Decisions on Networked Learning based on Fuzzy Cognitive Maps

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Abstract

In this paper we present Fuzzy Cognitive Maps, a well established decision making technique based on Fuzzy Logic, for making decisions concerning Networked Learning, based on the knowledge extracted by a domain expert. Based on this knowledge, a model of the interactions and causal relations among various key Networked Learning factors is created. Having the FCM created, a number of scenarios are introduced and the decision making capabilities of the technique are presented by simulating these scenarios and finding the predicted outcomes according to the model and expert's knowledge. The FCM is examined both statically and dynamically. A number of computer simulations are performed to examine the predicted consequences of specific decisions on Networked Learning. The capabilities of the technique are presented and the use of FCMs is examined for planning Network Learning and for enhancing success of learning programs.

Keywords

Networked Learning, Decision Making, Fuzzy Cognitive Maps, Predictions, Fuzzy Logic

1. Introduction

Cognitive Maps (CMs) were introduced by Axelrod in the late 1970s (Axelrod, 1976). The introduction of Fuzzy Logic gave new representing capabilities to CMs and led to the development of Fuzzy Cognitive Maps (FCMs), by Kosko in the late 1980s (Kosko,1986), (Kosko, 1992). FCMs models are created as collections of concepts and the various causal relationships that exist between these concepts. The concepts are represented by nodes and the causal relationships by directed arcs between the nodes. Each arc is accompanied by a weight that defines the degree of the causal relation between the two nodes. The sign of the weight determines the positive or negative causal relation between the two concepts-nodes. An example of FCM concerning Distance Education is given in figure 1 and was presented in (Cole and Persichitte, 2000). FCMs were also used by various researchers for other E-Learning topics such as the recognition of learner's style and profile (Georgiou and Makry, 2004) or for the evaluation of teaching-learning process (Laureano-Cruses, Ramirez-Rodriguez and Teran-Gilmore, 2004).

In FCMs, although the degree of the causal relationships could be represented by a number in the interval [-1,1], each concept, in a binary manner, could be either activated or not activated. Certainty Neuron Fuzzy Cognitive Maps (CNFCMs) are introduced (Tsadiras and Margaritis, 1997), to provide additional representing capabilities to FCMs, by allowing each concept's activation to be activated just to a degree. Function f_M () that was used in MYCIN Expert System (Buchanan and Shortliffe, 1984) for certainty factors' handling is used for the aggregation of the influences that each concept receives from other concepts. The dynamical behaviour and the characteristics of this function are studied in (Tsadiras and Margaritis, 1998). Certainty Neurons are defined as artificial neurons that use this function as their threshold function (Tsadiras and Margaritis, 1996). Using such neurons, the updating function of CNFCMs as a dynamic evolving system is the following:

$$A_i^{t+1} = f_M (A_i^t , S_i^t) - d_i \ A_i^t$$

where, A_i^{t+1} is the activation level of concept C_i at time step t+1,

$S_i^t = \sum_j w_{ji} A_j^t$ is the sum of the weight influences that concept C_i receives at time step t from all other concepts,
d_i is a decay factor and

$$f_M(A_i^t, S_i^t) = \begin{cases} A_i^t + S_i^t(1 - A_i^t) = A_i^t + S_i^t - S_i^t A_i^t & if\, A_i^t \geq 0,\ S_i^t \geq 0 \\ A_i^t + S_i^t(1 + A_i^t) = A_i^t + S_i^t + S_i^t A_i^t & if\, A_i^t < 0,\ S_i^t < 0 \quad \left|A_i^t\right|,\left|S_i^t\right| \leq 1 \\ (A_i^t + S_i^t) \big/ \left(1 - \min\left(\left|A_i^t\right|,\left|S_i^t\right|\right)\right) & otherwise \end{cases}$$

is the function that was used for the aggregation of certainty factors to the MYCIN expert system.

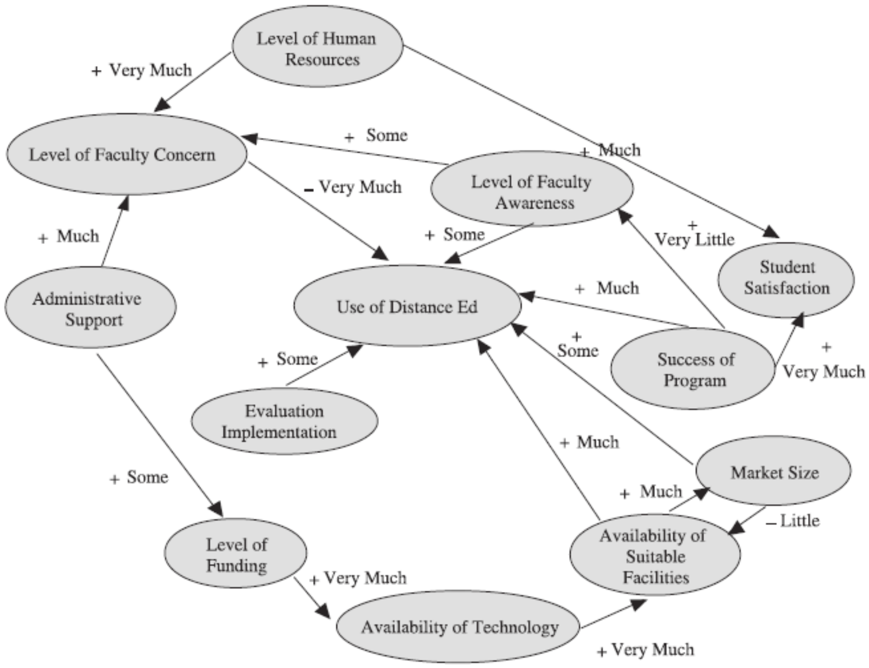

Figure 1. FCM concerning Distance Learning (Cole and Persichitte, 2000)

2. Development of a Fuzzy Cognitive Map for Network Learning

The construction method of the FCM should follow rules that ensure its reliability. Furthermore, because the FCM is created by the personal opinions and points of view of the expert(s) on the specific topic, the reliability of the model is heavily depended on the level of expertise of the domain expert(s). In our case we used the Questionnaire method (Roberts, 1976), which involves interviews and filling in of questionnaires by domain experts. Our domain expert, a faculty member of a Department of Information Technology who is an expert on Network Learning, provided the actors and factors of the FCM, as well as the possible alternative scenarios to be imposed to the system.

After extended interviews and long discussions with the expert, the list of the concepts that were identified as playing important role in Network Learning and should appear in the FCM, are the following:

Concept 1. Simplicity of Learning Environment
Concept 2. Collaboration (between students, between teachers, between students and teachers)
Concept 3. Administrative/Technical Support
Concept 4. Course Domain (relevance to computers, suitable for techno lovers or technophobic groups)
Concept 5. Institutional Policy on Networked Learning
Concept 6. Size of Target Group

Concept 7. Size of Class
Concept 8. Quality of Networked Learning
Concept 9. Number of Tutors per Class
Concept 10. Student Satisfaction

After a structured procedure of filling in of specific questionnaires by our domain expert, the causal relationships that exist between the concepts above were identified and the model presented in figure 2 was developed. In figure 2, the arcs-causal relationships between the concepts are shown. The weights of the arcs are given in Appendix A. This FCM can be studied both statically and dynamically.

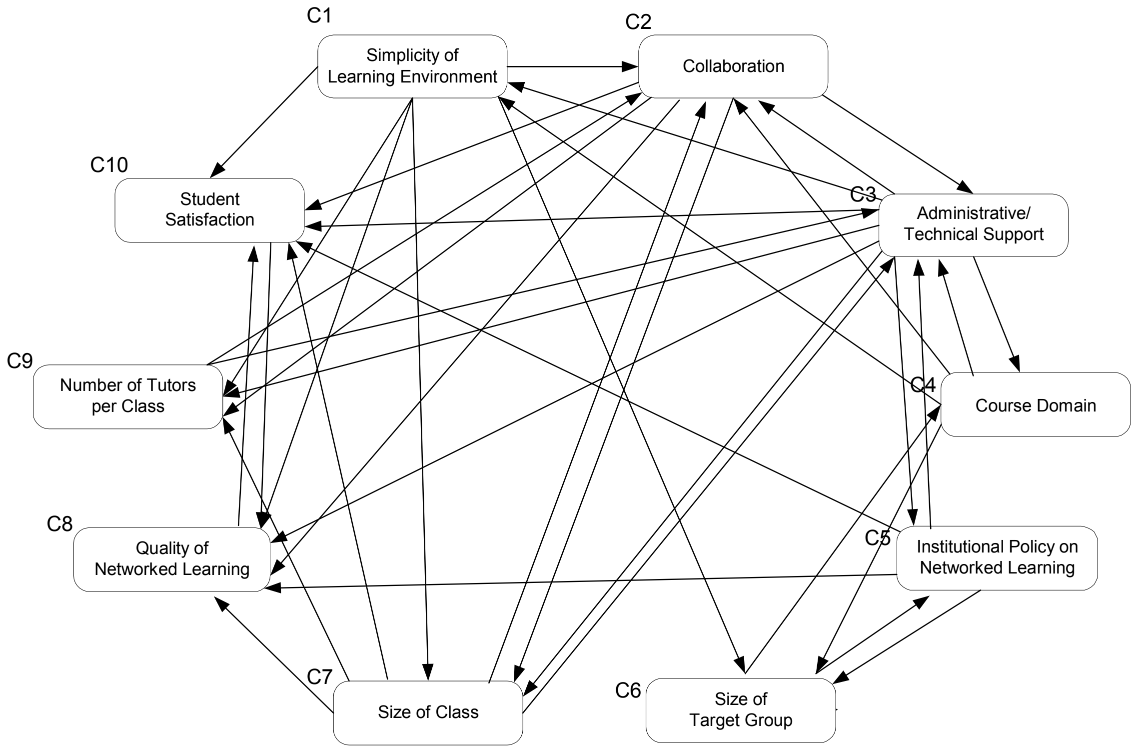

Figure 2: FCM for Networked Learning

3. Static Analysis of FCM

The static analysis of an FCM is based on studying the characteristics of the weighted directed graph that represent it, using graph theory techniques. The most important feature that should be studied is that of the feedback cycles that exist in the graph. Each cycle is accompanied by a sign, identified by multiplying the signs of the arcs that participate in the cycle. Positive cycle behaviour is that of amplifying any initial change, leading to a constant increase, in case an increase is introduced to the system. An example of a positive cycle is that of C1: Simplicity of Learning Environment⇨ C6: Size of Target Group⇨ C4: Course Domain ⇨ C1: Simplicity of Learning Environment. Through this cycle, an initial increase to the Simplicity of Learning Environment will cause an additional increase to it.

Negative cycles on the other hand, counteract any initial change. This means that in the case where an increase is introduced in these cycles, they lead to decrease. An example of a negative cycle is that of C1:Simplicity of Learning Environment ⇨ C2: Collaboration (-) ⇨ C3: Administrative/Technical Support ⇨ C1: Simplicity of Learning Environment. Through this cycle, an initial increase to the Simplicity of Learning Environment will return to a decrease to it.

Using a computer program written in Prolog to examine the static characteristics of FCM, we found that the weighted directed graph of Figure 2, contains a total of 252 cycles from which 123 are positive cycles

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and 129 are negative cycles. The existence of such a high number of cycles implies strong and long interactions between the concepts of the FCM.

Another way to examine statically the FCM's graph is by calculating its density (Hart, 1977). The density d is defined as

$$d = \frac{m}{n(n-1)}$$

where m is the number of arcs in the model and n is the number of concepts of the model. Density gives an indication of the complexity of the model. Typical values of density are in the interval [0.05, 0.3]. The density of the graph in Figure 2 is 39/(10x9) = 0.433 which is extremely high and gives an indication of the great complexity of the problem that it represents.

Graph Theory provides also the notion of node's importance (Axelrod, 1976) that assists the static analysis of FCMs. Node's importance gives an indication of the importance that the node/concept have for the model, by measuring the degree to which the node is central to the graph. The importance of a node i is evaluated as

$$imp(i) = in(i) + out(i)$$

where in(i) is the number of incoming arcs of node i and out(i) is the number of outcoming arcs of node i. According to this definition, the importance of the nodes of the FCM of figure 2 is given in Table 1. It is found that the most central/important concept is C3: "Administrative/Technical Support", followed by C2: "Collaboration".

Table 1. Importance of nodes

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
In	2	5	5	2	3	3	3	6	4	6
Out	6	5	8	4	4	2	5	1	2	2
Imp	**8**	**10**	**13**	**6**	**7**	**5**	**8**	**7**	**6**	**8**

4. Dynamic Study of FCM

The FCM model concerning the Networked Learning was also simulated using the CNFCM technique that was mentioned in Section 1. The 10 concepts of the model and the 39 causal relationships that exist among these concepts were inserted to the CNFCM simulation program we developed. After that, various scenarios could be imposed to the system. The "what-if" scenarios that were tested were chosen in order to show the decision making capabilities of the method presented to the paper. The scenarios are shown in Table 2.

Table 2. Scenarios imposed to FCM concerning Networked Learning

Scenario	Description
#1	All concepts are free to interact
#2	Activation of C7: "Size of Class" is set & kept to 0.5 (moderate increase). All other concepts are free to interact.
#3	Activation of C6: "Size of Target Group" is set & kept to 0.25 (low increase). All other concepts are free to interact.
#4	Weight w34 is changed from 0.6 to -0.4. The way an increase to Administrative/Technical support is affecting Courses Domain towards computer related course is changed. All concepts are free to interact.
#5	Activation of C1: "Simplicity of Learning Environment" is set & kept to 0.5 (moderate increase). All other concepts are free to interact.

In the first scenario, all concepts are free to interact with each other. The dynamical behavior of the system, as simulated by the CNFCM technique for this scenario is shown in figure 3. From that figure, we can see that after a long transition phase with a lot of interactions, concepts reach equilibrium at the following values.

Simplicity of Learning Environment	Collabo-ration	Administrative /Technical Support	Course Domain	Institutional Policy on Networked Learning	Size of Target Group	Size of Class	Quality of Networked Learning	Number of Tutors per Class	Student Satisfa-ction
-0,586	0,779	0,807	0,792	0,794	-0,475	-0,819	0,922	-0,396	0,937

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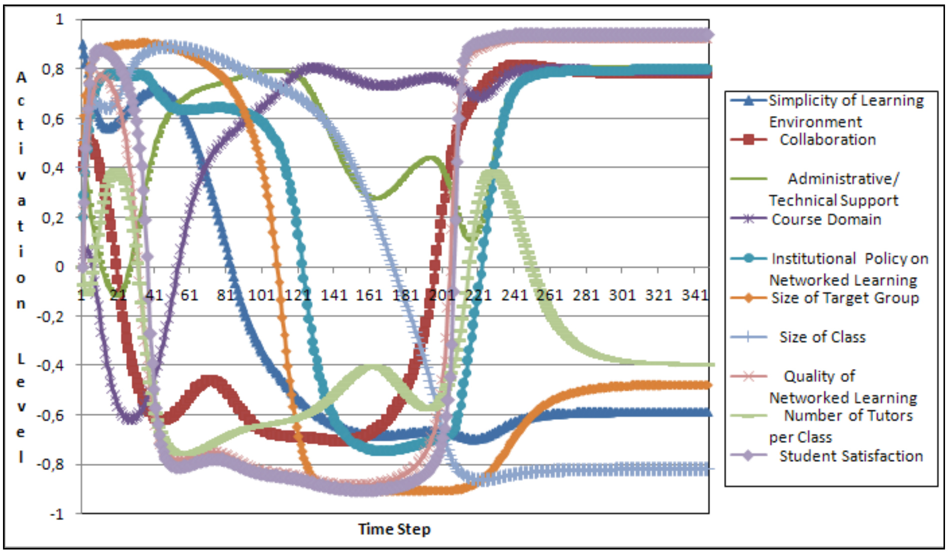

Figure 3: Simulation of FCM concerning Networked Learning. Transition phase to equilibrium for scenario #1 (concepts are free to interact).

It can be concluded that according to our expert, FCM views for Networked Learning Courses, an increase of Student Satisfaction and an increase of the Quality of the Networked Learning, having increased the Collaboration, the Administrative and Technical support and a favourable Institutional Policy. At the same time, decreased is the Size of Classes and the Number Tutors per Class, while a medium decrease exist in Simplicity of Learning Environment and the Size of Target Group.

In the second scenario, C7: "Size of Class" is set and kept to activation 0.5 (moderate increase). All other concepts are free to interact with each other. The dynamical behavior of the FCM for this scenario, is shown in figure 4.

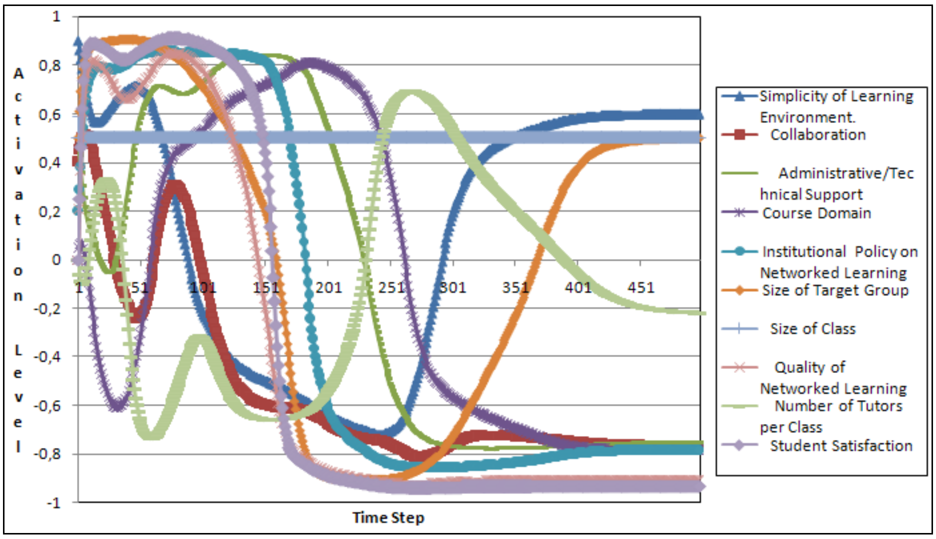

Figure 4: Simulation of FCM concerning Networked Learning. Transition phase to equilibrium for scenario #2 ("Size of Class" is set & kept to 0.5-moderate increase).

In this scenario, we can see that after a long transition phase with a lot of strong interactions, concepts reach equilibrium at the following values.

Simplicity of Learning Environment	Collabo-ration	Administrative /Technical Support	Course Domain	Institutional Policy on Networked Learning	Size of Target Group	Size of Class	Quality of Networked Learning	Number of Tutors per Class	Student Satisfa-ction
0,598	-0,769	-0,752	-0,785	-0,784	0,500	0,5	-0,912	-0,224	-0,933

It can be concluded that a steady moderate increase in the size of Networked Learning Classes, will lead to the severe decrease of Student's Satisfaction and of the Quality of the Networked Learning, and at the same time decrease Collaboration, Administrative/Technical Support and Institutional Policy. The size of Target Group is moderate increased and the same happen to the Simplicity of Learning Environment . These can not stop the decrease in Quality of the provided Networked Learning.

In the third scenario, C6: "Size of Target Group" is set & kept to 0.25 (low). All other concepts are free to interact with each other. The dynamical behavior of the FCM for this scenario, is shown in figure 5

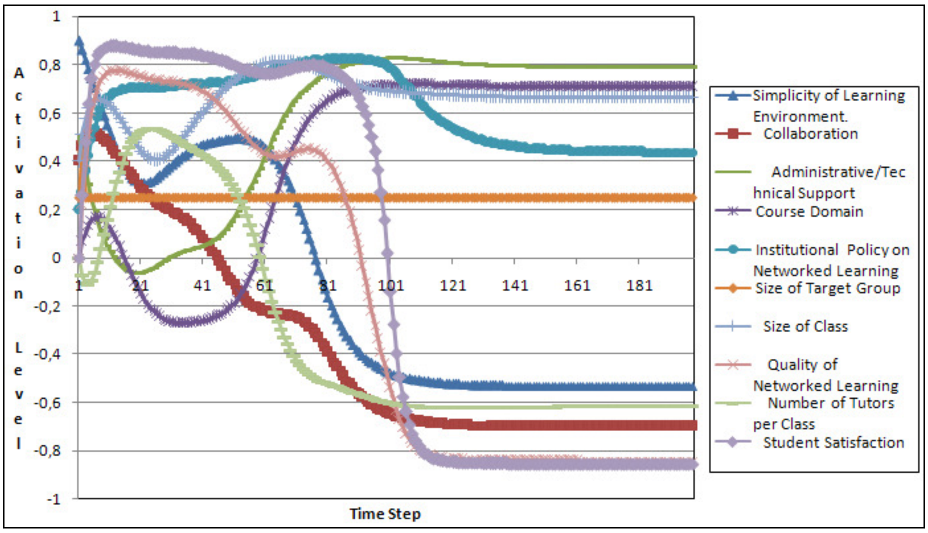

Figure 5: Simulation of FCM concerning Networked Learning. Transition phase to equilibrium for scenario #3 ("Size of Target Group" is set & kept to 0.25-low).

In this scenario, we can see that after a short transition phase, concepts reach equilibrium at the following values.

Simplicity of Learning Environment	Collabo-ration	Administrative /Technical Support	Course Domain	Institutional Policy on Networked Learning	Size of Target Group	Size of Class	Quality of Networked Learning	Number of Tutors per Class	Student Satisfa-ction
-0,532	-0,699	0,790	0,707	0,436	0,25	0,664	-0,842	-0,617	-0,855

It can be concluded that a steady low increase in the size of the Target Group, will lead to the strong decrease of Student's Satisfaction and of the Quality of the Networked Learning and at the same decrease Collaboration and number of Tutors per Class. Administrative and Technical support, Institutional Policy, size of Class are increased but these can not stop the decrease in Quality of the provided Networked Learning.

In the fourth scenario, the weight w34 that connect Administrative/Technical Support to Course Domain is changed from 0.6 to -0.4. This is not a change only to the size but also to the kind of causal relationship that we believe that exist between the two concepts. In this scenario, an increase to Administrative/Technical Support will increase the introduction of Network Learning Courses for not computer related topics (-0.4). All concepts are free to interact with each other. The dynamical behavior of the FCM for this scenario is shown in figure 6.

In this scenario, we can see that after a quite short transition phase, concepts reach equilibrium at the following values.

Simplicity of Learning Environment	Collabo-ration	Administrative /Technical Support	Course Domain	Institutional Policy on Networked Learning	Size of Target Group	Size of Class	Quality of Networked Learning	Number of Tutors per Class	Student Satisfa-ction
0,785	-0,728	0,521	-0,744	0,532	0,900	0,896	-0,828	-0,779	-0,857

We should compare this equilibrium with that found in scenario #1, since scenario #1 and #5 are different only to the weight w34 mentioned above. We can see that now decrease instead of increase is predicted for Student's Satisfaction and the Quality of the Networked Learning. Collaboration is decreased and the same happens to the Number of Tutors per Class and Course Domain. Administrative and Technical support and Simplicity of Learning Environment are moderately and highly increased correspondingly.

Institutional Policy is moderated increased and the size of target group is highly increased. But these can not stop the severe decrease of the quality of the provided Networked Learning.

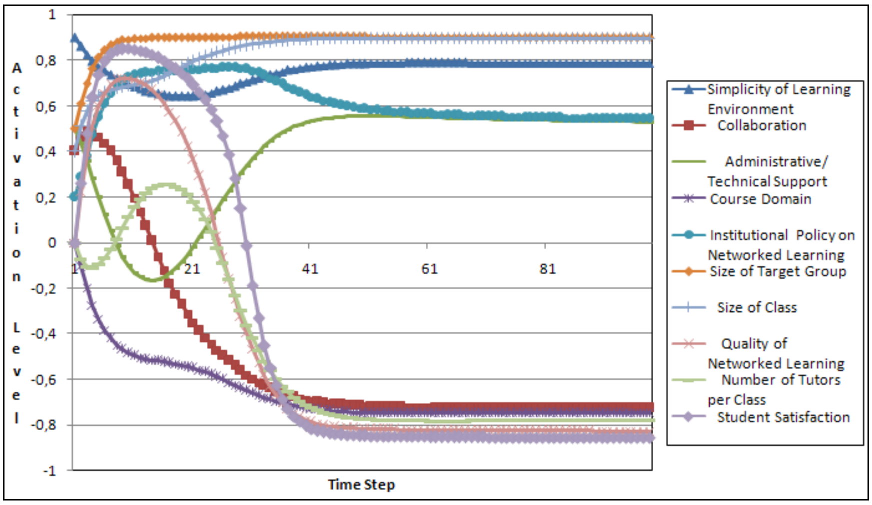

Figure 6: Simulation of FCM concerning Networked Learning. Transition phase to equilibrium for scenario #4 (Weight w34 is changed from 0.6 to -0.4. The way an increase to Administrative/ Technical Support is affecting Courses Domain towards computer related course is changed. All concepts are free to interact).

In the fifth scenario, C1: "Simplicity of Learning Environment" is set & kept to 0.5 (moderate increase) and weight w34 is set back to 0.6. All other concepts are free to interact with each other. The dynamical behavior of the FCM for this scenario, is shown in figure 7.

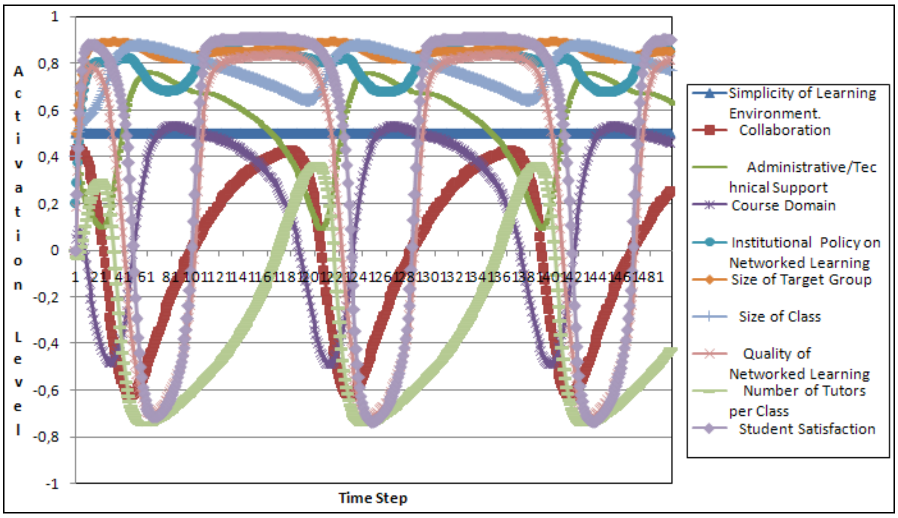

Figure 7: Simulation of FCM concerning Networked Learning. Transition phase to equilibrium for scenario #5 ("Simplicity of Learning Environment" is set & kept to 0.5-moderate increase).

In this scenario, we can see that no equilibrium point is found, but instead of that, the system enters a limit cycle periodic behaviour with concept "Quality of Networked Learning" and other concepts to increase and decrease periodically. We can conclude that no clear predictions or decisions can be made for this scenario, since there are strong interactions between the concepts and the system can reach equilibrium only with the help of factors that are external to it.

5. Summary – Conclusions

After long discussions and extended interviews with a Networked Learning expert, a Fuzzy Cognitive Map is created that models the key factors of Networked Learning and the various causal relationships that exist among them. The model was first examined statically. The density of model's graph was calculated and found extremely 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 consequently the most important concepts of the model were found.

After that, dynamic studies of the FCM model are made and the FCM technique is identified as an important and useful tool that can assist Networked Learning Decision Makers. This is because, it is capable of providing support by making predictions on various scenarios that are imposed to the Networked Learning model that FCM creates. It can also be used for studying structural changes to Networked Learning, by first testing using the FCM, what these changes would cause to the various concepts of the FCM model and proceed with the changes only if the effects are the desirable.

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Appendix A. – Weight Matrix of FCM of Figure 2

Concepts / Weights	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1: Simplicity of Learning Environment	0	0,6	0	0	0	0,8	0,9	0,3	-0,4	0,2
C2: Collaboration	0	0	-0,5	0	0	0	-0,7	0,9	0,5	0,9
C3: Administrative/ Technical Support	0,3	0,3	0	0,6	0,5	0	0,4	0,6	-0,5	0,8
C4: Course Domain	-0,6	0,4	0,3	0	0	-0,5	0	0	0	0
C5: Institutional Policy on Networked Learning	0	0	0,6	0	0	0,9	0	0,2	0	0,2
C6: Size of Target Group	0	0	0	-0,3	0,3	0	0	0	0	0
C7: Size of Class	0	-0,6	-0,4	0	0	0	0	-0,6	0,4	-0,3
C8: Quality of Networked Learning	0	0	0	0	0	0	0	0	0	0,9
C9: Number of Tutors per Class	0	0,3	-0,1	0	0	0	0	0	0	0
C10: Student Satisfaction	0	0	0	0	0,4	0	0	0,3	0	0