia Smith et al. [12] designed a strategy for the "Citizenship and Technology" course for the students. The design was proposed in a mixed-model scheme through which they detected areas of opportunity that signaled the need to make important adjustments in the activities design. They claimed that these changes in the strategy are needed to fulfill the following four major goals. These goals are to generate evidence of competence development; make adjustments to class dynamics for the correct teaching process, simplification of the evaluation mechanisms, and reconceptualization of special guests profile. Their study forms the basis for showing that the TEC21 model is not static but is open to changes. As the focus of the model is on the development of transverse competencies among students, there is a clear need for the methods for its development. Helena Belchior-Rocha et al. [13] have studied the importance of transverse competencies among the students enrolled in higher education courses. The authors in their latest work have stated that the acquisition of transversal competencies is affected by social, economic, technological, and political changes in the surrounding environment. Jean Cushen [14] evaluated the significance of the development of transversal competencies among the students of higher education. Through a comprehensive evaluation of its importance in the industry, the authors concluded that transversal competencies are expected to play a definitive role in future work scenarios. They analyzed the decisions and impacts surrounding the integration of transversal competencies into higher education assessments. They also focussed on the changes that higher education leaders must make. Jesús García-Álvarez et al. [15] provided a systematic review of the transversal competencies for employability in university graduates from an employer's perspective, with consideration of the importance of the topic in the cross-national context. The authors claimed the importance of these competencies through data collected from published articles from Scopus and Web of Science journals. For this purpose, the authors classified 41 transversal competencies into five dimensions. Hanesová et al. [16] focussed their research mainly on the development of transverse competencies together with taking into consideration the changing the forms of education so that they lead to the development of these competencies. The author's main objective was to design a new framework for mastering transversal competencies in a higher education environment.

Later they proposed that their framework could be updated based on processes of critical thinking and reflection. The extensive literature survey has given us more insights and data that influence the determinate factors in a significant manner. Like authors [1] Deci and Ryan discussed how intrinsic and extrinsic motivations drive student´s behaviors and learning outcomes. They emphasize that motivation is influenced by various internal and external factors, making it a complex and variable aspect of education. This is considered indeterminate as motivation fluctuates based on personal interests, external rewards, and situational factors, introducing uncertainty into its measurement and influence on educational outcomes. On the other hand, Hattie highlights the significant impact of different teaching methods on student achievement [2]. The effectiveness of these methods varies depending on context, student needs, and implementation strategies. This is considered an indeterminate factor in current work as the variability in the teaching method´s effectiveness, dependent on numerous contextual factors, introduces uncertainty in their impact on student learning. Garrison and Kanuka explored the transformative potential of blended learning, which combines online and face-to-face instruction [3]. The impact of technological tools varies based on their integration, student engagement, and technological proficiency. This factor is indeterminate as the effectiveness of technological tools is uncertain due to differences in implementation quality, technological accessibility, and student´s adaptability to technology. The renowned researcher Fraser discusses the development and importance of classroom environment instruments, emphasizing how physical and psychological classroom conditions affect student learning and behavior [4]. They emphasized that the classroom environment is influenced by dynamic interactions between students and teachers, as well as the physical setup, making its impact on learning unpredictable. Therefore this plays an important role in the successful implementation of any educational model. This can be considered as an indeterminate factor for this study.

Many researchers have emphasized the assessments happening in institutions for the successful implementation of educational models. Black and Wiliam analyzed various assessment techniques and their effects on learning [5]. They highlighted that the effectiveness of assessments depends on their design, implementation, and student´s perceptions. The impact of assessment techniques is indeterminate due to differences in assessment types, teacher practices, and student responses to assessments. Therefore, all these factors are termed as indeterminate or uncertain throughout the study. Below we mention five such factors I1-I5.

- Student Motivation (I1) [1]
- Teaching Methods (I2) [2]
- Technological Tools (I3) [3]
- Classroom Environment (I4) [4]
- Assessment Techniques (I5) [5]

The indeterminate factors I1-I5 are mathematically represented by the neutrosophic sets and systems. Netrosophic theory is not limited to the field of mathematics but it is spreading its wings in various other fields. Researchers around the globe have employed neutrosophic techniques to solve several problems prevailing in the current scenario i.e. in [18] [19] it is being used to solve the problem in multi-criteria decision-making. Authors in [20] have used neutrosophic sets in understanding and enhancing the supply chain sustainability in the current scenario. The proposed approach claims to be efficient in solving decision-making problems while meeting the supply chain sustainability requirement. Authors in [21] used IoT and Fog computing to propose a healthcare system for the prediction and diagnosis of diseases. For this purpose, they introduced a neutrosophic multi-criteria decision-making technique. The above work by prominent researchers proved that the application of neutrosophic theory in various fields of research is the need of the hour and our research methodology for addressing the uncertainty in educational models is based on this.

3. Methodology

The proposed solution to indeterminacy uses the concept of a Neutrosophic Cognitive Map (NCM). It is a technique in Neutrosophy introduced by W. B. Vasantha Kandasamy [23]. The concept of Neutrosophic logic was introduced by Florentine Smarandache [22] [23], which is a merger of fuzzy logic together with the inclusion of indeterminacy.

When data under scrutiny contains indeterminate concepts, we are not able to formulate mathematical expressions. Presentation of Neutrosophic logic by Florentine Smarandache [24] [25] has put forward a panacea to this problem. It is the reason Neutrosophy has been introduced as an additional notion for the evaluation of educational models. Fuzzy theory evaluates the existence or non-existence of associateship but it has been less efficient to attribute the indeterminate relations among concepts but most data collected in the educational setup has many indeterminate and uncertain concepts. Therefore we have employed Neutrosophic Cognitive Maps (NCMs) in place of Fuzzy Cognitive Maps (FCMs) to evaluate the TEC21 model. Earlier research for evaluating the TEC21 model has not included indeterminacy which is a part and parcel of real life. Hence when it comes to assessing the development of transverse competencies and critical thinking by educational models, indeterminacy needs to be considered. Contemplating the importance of indeterminacy we propose to use NCM in evaluating the TEC21 model [8]. Now indeterminacy has been introduced in Fuzzy Cognitive Maps (FCMs) and the generalized structure so obtained is referred to as Neutrosophic Cognitive Maps (NCMs) by W. B. Vasantha Kandasamy [23]. NCM is a neutrosophic directed graph (a directed graph with a dotted edge representing indeterminacy) with concepts represented as nodes of the directed graph and relationship or indeterminacy as the edge of the graph. Let us suppose C_1, C_2,……, and C_n are n nodes from the Neutrosophic vector space V. The edges of the graph are represented by (x_1,x_2,…..,x_n) where x_i's can be'0' or '1' or 'I' (I shows indeterminacy) where $x_i = 1$ indicates the ON state of the node whereas $x_i = 0$ indicates the OFF state and $x_i = I$ indicates the indeterminate state of a node in that situation. Suppose C_i and C_j are two nodes in this model (NCM), a directed edge from C_i to C_j represents the relationship of C_i and C_j. The edges of the directed graph in NCM are weighted having value in set {-1, 0, 1, I}. When e_{ij} is the weight assigned to the directed edge from C_i to C_j then if the value of e_{ij} is '0' it shows C_i does not affect C_j, it is '1' representing an increase (or decrease) of C_i leads to an increase (or decrease) of C_j, when it is '-1' representing increase (or decrease) of C_i leads decrease (or increase) of C_j and when the value is 'I' it shows effect of C_i on C_j is indeterminate. These NCMs are called simple NCMs. Let N (E) be a matrix defined as N (E) = (e_{ij}) then N (E) is called a Neutrosophic adjacency matrix.

3.1. Neutrosophic Concepts

3.1.1. Neutrosophic Sets:

A neutrosophic set is a generalization of a classical set in which the membership of an element is characterized by three functions: truth membership (T), indeterminacy membership (I), and falsehood membership (F) [25] [26].

It can be said that a neutrosophic set A is defined as:

$$A=\{x|\mu_A(x)=(T(x),\ I(x),\ F(x))\},$$

where x is an element of the set and $\mu_A(x)$ represents the membership values of x in set A. It's used to model uncertain survey responses which very much occurs while carrying out surveys for educational research.

3.1.2. Neutrosophic Membership:

Neutrosophic membership values indicate the degree to which an element belongs to a neutrosophic set, taking into account truth, indeterminacy, and falsehood. For an element x in a neutrosophic set A, the neutrosophic membership value is represented as $\mu_A(x)=(T(x),\ I(x),\ F(x))$ where $T(x)+I(x)+F(x)\leq 1$ and $T(x)$, $I(x)$, and $F(x)$ are the degrees of truth, indeterminacy, and falsehood, respectively [25]. This can be understood from the following diagram. For example Neutrosophic membership values for a single day with a condition very hot with a bit of uncertainty, membership values = [0.8, 0.1, 0.1] is represented in Figure 1.

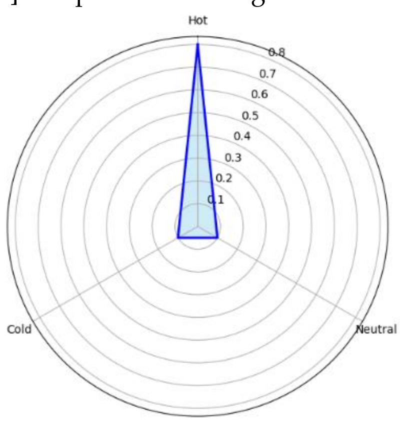

Figure 1 Neutrosophic Membership

3.1.3. Neutrosophic Cognitive Maps (NCMs):

An extension of fuzzy cognitive maps incorporating neutrosophic logic to model complex systems with uncertainties. It can be used to represent and analyze relationships between factors influencing critical thinking. This helps in modeling not only the determinate factors but also indeterminate factors that are also taken into consideration [23]. We can say that in the educational context, the nodes of NCM represent factors like "Innovative Teaching Methods," "Student Engagement," etc., with weighted edges reflecting the strength and uncertainty of their influence.

4. Results

4.1. FCM Adjacency Matrix

The FCM adjacency matrix captures the causal relationships between the determinate factors. Values are assigned based on literature and expert opinions, typically ranging between 0 and 1, where 0 means no influence and 1 means maximum influence. Relationships among Factors in FCM can be understood like C1 (Critical Thinking Skills) has a strong influence on C2 (Problem-Solving Ability) (0.4) and C7 (Reflective Thinking) (0.3). But on the other hand has a moderate influence on C3 (Creativity) (0.3), C4 (Collaboration) (0.2), and C6 (Self-Regulation) (0.2). Likewise, all values are assigned by taking into consideration the expert's opinions and extensive literature survey. These can be seen in the Table 1 and corresponding FCM is shown in Figure 2.

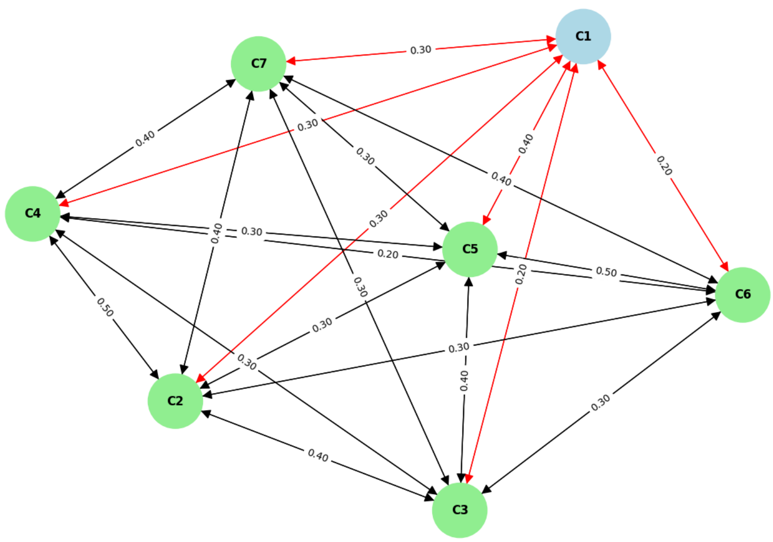

Figure 2 FCM: Factors Relationship to Critical Thinking (C1)

Table 1 Fuzzy Adjacency Matrix: Showing Relationship Among Determinate Factors

Determinate Factors	C1	C2	C3	C4	C5	C6	C7
C1	0	0.4	0.3	0.2	0.1	0.2	0.3
C2	0.3	0	0.5	0.4	0.2	0.3	0.4
C3	0.2	0.4	0	0.3	0.4	0.3	0.2
C4	0.3	0.5	0.3	0	0.4	0.2	0.3
C5	0.4	0.3	0.4	0.3	0	0.5	0.3
C6	0.2	0.3	0.3	0.2	0.5	0	0.4
C7	0.3	0.4	0.3	0.4	0.3	0.4	0

4.2. NCM Adjacency Matrix

The NCM adjacency matrix includes both determinate and indeterminate factors. Indeterminate factors are denoted as 'I' (values between 0 and 1) in the matrix. Relationships among factors in NCM can be understood as C1 (Critical Thinking Skills), Influences C2 (Problem-Solving Ability) (0.4), C3 (Creativity) (0.3), C4 (Collaboration) (0.2), C5 (Communication Skills) (0.1), C6 (Self-Regulation) (0.2), C7 (Reflective Thinking) (0.3), and indeterminate factors I1 (Student Motivation) (0.2**),** I2 (Teaching Methods) (0.1), I3 (Technological Tools)(0.2), I4 (Classroom Environment) (0.1), I5 (Assessment Techniques) (0.2). The NCM graph shown in Figure 3 shows all the nodes whether determinate or indeterminate. All the nodes are in the same color except C1 as it is the primary node that represents critical thinking in the system. This is done to emphasize its central role. In the graphs, each node represents a factor, and the edges represent the relationships between these factors, with the weight of the edges indicating the strength of these relationships. The directed edges indicate the influence from one factor to another. For example, an edge from C1 to C2 with a weight of 0.4 means that C1 influences C2 with a strength of 0.4. There are some thicker edges representing stronger relationships among nodes. For instance, C2 has a strong influence on C3 (weight 0.5) compared to its influence on C1 (weight 0.3). In a uniform color scheme, the emphasis can be placed on the edges connecting to and from C1 to show its influence. As per NCM in Figure 3 the corresponding neutrosophic adjacency matrix is formed in Table 2.

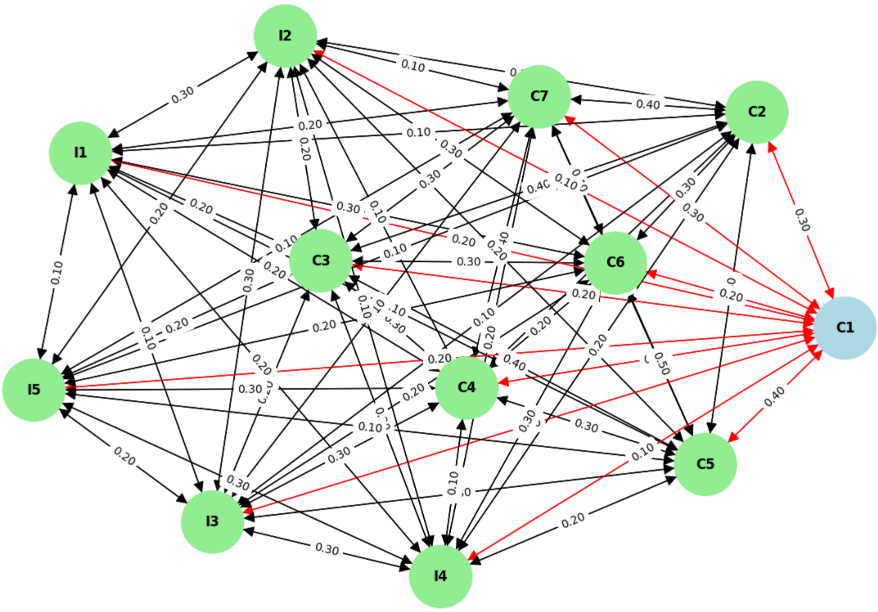

Figure 3 NCM: Factors Relationship to Critical Thinking (C1)

Table 2 Neutrosophy Adjacency Matrix: Showing Relationships Among Determinate and Indeterminate Factors

Determinate & Indeterminate Factors	C1	C2	C3	C4	C5	C6	C7	I1	I2	I3	I4	I5
C1	0	0.4	0.3	0.2	0.1	0.2	0.3	0.2	0.1	0.2	0.1	0.2
C2	0.3	0	0.5	0.4	0.2	0.3	0.4	0.1	0.3	0.1	0.2	0.1
C3	0.2	0.4	0	0.3	0.4	0.3	0.2	0.3	0.2	0.2	0.3	0.2

C4	0.3	0.5	0.3	0	0.4	0.2	0.3	0.2	0.1	0.3	0.1	0.3
C5	0.4	0.3	0.4	0.3	0	0.5	0.3	0.1	0.2	0.3	0.2	0.1
C6	0.2	0.3	0.3	0.2	0.5	0	0.3	0.3	0.3	0.2	0.3	0.2
C7	0.3	0.4	0.3	0.4	0.3	0.4	0	0.2	0.2	0.1	0.2	0.1
I1	0.2	0.1	0.2	0.2	0.1	0.3	0.2	0	0.3	0.1	0.2	0.1
I2	0.1	0.3	0.2	0.1	0.2	0.3	0.1	0.3	0	0.3	0.1	0.2
I3	0.2	0.1	0.2	0.3	0.3	0.2	0.1	0.1	0.3	0	0.3	0.2
I4	0.1	0.2	0.3	0.1	0.2	0.3	0.2	0.2	0.2	0.3	0	0.3
I5	0.2	0.1	0.2	0.3	0.1	0.2	0.1	0.1	0.1	0.2	0.3	0

4.3. Iterative Process

The first iteration starts by keeping the critical thinking state as ON rest all other factors are considered null at this time. So the Initial State becomes S(0)=[1,0,0,0,0,0,0,0,0,0,0,0] . The iterations for both FCM and NCM are done separately. The further iterations are carried out using the formula mentioned below. Iterations for FCM:

Iteration 1: S(1)=S(0)×WS(1)=S(0)×W
Iteration 2: S(2)=S(1)×WS(2)=S(1)×W
Iteration 1: S(1)=S(0)×WFCMS(1)=S(0)×WFCM
Iteration 2: S(2)=S(1)×WFCMS(2)=S(1)×WFCM

4.3.1. Iterations Results for FCM:

Initial State Vector V=(1,0,0,0,0,0,01,0,0,0,0,0,0)

1. **State after iteration 1:** (0.4,0.3,0.2,0.3,0.4,0.2,0.30.4,0.3,0.2,0.3,0.4,0.2,0.3)
2. **State after iteration 2:** (0.56,0.63,0.65,0.61,0.57,0.65,0.610.56,0.63,0.65,0.61,0.57,0.65,0.61)
3. **State after iteration 3:** (0.803,0.748,0.767,0.783,0.778,0.766,0.7830.803,0.748,0.767,0.783,0.778,0.766,0.783)
4. **State after iteration 4:** (0.924,0.925,0.93,0.926,0.929,0.93,0.9260.924,0.925,0.93,0.926,0.929,0.93,0.926)
5. **State after iteration 5:** (0.977,0.974,0.976,0.975,0.975,0.976,0.9750.977,0.974,0.976,0.975,0.975,0.976,0.975)
6. **State after iteration 6:** (0.994,0.991,0.992,0.992,0.992,0.992,0.9920.994,0.991,0.992,0.992,0.992,0.992,0.992)
7. **State after iteration 7:** (0.998,0.997,0.997,0.997,0.997,0.997,0.9970.998,0.997,0.997,0.997,0.997,0.997,0.997)
8. **State after iteration 8:** (0.999,0.999,0.999,0.999,0.999,0.999,0.9990.999,0.999,0.999,0.999,0.999,0.999,0.999)
9. **State after iteration 9:** (1.000,0.999,0.999,0.999,0.999,0.999,0.9991.000,0.999,0.999,0.999,0.999,0.999,0.999)

4.3.2. Iterations Results for NCM:

Initial State Vector V=(1,0,0,0,0,0,0,0,0,0,0,0,01,0,0,0,0,0,0,0,0,0,0,0,0)

Iterations:

1. **State after iteration 1:** (0.4,0.3,0.2,0.3,0.4,0.2,0.3,0.2,0.1,0.2,0.1,0.20.4,0.3,0.2,0.3,0.4,0.2,0.3,0.2,0.1,0.2,0.1,0.2)
2. **State after iteration 2:** (0.8793,0.7827,0.7821,0.7982,0.7686,0.7951,0.8003,0.7824,0.7488,0.7821,0.7488,0.78210.8793, 0.7827,0.7821,0.7982,0.7686,0.7951,0.8003,0.7824,0.7488,0.7821,0.7488,0.7821)
3. **State after iteration 3:** (0.9352,0.8685,0.8675,0.8836,0.8541,0.8801,0.8856,0.8679,0.8324,0.8675,0.8324,0.86750.9352, 0.8685,0.8675,0.8836,0.8541,0.8801,0.8856,0.8679,0.8324,0.8675,0.8324,0.8675)
4. **State after iteration 4:** (0.9518,0.8926,0.8910,0.9071,0.8776,0.9042,0.9090,0.8913,0.8578,0.8910,0.8578,0.89100.9518, 0.8926,0.8910,0.9071,0.8776,0.9042,0.9090,0.8913,0.8578,0.8910,0.8578,0.8910)
5. **State after iteration 5:** (0.9661,0.9161,0.9154,0.9256,0.9066,0.9227,0.9271,0.9155,0.8870,0.9154,0.8870,0.91540.9661, 0.9161,0.9154,0.9256,0.9066,0.9227,0.9271,0.9155,0.8870,0.9154,0.8870,0.9154)
6. **State after iteration 6:** (0.9743,0.9299,0.9295,0.9358,0.9216,0.9332,0.9372,0.9296,0.9020,0.9295,0.9020,0.92950.9743, 0.9299,0.9295,0.9358,0.9216,0.9332,0.9372,0.9296,0.9020,0.9295,0.9020,0.9295)
7. **State after iteration 7:** (0.9791,0.9375,0.9372,0.9417,0.9302,0.9395,0.9433,0.9373,0.9115,0.9372,0.9115,0.93720.9791, 0.9375,0.9372,0.9417,0.9302,0.9395,0.9433,0.9373,0.9115,0.9372,0.9115,0.9372)
8. **State after iteration 8:** (0.9820,0.9419,0.9417,0.9453,0.9352,0.9433,0.9469,0.9418,0.9170,0.9417,0.9170,0.94170.9820, 0.9419,0.9417,0.9453,0.9352,0.9433,0.9469,0.9418,0.9170,0.9417,0.9170,0.9417)
9. **State after iteration 9:** (0.9839,0.9447,0.9445,0.9474,0.9383,0.9456,0.9491,0.9446,0.9205,0.9445,0.9205,0.94450.9839, 0.9447,0.9445,0.9474,0.9383,0.9456,0.9491,0.9446,0.9205,0.9445,0.9205,0.9445)
10. **State after iteration 10:** (0.9852,0.9464,0.9463,0.9489,0.9403,0.9472,0.9506,0.9463,0.9226,0.9463,0.9226,0.94630.9852 ,0.9464,0.9463,0.9489,0.9403,0.9472,0.9506,0.9463,0.9226,0.9463,0.9226,0.9463)

The results are stabilized after the 9th iteration in the case of FCM and after the 10th in the case of NCM. When we compare the results obtained we can compare and contrast the values on four very important factors convergence patterns, degree of variability, interpretation of influence, and implications for educational analysis. If we talk about convergence patterns we can say that in the case of FCM, the results after iteration 9 show that all values have converged very closely to 1 (either 1.000 or 0.999).

This indicates a high level of agreement or certainty in the relationships between the factors while in the case of NCM, the results after iteration 10 show values ranging from approximately 0.9226 to 0.9852 demonstrating that while the system has reached a steady state, there remains a greater diversity in the influence values, reflecting the inclusion of indeterminate components. On grounds of the degree of variability, we can conclude that FCM shows a lack of variability (values very close to 1) suggesting that the factors are strongly and uniformly interrelated, with minimal uncertainty while in the case of NCM, the presence of values less than 1 and the variation among them (0.9226 to 0.9852) indicate that the factors have varying degrees of influence on one another, capturing the inherent uncertainties and indeterminate relationships.

That is the main reason that forms the basis for the use of neutrosophy for educational data analysis purposes. If we talk about the interpretation of influence we can notice that FCM suggests a highly deterministic model where each factor strongly influences the others. This deterministic nature may overlook the nuanced, real-world complexities of educational data. On the other hand, by incorporating indeterminate factors, the NCM results provide a more realistic representation of the educational environment. The varied influence values reflect the complex and uncertain nature of the relationships between the factors. The comparison based on implications for educational analysis forms the basis of conducting this research. It says that close-to-unity values indicate that FCM may be suitable for contexts where relationships are well-defined and less subject to variability. But in the case of educational data, we have a lot of variability. Therefore, the broader range of values suggests that NCM is better suited for analyzing educational models like TEC21 for the development of transverse competencies or critical thinking, where indeterminacies and uncertainties are prevalent. This makes NCM a more robust tool for understanding and managing the complexities inherent in educational data and can be utilized to assess the development of critical thinking skills of the student using TEC21 model.

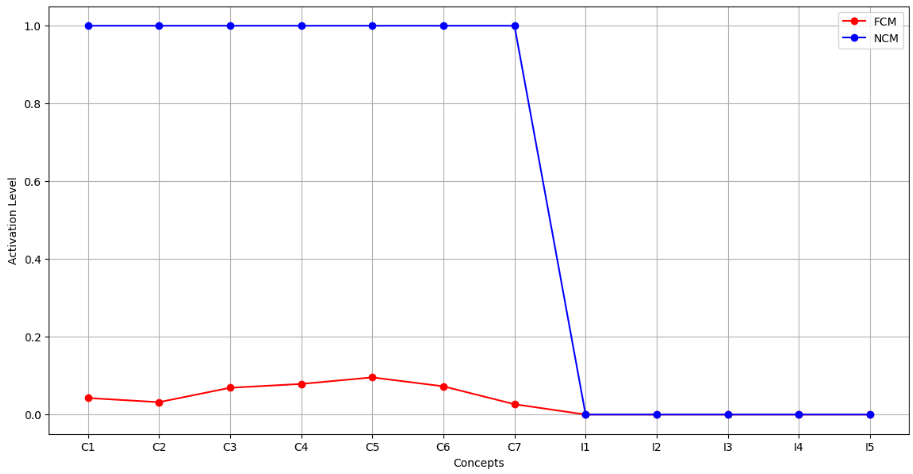

Figure 4 FCM vs NCM: Iterative Results Analysis

The graph in Figure 4 illustrates the activation levels of various concepts after iterative processes in both Fuzzy Cognitive Maps (FCM) and Neutrosophic Cognitive Maps (NCM). The red line represents the FCM results, which show a consistent convergence of activation levels close to 1, indicating stable and deterministic relationships between concepts. The blue line represents the NCM results, which exhibit higher variability and slower convergence, reflecting the inclusion of indeterminate factors and capturing the uncertainties within the system. This comparison highlights that while FCM provides a stable but simplistic view, NCM offers a more nuanced and realistic representation of complex, uncertain environments for assessing the critical thinking skills of the students in the TEC21 model.

Conclusion

In conclusion, the TEC21 model implemented by TEC de Monterrey represents a significant advancement in fostering critical thinking skills among students. By utilizing real-time data collected through the eOpen instrument, this research highlights the importance of addressing the inherent uncertainties and indeterminacies in educational data for determining the critical thinking skills of the students. The application of Neutrosophic Logic in analyzing the TEC21 model has proven to be highly effective, offering a more nuanced and comprehensive representation of the data. The comparative analysis between Neutrosophic Cognitive Maps (NCM) and Fuzzy Cognitive Maps (FCM) further demonstrates the superior capability of NCM in capturing and managing the indeterminate factors that influence educational outcomes. This pioneering work underscores the potential of neutrosophy in enhancing the analysis of educational models also to assess critical thinking skills, particularly in environments characterized by significant uncertainty. By using this innovative approach, educational institutions can better prepare students with the critical thinking skills necessary for their future success.

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