Archives of Materials Science and Engineering
Volume 39
Issue 1
September 2009
Pages 45-52
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Assessment of the didactic measurement results using FCM type networks

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Received 23.04.2009; published in revised form 01.09.2009

ABSTRACT

Purpose: The paper presents students egzamination system developer for the scaleable e-learning system. Organisation of the teaching and examination processes, as well as the implementation details are described. An intelligent system based on one of the Artificial Intelligence methods – FCM (Fuzzy Cognitive Maps) type network is being developed within the framework of current work on the e-learning process topic, to model the behaviour and functioning the system as a whole.

Design/methodology/approach: The intelligent examination system for students was developed based on mechanism derived from HotPotatoes system. Programming languages like PHP and JavaScript were also used. Fuzzy Cognitive Maps were used to model the e-learning process and an example of the system use is presented.

Findings: The project effect is the intelligent examination system supporting the statistical analysis of the difficulty level of test problems, generating comments and materials individually for every user. The didactic process was modelled using FCM method.

Practical implications: Reduction of test checking time consumption, individual attitude to every student, score advised to the students along with the comments pertaining to the wrong answers and recommended study topics - all immediately after the test, sent to the student's mailbox.

Originality/value: Employment of FCM AI tool for evaluation of the teaching process effectiveness.

Keywords: E-learning; Computer aided teaching; Course management system; Fuzzy Cognitive Maps (FCM), Intelligent learning systems

Reference to this paper should be given in the following way:

M. Gumińska, J. Madejski, Assessment of the didactic measurement results using FCM type networks, Archives of Materials Science and Engineering 39/1 (2009) 45-52.

EDUCATION AND RESEARCH TRENDS IN MATERIALS SCIENCE AND ENGINEERING

1. Introduction

Institute of Engineering Materials and Biomaterials decided already many years ago to extend the conventional teaching model offering students knowledge with the distance learning method. Currently the Institute's e-learning Platform operates successfully, with the benefit for the students complementing regularly their knowledge acquired during lectures, laboratories, and classes in the area of materials science. [1-5] This form of distance learning over Internet, carried out using the computer-tele-communication technology keeps on developing and its popularity grows; therefore, development of new method and solutions that will suport this dicastic process is justified.

The e-learning platform project was developed within the framework of a work dedicated to this problem, along with the description of the system operations principle, with the carefully planned platform structure and contents. The database development process was carefully documented, including specification of the design requirements for the database, specification of data flow presented with the DFD model, and development of the entity relationship diagrams ERD – tables were created which were subjected to normalisation process, and finally the database was created using the MySQL software tool. The platform used interface design was worked out using the relevant software (XaraX, Adobe Photoshop), completed as an HTML document with Cascading Style Sheets. The style sheets (CSS) were developed both for the screen version of the WWW page and for printing of the articles. Mergin the e-learning platform with the My-SQL database was done using PHP language, which is presented in an example of the „*Administration Panel*" functioning, for which relevant forms were designer for adding, modifying, deleting and searching data at the e-learning platform level [6, 7]

Extending this topic, the method for generating the didactic materials was worked out, whose contents is acquired from the database and forwarded to the platform, their access method for the users, the students' tests marks saving procedure, or the dynamic generation of the personalised PDF documents like, e.g., course completion certificates. Examination system was also developed, making generation of the personalised problems sets possibile for etery student, and assessing effectively knowledge acquisition progress for every student. The system can also generale comments to these areas of the subject matter in which a particular student is not proficient. The system supports also statistical analysis of the difficulty level of test problems making it possibile to modify them [6, 8]

The e-learning platform, for which the examination system was developed, is a scaleable one, which means that it can be used both for the entire e-learning course for students who cannot attend the day studies, and also as the teaching process support system for classes carried out in a traditional way. The e-learning platform is such a flexible system that it can be used for any number of courses, any number of subjects, tests, and students. The platform can be employed for one or more subjects within a course framework, and also for any number of teachers who may wish to use it [6].

The development process of the scaleable e-learning platform examining system is described below, and further new possibilities of the complex system modelling using the FCM network is discussed.

Goals specified at the beginning of the project were as follows:

- carrying out the test (exam),
- advising the student about the test result and generating comments to it along with references to these parts of the subject matter for which he or she did get approval,
- support of the test problems difficulty level analysis.

Carrying out the particular tasks was begun from development of the DFD diagram, describing the data flow between processes which will take place in the examination system for students (Fig. 1).

The scope of the examination system tasks includes:

- preparation of problems for the entire subject matter area,
- preparation of individual tests for every student (from the problems drawn from the database for his subject matter to be tested, including his eventual arrears),
- assessment of the replies and generating comments to the subject matter that was not mastered satisfactorily (personalised PDF document),
- working out (updating) statistics of arrears for the students group and updating the difficulty level of the problems [6,7,9].

The teacher (main lecturer) works out the test problems based on information about the lecture data in the database (data flow 1.1) (Fig.1) from the entire subject area which will be obligatory for the student within the framework of the particular subject (data flow 1.2). Next, all prepared problems and all data pertaining to them (subject ID, problem ID, problem text, problem reply versions, comments) are send to the database (data flow 1.3).

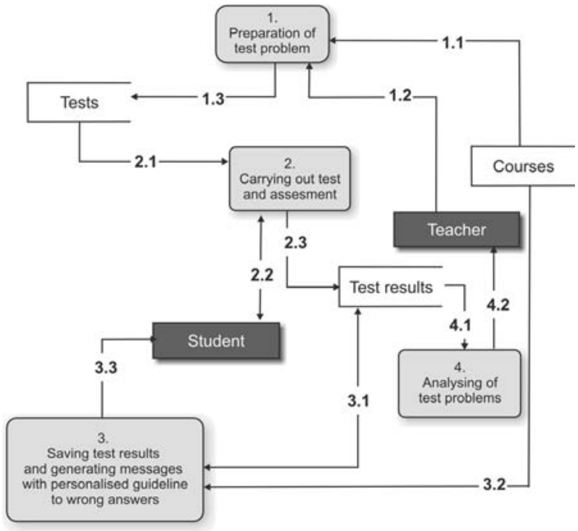


Fig. 1. Data flow diagram of the examination system on the e-learning platform

Test problems are generated for each student individually. The test problems are collected randomly from the database and inerted into the relevant location of the template generated using Hot Potatoes, forming the approval test for the part of the subject matter that was not yet passed by the student or for which he or she not get approval (data flow 2.1). Next, the test as acquired by tge student (data flow 2.2) and sent to the database with the replies selected (data flow 2.2). Information about the percentage of the correct replies is sent to the student and to the database after he or she solves the last problem (data flow 2.3).

The test mark is calculated based on the percentage of correctly solved problems and saved in the database (data flow 3.1), with the simultaneous generating of comments and references to the lecture materials to this part of the subject matter for which the student had provided wrong answers (data flow 3.2). The mark obtained along with the comments and references is emailed as a personalised PDF document generated individually for each student (data flow 3.3).

Statistics of arrears is kept based on data stored in the database, advising the teacher about achievements in study for the en tire groups and individually for each student. The process evaluates difficulty of the prepared test problems, which is an advice to the teacher should he or she modify the problems (data flow 4.2). Based on this information the teacher may update the test problems modifying them and eventually adding new ones to the set of test problems (data flow 1.2) [7, 9].

2. Organisation of the teaching process and examination system

The available courses are revelant to teaching areas in the particular educational centre and may include as many as a dozen or many dozens of subjects, depending on the course type. Various classes types may be planned for every subject: lectures, classes, laboratories, projects, seminars for which educational materials are prepared to be made available in various formats: (doc, pdf, html, ppt, swf). Simultaneously, the relevant knowledge tests are prepared for every form of classes in many forms – multiple-choice questions, short answer quizes, gap fill exercises, crosswords, drag and drop match-up exercises, or drag and drop match-up exercises with pictures and target language words [7, 9]. Classificaiton and organisation of the educational materials on the educational platform is shown in Figure 2.

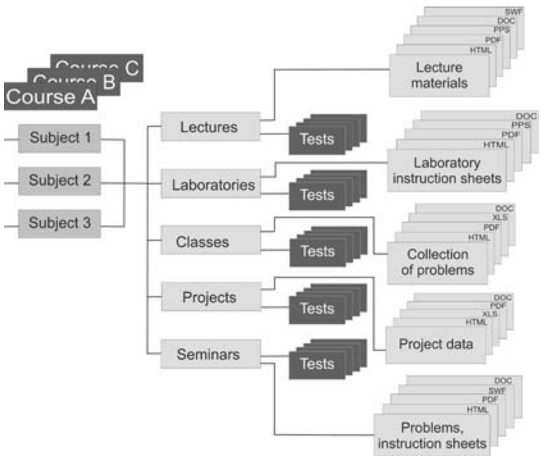


Fig. 2. Organisation of the educational materials

The subject „Design of cutting tools and technological equipment" in one of the courses may serve as an example. Figure 3 presents one slide from the lecture materials and generated exemplary test pertaining to the selected lecture material, which a student will have to solve [9].

The course lecture materials are divided into parts according to the binding syllabus. A specific set of problems is created for each lecture materials part, which pertain to the particular material section identified by a key. The problem attributes include: unique identifier, key to the course lecture materials, texts of the problem and relevant answers, as well as the comment; comment includes hypertext linx to the other course parts also, related to the issue presented to the student. The exemplary relationship diagram of problems, answers, and comments related to the particular test is presented in Figure 4.

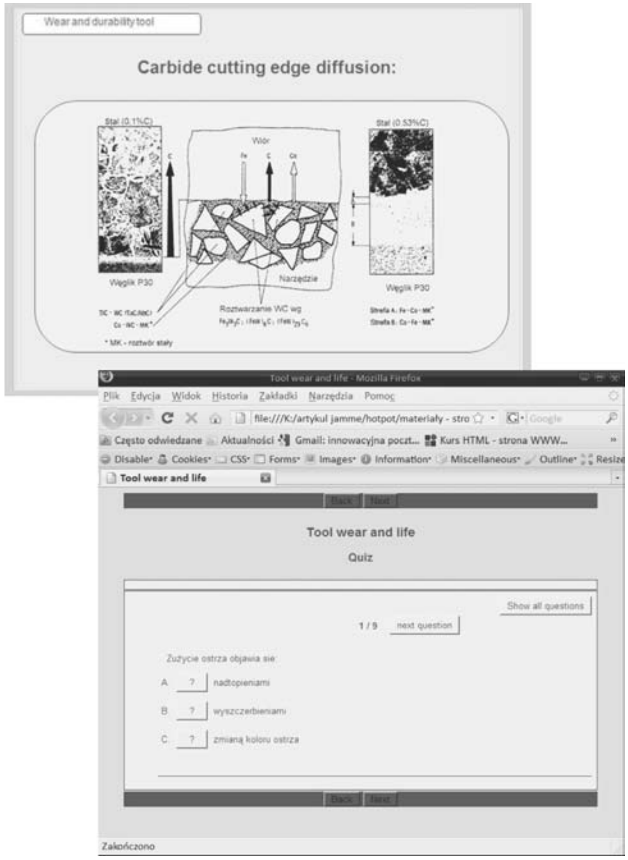


Fig. 3. Example of the lecture material and generated test

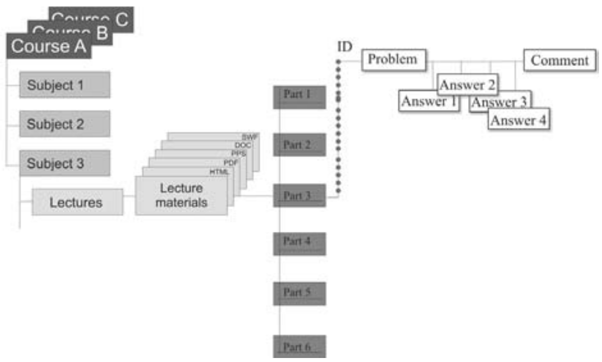


Fig. 4. Organisation of tests on the e-learning platform

Subject material parts are defined for each student individually which he has to get approvals for (taking into account previous tests which feature the student's arrears), which is done by generating a list of topics for which was not yet credited. At the same time a number of tests approved for the student is calculated, which is required to issue the final certificate for the student to certify the successful crediting of the subject, should he fulfill the particular conditions, that is get credits for the required number of tests from the required subject matter scope [7].

Coming back to the examination process, as soon as the student logs into the system and selects the particular scope of the subject matter for the test, the set of randomly selected problems is prepared individually for every student. A template is used obtained by generating a test using Hot Potatoes tool [2]. for generating the test for the student. Once generated Hot Potatoes script features a template to which randomly generated test problems from the database are inserted. This template is a HTML code in fact, with the JavaScript scripts, in which PHP scripts replaces fragments of character strings for other ones – successive test problems from the database [10].

The student's answers after commencing the test are saved with his or her ID in the relevant database table on the fly and when the test is completed the score is advised to the student. Moreover, the student is advised about the mark he has got for the test and is sent comments to these test problems for which he did not provide correct answers. The student obtains this information as a personalised PDF document consisting of certificate, part in which information about crediting the test is confirmed and the part commenting errors made by the student. This document is waiting for collection by the student at his personal account, the so called *Student's Room* [6] immediately after sending from him the answer to the last test problem. The certificate is generated based on the previously generated PDF template, so that it is a fully print ready document [7,11].

Thanks to the examination system, the statistics of answers to the test problems is updated based on students' test results, so that their dicciculty level may be analysed. Should the examined students give always – or very often - correct, or wrong answers to a certain set of questions, it may indicate that the teacher has worked out the wrong question(s) and test results do net reflect the true knowledge level of the students. Based on the statistics of answers the teacher can edit the test problems and make corrections to bring their difficulty level closer to the average.

A system was developed in this part of the project that makes it possible to carry out effectively exams for the e-learning students or for the day students in the educational centre. The developed system makes it possible to generate the personalised test problems for each student individually, and also effectively assesses his or her progress. It can also generate comments to these parts of the materials which were not mastered by the student, which is known from the wrong answers he gave [9].

The examination system developed for the e-learning platform supports carrying out statistical analysis of the difficulty level of the test problems, making it possible to make corrections in them. Such solution is beneficial not only for the students, who – in case of failing to obtain credits – are instructed immediately where they had made the eventual mistakes, what reading matter they should consult to make up their arrears, and where they can find correct answers in the course materials, but also the teachers benefit from it. One may expect that during the traditional exam lasting one hour the teacher saves about 17 hours of his time spent on verifying the tests for a group of two hundred students at their first attempt (assuming, based on many years long experience that checking one test takes about five minutes). According to the syllabus the teacher delivers 15 hours of lectures from one subject, and the labour consumption connected with verification of tests made in the "traditional" way is much higher than the time spent for the lectures. Moreover, assuming that half of the students will not pass the exam at their first attempt, then the teacher could save next eight hours that would be spent on checking the test results from the second attempt. An additional advantage of the system is that it evaluates students' knowledge in an objective and fair, with no assessment mistakes which may happen to a human.

An intelligent system based on one of the Artificial Intelligence methods – FCM *(Fuzzy Cognitive Maps)* type network is being developed within the framework of current work on the e-learning process topic, to model the behaviour and functioning the system as a whole [12]. The system during the learning process should autonomously, automatically judge when the learning process should be stopped, what knowledge should be passed on a certain topic and what knowledge should be passed at a certain moment. Taking into account different types of errors made, the best solution will be to adjust the e-learning system reactions according to the characteristic features of the individual users. FCM is to be used for tuning up this process. Using FCM it is possible to develop the mechanism of the immediate, individualised reaction to the student's activity.

3. Fuzzy Cognitive Maps

The FCM network has been designed to model functioning of systems that are defined using certain concepts corresponding to their characteristic features or states. Once the concepts/states are defined they are presented in a form of a directed signed graph illustrating the causes and their effects. The concepts are represented by nodes in the graph, while the casual influences between the concepts are its edges. The nodes have values representing the degree of activity of the concept at a given time. The node's value is calculated by totaling the weights of the incoming edges and the value of the originating concept at the preceding state. Therefore calculation of the node's value should be carried out iteratively, until it assumes a certain value and does not change any more, which reflects reaching an equilibrium state after some forced excitation of the network. Finally the threshold function may be applied to the weighted sums which can be fuzzy in nature. The concept values are defined in a normalized range which describe rather a degree of activation than its exact quantitative value [12-15].

FCMs have been applied in knowledge base design, modelling of strategies, simulation, decision analysis, failure effects analysis, managerial problems solving, urban design support, relationship management in airline services, and many others [14], like modeling of the gastric-appetite behaviour and popular political developments. There are many applications of FCMs in engineering - Styblinski (1988) used FCMs for analysis of electrical circuits, Gotoh and Murakami (1989) used FCMs for modelling plant control. Many their varied applications include: [12,14]:

- modelling of supervisory systems;
- simulation of strategic planning process in intelligent systems;
- design of hybrid models for complex systems;
- hyper-knowledge representation in strategy formation;
- mobile robots and in intimate technology, such as office plants; analysis of business performance assessment;
- traffic and transportation problems;

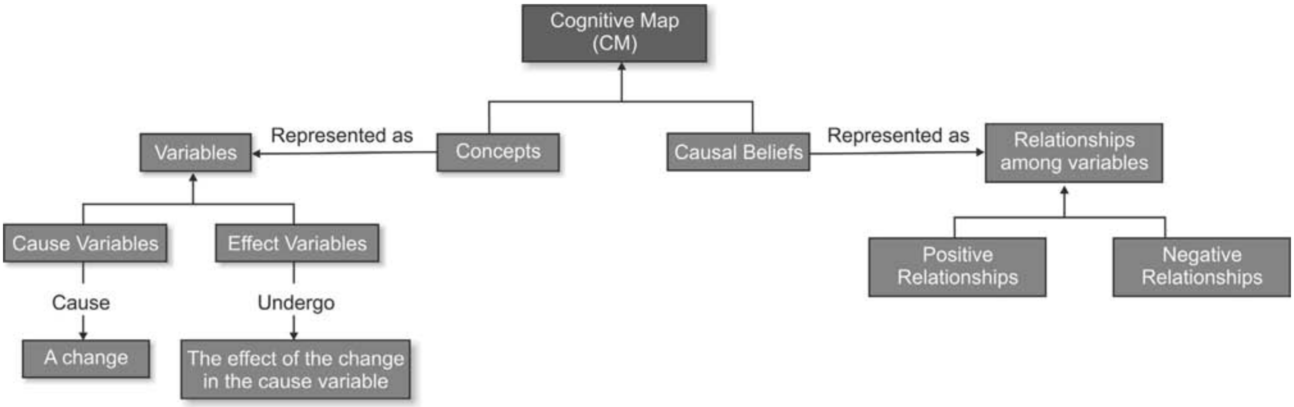


Fig. 5. Basic elements of Cognitive Maps (CM) [14

- web-mining inference application;
- industrial relations: between employer and employee, maximizing production and profit;
- decision support in intelligent intrusion;
- detection systems;
- medical diagnostics;
- creating metabolic and regulatory network models
- child labour problem [12-17].

4. FCM methodology

4.1. Cognitive Map Concept

The concept of Cognitive Maps (CMs) was first presented and applied by Axelrod (1976). A Cognitive Map is a signed digraph intended to capture the causal assertions of a person with respect to a particular area and used to analyse the effects of alternatives, e.g., policies or decisions to achieve certain goals [13]. The main cognitive map elements are shown in Figure 5

In case of a positive relationship between the concepts, a value change in a cause variable results in the change of the effect variable or variables in the same direction (e.g., increase or decrease). On the other hand, in case of a negative relationship the change of the effect variable, is in the opposite direction. Figure 6 shows the graphical representation of a CM [12,14]. In this figure X, W, Y, Z and F are the variables represented as nodes; the causal relationships between them are represented as directed graphs between variables; therefore, the CM is represented as a signed digraph. As in all graphs a path between two variables X and Y in a CM is a sequence of all connected nodes which from the first node X to the last node Y.

Two rules determine the direction of the resulting effect of changes in cause variables: the indirect effect of a path from a cause variable X to an effect variable Y, I(x, y), is positive if the path has an even number of negative weights, and it is negative if it has an odd number of negative weights. Therefore, the indirect effect of variable (X) on variable (Y) along P(xwy) path in Fig. 6 is positive. The total effect of a cause variable X on an effect variable Y is denoted by T(x, y), and is the sum of all the indirect effects from the cause variable X to the effect variable Y. The total effect of variable X on variable Y in Fig. 6, is the sum of the indirect effect of X on Y along the P(xwy) and P(xfzy) paths. Both indirect effects are positive; therefore, the total effect is also positive. Fig. 6 is an example of a signed digraph where each relationship is attributed only with a sign, thus modeling only the change direction. One can model more specific cognitive maps containing more information substituting positive or negative numbers for these signs, which makes it possible to show also a magnitude of a change instead of its direction only. This CM version is called the weighted cognitive maps, which can also determine the total effect of all negative and positive effects. And lastly, the functional cognitive maps feature a third CM variation in which a specific function is assigned to each causal relationship to represent more accurately the direction and magnitude of the change. In particular, Kosko (1986) introduces the concept of Fuzzy Cognitive Maps (FCMs), being the weighted cognitive maps with fuzzy weights [17-19,20].

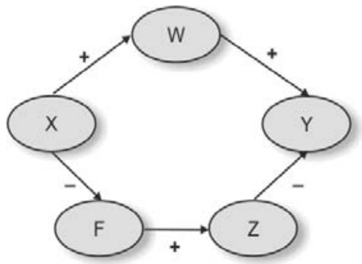


Fig. 6. Example of part of a CM [12]

4.2. Fuzzy Cognitive Maps

Fuzzy Cognitive Maps (FCM) feature a soft computing tool which is a combination of fuzzy logic and neural networks techniques [21].

Fuzzy Cognitive Maps (FCMs), constituting a new approach to modelling the behaviour of complex systems, were introduced by Bart Kosko in 1986 [12]. Like the original CMs, they describe the behavior of a system in terms of concepts and causal relationships between them. Since their advent, their use has been extended to many real-world situations ranging from analysis of investments to supervisory system control [1,5,24-31]. Similarly to the original CM concept, the FCMs are represented by a digraph, in which the nodes are concepts describing the main features of the system, and the edges between nodes represent causal relationships between concepts. The FCM graphical illustration presented in Figure 7 describes which concepts influence other ones, showing the interconnections between concepts [21].

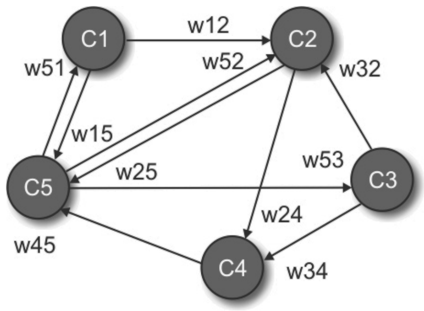


Fig. 7. A simple Fuzzy Cognitive Map

If the the weight sign indicates positive causality between concepts Ci and Cj, i.e., wij > 0, then an increase in the Ci concept value will cause an increase in the Cj concept value, and a decrease in the value of concept Ci will cause a decrease in the Cj concept value. In case of a negative causality between two concepts, i.e., wij < 0, an increase in the first concept Ci value causes a decrease in the second concept value and a decrease of the Ci concept causes an increase in value of Cj. When there is no relationship between two concepts, then wij = 0. The value of the wij weight represents the degree of influence between concepts Ci and Cj.

The values of all concepts at every simulation step are calculated, evaluating the influence of the interconnected concepts on the particular concept, according to the following formula [21]:

$$A_i(t) = f\left(A_i(t-1) + \sum_{\substack{j=1 \\ j\neq 1}}^{n} A_j(t-1) \cdot w_{ji} \right) \tag{1}$$

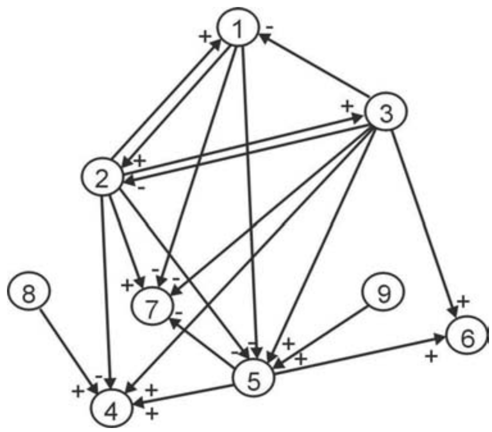
where $A_i(t)$ is the value of concept C_i at time t, $A_j(t-1)$ is the value of concept C_j at time t - 1, w_{ji} is the weight of the interconnection from concept C_j to concept C_i and f is the sigmoid function, belonging to the family of squeezing functions. This is the unipolar sigmoid function (2), where $\lambda > 0$ determines the steepness of the continuous function f(x). Usually the following sigmoid function form is used [21]:

$$f(x) = \frac{1}{1+\exp(\lambda x)} \tag{2}$$

All the values of concepts and weights in the FCM have fuzzy nature representing issues, states and variables using linguistic notion. These fuzzy variables have to be defuzzified in order so that the mathematical functions can be used to calculate the corresponding results. Thus, values of concepts are in the |0; 1| range and values of weights are in the |1; 1| interval. Using the sigmoid function the calculated values of concepts after each simulation step will belong to the interval |0; 1|. Experts design and develop the fuzzy graph structure of the FCM, consisting of concept-nodes that represent the key principles-factors-functions of the system operation – it is also possible to include in them varying views and knowledge of a group of experts. In this way certain experts can add to the overall system picture their perception, with some concepts that others might have overlooked or decidned not to include in the model. Then, the structure and the weighted interconnections of the FCM is defined using fuzzy conditional statements [21]. Very often experts asked to describe the relationships between concepts use IF–THEN rules to justify their cause and e□ect suggestions among concepts, applying a linguistic weight for each interconnection. If a group of experts is asked to develop the FCM model then every expert describes interconnections with fuzzy rules. In all cases the inferences of the rules are the linguistic variables describing the relationships between the the concepts and determining the grades of causality between the pairs of concepts [22].

5. Application example

The fuzzy cognitive map shown in Fig. 8 was elaborated based on the work of García et al. and Laureano-Cruces [19,20]. This figure represents the teaching–learning process model; e.g., the node labelled as ERROR directly feeds the NEED FOR INTERRUPTION, the node labelled IDLE TIME directly feeds THE USE OF INCENTIVES. Table 1 shows two different situations resulting from two different initial states [20].



1. Interest in the topics
2. Joy to continue
3. Need for aid
4. Use of incentives
5. Need for interruption
6. Possibility to quit
7. Expectance
8. Idle time
9. Error

Fig. 8. Fuzzy Cognitive Map

The different conditions of the FCM reaching a steadfast state, due to different actual events at a specific stage of the teaching-learning process, represent the events generated by the tutor with his didactic actions aimed at making the teaching - learning process reliable. The different didactic tactics will be taken according to the event that gave rise to that condition. For instance, in example 1, they are presented by an initial condition: lack of interest (1) and lack of enthusiasm (2) in the topic, and clearly, lack of expectancy (learning stage, 7). At the first stage, a need of help direct from the tutor and the usage of incentives (any encouragement means should be considered) are suggested. It is suggested at the second stage to make a direct interruption (for an explanation or to ask directly what it is still unclear). At the third stage, it is suggested to use incentives. Please note that the possibility to quit was present at every stage; moreover, after the second stage the expectancy occurs [20,23].

Table 1
Fuzzy cognitive map simulation

Partial states	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Initial state 1	-1	-1	0	0	0	0	-1	0	0
First state	0	0	1	1	0	1	0	0	0
Second state	0	0	0	1	1	1	0	0	0
Third state	0	0	0	1	0	1	1	0	0
Final state	0	0	0	0	0	0	0	0	0
Partial states	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Initial state 2	0	0	0	0	0	0	-1	1	1
First state	0	0	1	1	0	1	0	0	0
Second state	0	0	0	1	1	1	0	0	0
Third state	0	0	0	1	0	1	1	0	0
Final state	0	0	0	0	0	0	0	0	0

The tutor may choose a certain chain of actions (path in the graph) or just one action. The student's mental model constantly changes and it is believed that every didactic action has a beneficial effect on the learning process. On the other hand, the didactic tactics that the tutor may use are represented by the set {3,4,5} of the FCM nodes. It will be required to have some more specific actions when analysing in depth sources of teaching process mistakes and depending on their severity the weight assigned to the FCM input will be a fuzzy value between |0,1| [20- 25].

FCM can be used for selection of the additional study topics for a student whose knowledge has been found inadequate in a certain area – this situation represented by a FCM node has its influence on states of other nodes. Therefore, FCM reaching its equilibrium provides as a result a list of the recommended reading. Clearly, all subject syllabus has to be modelled in the FCM – just like shown in the example in Fig.8, fuzzy weights being applied according to the relative importance of the particular topics at the tutor's discretion. Links to the relevant reading matter (PDF documents) correspond to the particular FCM nodes relating to the subject detailed topics. In this way, analysis results of the student's test results may be converted directly into the contents of the additional/repeated study topics, being the base for generation of the relevant individualized PDF document.

6. Conclusions

The following conclusions can be reached from the exemplary results obtained:

- Control of the diagnostic process using the FCM intelligent learning system is possible;
- There is a possibility to include the expert's knowledge by modeling it as the conceptual genetic graph;
- The FCM network models reactive environments characteristic of the teaching-learning process, making more precise improvement of the sensitive e-learning possible;
- The method is proposed for conversion of the analysis results of the student's test into the contents of the additional reading matter recommended for the student.

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