Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 31 No. 2 (2024)

A Study of Problems Faced by Engineering Students in Mathematical Subjects using Fuzzy Cognitive Mappings

[1]Muna Al Kalbani, [2] Neena Uthaman, [3]S. Dhanasekar
[1] Muscat College, Sultanate of Oman
[2] Arab Open University,Oman
[3] VIT University, Chennai Campus

Article History:
Received: *10-01-2024*
Revised: *24-03-2024*
Accepted: *12-04-2024*

Abstract:
Introduction: One of the main concerns and issues for educators, particularly for engineering students, has been the caliber of mathematics instruction and learning. There are many different concepts and skills that make up mathematics. The improvement of problem-solving skills is one of mathematics' key functions. Numerous colleges struggle with the issue of students quitting because of mathematics because it is frequently thought of as a topic that students find difficult to master.

Objectives: The study's goal is to examine the reasons why engineering students struggle with math. In this research, using fuzzy cognitive map techniques (FCM), we analyze the challenges engineering students encounter when trying to earn grades in math-related courses. FCM is a blend of some fuzzy logic and neural network ideas. FCM is made up of collections of concepts and all the different causal relationships that connect them.

Methods: We created a model of the issues and causal relationships that engineering students faced when trying to succeed in mathematics classes. Both statically and dynamically, utilizing concepts from graph theory and simulations, the model is examined. Also we applied DEMATEL one of the Multi Criteria Decision Making method.

Results: The analysis reveals that the main issue is not just the students' lack of mathematical background knowledge, but also their attitude toward learning, psychological response to the first failure, and lack of effort to complete additional tasks or attend tutorials.

Conclusions: Using the FCM method, a model was created for the case of problems faced by engineering college students in scoring marks in mathematical related subjects based on the opinion of a domain expert. The model was first examined statically. The model was then simulated in a dynamic and it was predicted that there should be an attitude change in teachers and as well as students. Through the above static and dynamic studies of the FCM model was identified as important and useful decision support system, since it capable to provide support to decision makers, by making predictions on various scenarios that are imposed on the FCM model.

Keywords: Fuzzy cognitive maps, hidden Pattern, Fixed cycles, Path, Graph theory.

1. Introduction

Interactive computer-based systems, which help decision makers utilize data and models to solve unstructured problems" is the definition of a decision support system (G. M. Gorry and M. S. S. Morton, 1971). "Fuzzy, complex problems for which there are no cut-and-dry solutions" is the definition of unstructured problems (Turban and J. E. Aronson, 1998). According to international relations theory, decision support systems can help in unstructured or semistructured domains like negotiations and crisis management (I. Kouskouvelis, 1997) by bringing fresh perspectives to the decision-making process. Such models' structural and decision-making potentials were examined, and their capacities for explanation and prediction were determined (R. Axelrod, 1976), (J.A. Hart, 1997). Axelrod (R. Axelrod, 1976) first presented the Cognitive Map (CM) models in 1970. They were frequently used to analyze social issues and support decision-making in these situations. Fuzzy cognitive maps (FCM), developed by Kosoko in the late 1980s, are a result of fuzzy logic's introduction (Kosko, 1994; Zeidmane, 2012), which gives CMs new representational capabilities (Kosko, 1986).

As collections of concepts and the many causal relationships that exist between these concepts, FCM develops models. Concepts are represented by nodes, and causal connections between nodes are represented by directed arcs (Kandaswamy & Smarandache, 2003).

Each arc has a weight attached to it that indicates the degree of relationship between the two nodes. The causal relationship between the two concept nodes is indicated by the weight's sign, which can be either positive, negative, or zero.

For the majority of science and technology areas, mathematics is seen as the language utilized to describe the issues that arise. It is a subject that connects to other school subjects in terms of number and numeration, variation, graphs, fractions, logarithms and indices, algebraic processes, equation solving, as well as area and volume. Engineering education should place equal emphasis on the development of social competences like self-competence, cooperation, and communication as it does on the development of professional competences, such as professional knowledge, professional skills, and reflection. The caliber of each study subject determines how good an engineering education will be. Both directly and indirectly, mathematics studies have an impact on how engineers create the necessary results (Zeidmane, 2012). Everyone is aware of the immediate effects of mathematics, which is a tool for calculating and addressing a wide range of issues. The indirect effects of mathematics on learning outcomes like problem-solving abilities, the ability to employ symbolic language, and the ability to draw lengthy logical chains are significantly more significant.

2. Objectives

The study's goal is to examine the reasons why engineering students struggle with math. In this research, using fuzzy cognitive map techniques (FCM), we analyze the challenges engineering students encounter when trying to earn grades in math-related courses. FCM is a blend of some fuzzy logic and neural network ideas. FCM is made up of collections of concepts and all the different causal relationships that connect them.

3. Methods

Development of FCM models for the case of study about problems faced by engineering students in colleges:

An FCM model's creation approach, which complies with a set of standards to guarantee dependability, determines how reliable the model is. The level of competence of the domain experts is a major factor in the model's trustworthiness because it was built using the creator's personal opinion and recognition of the points made by the experts on a particular topic.

FCMs are often constructed using one of two methods:

(1) Documents that present claims about a certain subject are systematically coded using the documentary coding approach (M. T. Wrightson, 1976).
(2) The questionnaire approach, which entails having subject-matter experts fill out questionnaires and conducting interviews (Tsadirus & Kouskouvelis, 2005),(F. R. Roberts, 1976), (F. S. Roberts, 1975).

In our situation, the second method—discussion, interviewing, analysis, and also giving a domain expert questionnaire—was applied.

In our paper, the following points are considered which are suggested by domain experts.

$S_1:-$ Complicated nature of the subject.

The opinion on mathematics among the students is that it is a complicated, problem based and time consuming subject to understand.

$S_2:-$ Attitude of the Teacher

$S_3:-$ Application Part of the subject

Many students study the concepts of mathematics through formula rather than understanding it from the application perspective.

$S_4:-$ Basic Concepts

It is quite natural that knowing basic concepts in right sense play a vital role in learning mathematics and many students feel the same.

$S_5:-$ Laziness of the student

In this mobile era, the failure rate in mathematics is very high not because of the nature of the questions asked, it is because of the laziness in doing mathematics.

$S_6:-$ Inferiority complex of the student.

Many students are not fundamentally strong in mathematics which reflects in their mentality that they don't have the capacity to study mathematics.

$S_7:-$ Regularity to classes.

4. Results

Application for using FCM model

Based on the data collected from domain experts, we obtain the following adjacency matrix and the corresponding graph is generated using MATLAB.

$$E = \begin{pmatrix} 0 & 0 & -1 & 0 & 1 & 1 & -1 \\ -1 & 0 & 1 & 1 & 0 & -1 & 1 \\ -1 & 0 & 0 & 1 & 0 & -1 & 1 \\ -1 & 0 & 1 & 0 & 0 & -1 & -1 \\ 1 & -1 & -1 & -1 & 0 & 1 & -1 \\ 1 & 0 & -1 & -1 & 0 & 0 & -1 \\ -1 & 1 & 1 & 1 & 0 & -1 & 0 \end{pmatrix}$$

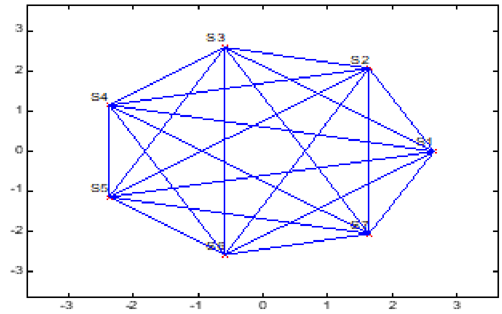

Figure 1: adjacency matrix and the corresponding graph

Static Analysis:

The static analysis of the model is based on studying the characteristics of the weighted directed graph that represent the model, using graph theory techniques. The first way to examine statically the models graph is by calculating its density. The density 'd' is given by d= m/n (n-1), where 'm' is the number of arcs in the model and 'n' is the number of concepts of the model. Product n (n-1) is equal to the maximum number of arcs that a graph of n nodes can have. Density gives an indication of the complexity of the model. High density indicates increased complexity in the model and respectively to the problem that the model represents. For this problem the density is d= 32/7*6=0.76 which is high and gives indication of the complexity of the problem that it represents.

Graph theory also provides the nodes importance that assists the static analysis of FCM models. Node's importance or cognitive or conceptual centrality as it is called gives an indication of the importance that the node or concept have for the model, by measuring the degree to which the node is central to the graph. The importance of the node i is evaluated as Imp (i) = in (i) +out (i)

Where in (i) = number of incoming arcs of node i

Out (i) = number of outgoing arcs of node i

According to this definition, the importance of the nodes of the FCM model is given by

$S_1\ S_2\ S_3\ S_4\ S_5\ S_6\ S_7\ in\ deg\ 4\ 5\ 4\ 4\ 6\ 4\ 5\ out\ deg\ 6\ 2\ 6\ 5\ 1\ 6\ 6\ total\ 10\ 7\ 10\ 9\ 7\ 10\ 11$

It is found that most central or important concepts were, S_1, S_3, S_5, S_6, S_7

Dynamical behaviour:

After adding the 7 model components and their causal links to the FCM simulation engine, several scenarios can be enforced. The "what-if" situations that were examined were selected to demonstrate the paper's method's capacity for making decisions.

In Scenario 1 Suppose A_1= (1 0 0 0 0 0 0) (i.e.) if S_1 is on

A_1E = (0 0 -1 0 1 1 -1)→ (1 0 0 0 1 1 0)= A'_1

A'_1E = (2 -1 -3 -2 1 2 -3)→ (1 0 0 0 1 1 0) = A''_1 =A'_1

The equilibrium point can be interpreted as if S_1 is on, S_5, S_6 are on. (i.e) if the attribute "complicated nature of the subject" is on, the attributes "inferiority complex of the students", "laziness of the students" are on.

In Scenario 2 Suppose A_2= (0 1 0 0 0 0 0) (i.e.) if S_2 is on

A_2E = (-1 0 1 1 0 -1 1)→ (0 1 1 1 0 0 1)= A'_2

A'_2E = (-4 1 3 3 0 -4 1)→ (0 1 1 1 0 0 1) = A''_2 =A'_2

The equilibrium point can be interpreted as if S_2 is on, S_3, S_4, S_7, are on. (i.e) if the attribute "Attitude of Teacher" is on, the attributes "Application Part of the subject", "Basic Concepts", "Regularity to classes" are on. Similarly In Scenario 3 if S_3 is of, convergent is not happening. In Scenario 4 If S_4 is on, S_3 is on. (i.e) if the attribute "Basic Concepts" is on the attribute "Application Part of the subject" is on. . In Scenario 5 If S_5 is on, S_1, S_6 are on. (i.e) if the attribute " Laziness' of the student" is on the attributes "complicated nature of the subject", "Inferiority complex of the student" is on. In Scenario 6 If S_6 is on, S_1, S_5 are on. (i.e) if the attribute "Inferiority complex of the student" is on, "Laziness' of the student" is on the attributes "complicated nature of the subject", "Laziness of the student" is on. In Scenario 7 If S_7 is on, S_2, S_3, S_4 are on. (i.e) if the attribute "Regularity to classes" is on, the attributes "Attitude of Teacher", "Application Part of the subject", "Basic Concepts" is on.

Scenarios with Chosen Concepts to Be Leveled Consistently

Next we will discuss the causal relation between the important nodes S_1, S_3, S_5, S_6, S_7.

The adjacency matrix is given by $S_1\ S_3\ S_5\ S_6\ S_7$

$$S_1\ S_3\ S_5\ S_6\ S_7\ (0\ -1\ 1\ 1\ -1\ -1\ 0\ 0\ -1\ 1\ 1\ -1\ 0\ 1\ -$$

$$1\ 1\ -1\ 0\ 0\ -1\ -1\ 1\ 0\ -1\ 0\ )$$

Suppose A_1= (1 0 0 0 0) (i.e.) if S_1 is on

A_1E = (0 -1 1 1 -1)→(1 0 1 1 0) = A'_1

A'_1E = (2 -3 1 2 -3) → (1 0 1 1 0) = A''_1 = A'_1

If S_1 is on, S_5, S_6 is on. (i.e) if the attribute "complicated nature of the subject" is on, the attributes "inferiority complex of the students", "laziness of the students" are on. If S_3 is on, S_7, is on. (i.e.) if the attribute "Basic concepts" is on, the attribute "Regularity to classes" is on. If S_5 is on, S_1, S_6 is on. (i.e.) if the attribute "laziness of the student" is on, the attributes "complicated nature of the subject", "inferiority complex of the students" is on. If S_6 is on, S_1, S_5 is on. (i.e.) if the attribute "inferiority complex of the students" is on, the attributes "complicated nature of the subject", "laziness of the student" is on. If S_7 is on, S_3, is on. (i.e) if the attribute "Regularity to classes" is on, the attribute "Basic concepts" is on.

Graph Theory Techniques:

Replace -1 by 0 in the adjacency matrix, we get the following:

$$S_1\ S_3\ S_5\ S_6\ S_7$$

$$S_1\ S_3\ S_5\ S_6\ S_7$$

(0 0 1 1 0 0 0 0 0 1 1 0 0 1 0 1 0 0 0 0 0 1 0 0 0)

In this graph there exists two major cycles. One is $S_1 \rightarrow S_5 \rightarrow S_6 \rightarrow S_1$. (i.e) The attribute "complicated nature of the subject" implies "Lazziness of the student" implies "inferiority complex of the students" implies "complicated nature of the subject". The second one is $S_2 \rightarrow S_3 \rightarrow S_4 \rightarrow S_3$. (i.e) The attribute "Attitude of Teacher" implies "Application Part of the subject" implies "Basic Concepts" implies "Application Part of the subject"

The other one is $S_7 \rightarrow S_3 \rightarrow S_4$. (i.e) The attribute "Regularity to classes" leads to "Application Part of the subject" leads to "Basic Concepts".

Multi Criteria Decision Making Methods

A helpful strategy for assisting decision makers in their subjective assessment of performance criteria is multicriteria decision making (MCDM). MCDM is an important field of study that has produced several useful applications (Bernard Roy, 1968). It is a crucial tool in management science that allows decision-makers to estimate many metrics when making decisions involving several, frequently contradictory goals, such as optimizing production and decreasing cost. The goal of MCDM is to choose the best option from a range of reachable options. Expert MCDM techniques allow decision makers to take into account various aspects and provide answers to the decision problem's queries.

One way to analyze a multiplex problem using MCDM is to break it down into smaller components. To provide the decision makers with a comprehensive depiction, these components are rebuilt. A decision problem in MCDM is associated with a set of criteria that may include precise or fuzzy forms for basic and statistical data. As a result, no single unique methodology can handle information or data from the outset to the conclusion of a decision-making process.

The 1960s saw the beginning of MCDM's establishment. MCDM was described in 1967 by Herring et al. (FG Herring, JH Hwang, and Wei-Cheng Lin, 1967) for a group decision-making issue in electron spin resonance. In the 1980s and early 1990s, MCDM research picked up speed and proceeded to grow exponentially (M Murat Köksalan, Jyrki Wallenius, and Stanley Zionts, 2011). A brief history of MCDM techniques from antiquity to the present was provided by Koksalan et al. (M Murat Köksalan, Jyrki Wallenius, and Stanley Zionts, 2011). The principles of multi-objective decision making were outlined in (Ralph L Keeney, Howard Raiffa, and David W Rajala, 1979). Afterwards, Tzeng et al. (Gwo-Hshiung Tzeng and Jih-Jeng Huang, 2011). examined a number of MADM techniques, including linear programming for multidimensional analysis of preference (LINMAP), elimination and choice translating reality (ELECTRE), technique for order of preference by similarity to ideal solution (TOPSIS), and simple additive weighting (SAW). In (Yoram Wind and Thomas.L Saaty, 1980), a thorough analysis of the analytic hierarchy process (AHP)'s marketing applications was provided.

However, (Hwang et al. C-L Hwang and Abu Syed Md Masud, 2012) provided a thorough analysis of multi-objective decision making (MODM) techniques and applications.

The Decision Making Trial and Evaluation Laboratory (DEMATEL) is regarded as a useful technique for determining the causal chain elements inside a complicated system. It examines how different aspects are related to one another and identifies the most important ones using a visual structural model. The DEMATEL technique was created by (Fontela and Gabus Emilio Fontela and Andre Gabus, 1974). Piegat and Salabum (Andrzej Piegat and Wojciech Sałabun, 2015) processed each person's subjective observations using DEMATEL, drawing short, impressionistic human insights into the intricacy of the problems in order to arrive at solutions. A visual representation, or mental map, is the final result of the analysis after the DEMATEL procedure. In order to maintain internal coherence, honor implicit priorities, and accomplish covert objectives, the respondent must plan his or her own actions in the world. Constant linguistic scales are constructed. In DEMATEL, decision makers can construct the total influence matrix (T), as follows,

$$T = X + X^2 + X^3 + \cdots + X^n = X(I - X)^{-1}, \text{ as } n \to \infty,$$

where X denote a normalized influence matrix, while I denote an identity marix.
When we apply DEMATEL for the decision matrix we get

		Total relation Matrix							
E	1	2	3	4	5	6	7	R	C
1	-4	2	2	4	1	-2	2	5	-2
2	3	-1	-3	-2	1	3	-1	0	3
3	2	-1	-4	-1	1	2	0	-1	-2
4	0	1	0	-1	1	0	-4	-3	2
5	-4	0	4	3	-1	-4	2	0	3
6	-2	1	2	1	-1	-4	0	-3	-2
7	3	1	-3	-2	1	3	-3	0	-4
	-2	3	-2	2	3	-2	-4		

Table 1. Total Relation Matrix

		Identity Matrix					
E	1	2	3	4	5	6	7
1	1	0	0	0	0	0	0
2	0	1	0	0	0	0	0
3	0	0	1	0	0	0	0
4	0	0	0	1	0	0	0
5	0	0	0	0	1	0	0
6	0	0	0	0	0	1	0
7	0	0	0	0	0	0	1

Table 2.   Identity Matrix

Prominence	Relation	
R+C	R-C	Rank
3	7	1
3	-3	1
-3	1	5
-1	-5	4
3	-3	1
-5	-1	7
-4	4	6

Table 3. Prominence Relation

We observe that $S_1:-$ Complicated nature of the subject, $S_2:-$ Attitude of the Teacher, $S_5:-$ Laziness of the student are the important attributes by their ranking in DEMATEL method.

Discussions

In the static analysis S_1, S_3, S_5, S_6, S_7 are the important attributes according to the in and out degree. In Dynamic analysis it is observed that

- S_1 is on, S_5, S_6 is on
- S_3 is on, $S_7,$ is on.
- S_5 is on, S_1, S_6 is on.
- S_7 is on, $S_3,$ is on

By using graph theory technique there exist two major cycles $S_1 \to S_5 \to S_6 \to S_1$ and $S_7 \to S_3 \to S_4$. By applying DEMATEL method we get that $S_1:-$ Complicated nature of the subject, $S_2:-$ Attitude of the Teacher, $S_5:-$ Laziness of the student are the important attributes. By analysing all the scenorios the following observation we made.

Observation

1. The thought of complicated nature influences the laziness of the student and inferiority complex in the students. Therefore we have to eradicate that thinking of the students about mathematics. In order to overcome this one can think of making the learning easy by giving some puzzles, teaching the concepts of the subject through an application, visualize the concepts using mathematical software, ask them to bring the physical model of the concept and group them to share their thoughts and views.

2. The positive attitude of the teacher influences the attributes, knowing application part, knowing basic concepts and regularity to classes. This can be achieved by having Faculty Development Program once in a year, Recent updates of the subject either through workshop or conference and regular training programs to interact with students.

3. If the inferiority complex of the student is on it influence the attributes, complicated nature of the subject, and laziness of the students. Students needs either teachers attention or psychological counseling to face those problems which can resolve the inferiority complex towards learning mathematics.

4. If the regularity to classes is on it influences the attributes knowing basic concepts and Application part. We should make the attendance compulsory (or) make a vigil on their regularity to classes by some means.

Conclusion

Using the FCM method, a model was created for the case of problems faced by engineering college students in scoring marks in mathematical related subjects based on the opinion of a domain expert. The model was first examined statically. The density of model's graph was calculated and found moderately high, indicating the complexity of the case. The conceptual centralities of the concepts that exist in the model were also calculated and the most central and the most important concepts of the model were found. The model was then simulated in a dynamic and it was predicted that there should be an attitude change in teachers and as well as students. We applied DEMATEL one of the methods used in MCDM toget the ranking of the attributes. Through the above static, dynamic and DEMATEL studies of the FCM model was identified as important and useful decision support system, since it capable to provide support to decision makers, by making predictions on various scenarios that are imposed on the FCM model. In addition to analyzing the system's ultimate equilibrium, conclusions about these possibilities are also derived from research on the FCM system's transition phase to equilibrium.

Refrences

[1] Kandaswamy, V., & Smarandache, F. (2003). Fuzzy Cognitive Maps and Neutrosophic Cognitive Maps. Xiquan, U.S.A.

[2] Kosko, B. (1993). Fuzzy Thinking: The New Science of Fuzzy Logic. Hyperion, New York.

[3] Kosko, B. (1986). Fuzzy cognitive maps. International Journal of Man-Machine Studies, 24(1), 65–75.

[4] Tsadiras, A. K., & Kouskouvelis, I. (2005). Using FCM as a decision support system for political decisions: The case of Turkey's integration into the European Union. NCS, 3746, 65-75.

[5] Zeidmane, A. (2012). Development of Mathematics Competences in Higher Education Institutions. In Proceedings of the International Conference on Interactive Collaborative Learning (ICL), 15.

[6] Bernard Roy . (1968). Classement et choix en presence de points de vue multiples. Revue francaise d informatique et de recherche operationnelle, 2(8) 57–75.

[7] M Murat Köksalan, Jyrki Wallenius, and Stanley Zionts. (2011). Multiple criteria decision making: from early history to the 21st century. World Scientific.

[8] Ralph L Keeney, Howard Raiffa, and David W Rajala. (1979). Decisions with multiple objectives: Preferences and value trade-offs. IEEE transactions on Systems, man, and cybernetics, 9(7):403–403.

[9] Gwo-Hshiung Tzeng and Jih-Jeng Huang. (2011). Multiple attribute decision making: methods and applications. CRC press.

[10] Yoram Wind and Thomas.L Saaty. (1980). Marketing applications of the analytic hierarchy process. Management science, 26(7) , 641–658.

[11] C-L Hwang and Abu Syed Md Masud. (2012). Multiple objective decision making—methods and applications: a state-of-the-art survey, Springer Science & Business Media, 164.

[12] Emilio Fontela and Andre Gabus. (1974). Events and economic forecasting models. Futures, 6(4):329–333.

[13] Andrzej Piegat and Wojciech Sałabun.(2015). Comparative analysis of mcdm methods for assessing the severity of chronic liver disease. In International conference on artificial intelligence and soft computing, Springer, 228–238

[14] M. T. Wrightson. (1976). The Documentary Coding Method, in Structure of Decision. The Cognitive Maps of Political Elites, R. Axelrod, Ed. Princeton, New Jersey: Princeton University Press, 291-332.

[15] F. R. Roberts. (1976). Strategy for The Energy Crisis: The Case of Commuter Transportation Policy,in Structure of Decision. The Cognitive Maps of Political Elites, R. Axelrod, Ed. Princeton, New Jersey: Princeton University Press, 142-179.

[16] F. S. Roberts. (1975). Weighted Digraph Models for the Assessment of Energy Use and Air Pollution in Transportation Systems, Environment and Planning, 7. 703-724.

[17] FG Herring, JH Hwang, and Wei-Cheng Lin.(1967). Electron spin resonance of x-ray irradiated polycrystalline and single-crystal sodium hexafluoroantimonate. The Journal of Physical Chemistry, 71(7), 2086–2090.

[18] G. M. Gorry and M. S. S. Morton. (1971) “A Framework for Management Information Systems”, Sloan Management Review.

[19] Turban and J. E. Aronson. (1998). Decision Support Systems and Intelligent Systems (5th edition): Prentice Hall.

[20] I. Kouskouvelis. (1997). Decision Making, Crisis, Negotiation (in Greek): Papazisis.

[21] R. Axelrod, (1976). Structure of Decision. The Cognitive Maps of Political Elites. Princeton, New Jersey: Princeton University Press.

[22] J.A. Hart, (1997). Cognitive Maps of Three Latin American Policy Makers, World Politics, 30, 115-140.