Chapter fourteen

The Use of Fuzzy Cognitive Maps for Learning and Development of Medical Case Learning Scenarios

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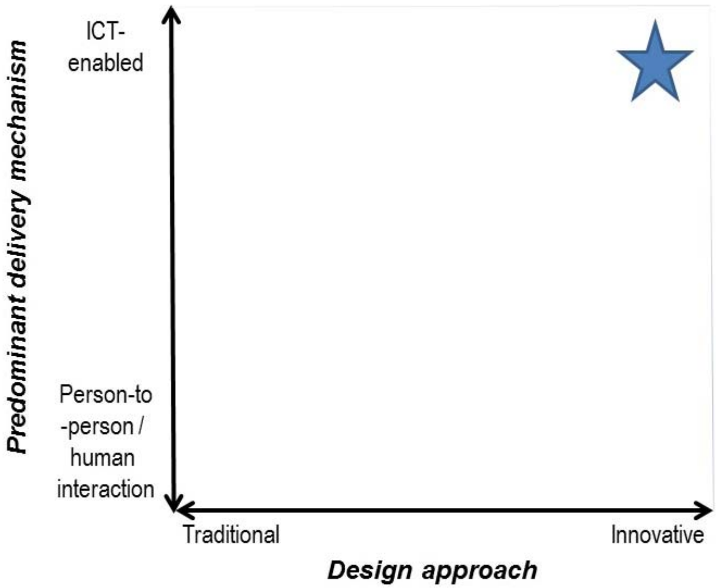

Introduction

Case studies are widely used in medical education to teach reasoning and decision-making skills and to prepare medical students and young professionals to move on to clinical practice. With case studies, students can see how they can transfer their knowledge and skills to the actual clinical setting without the pressure, constraints, and stress of being actually involved with a patient in a critical situation.

Scenario-based learning (SBL) refers to any educational approach that involves the intentional use of, or dependence upon, scenarios to bring about desired learning outcomes. Scenarios within this context may be a given set of circumstances that can potentially occur in a particular case, such as a description of human behaviour, trigger events, critical incidents or even a human dilemma, (Errington, 2003; Tripp, 1993; Wilkie, 2000).

Fuzzy Cognitive Map (FCM) development is a soft computing approach based on exploiting human knowledge and experience through an interactive procedure where a group of subject matter experts is assembled to provide their experience and to design the FCM. Then, by way of aggregation, an integrated FCM is produced. In a similar way, a group of learners can collaborate and co-work to study and understand a problem. Based on this they suggest and create a mental model and represent it in the form of a FCM. The abstract model produced by every group of students is compared with an established model put forward by the teacher. The students are then able to change and update their proposed model and to examine different scenarios so that at the end they have acquired thorough knowledge and experience of the problem.

Case studies and scenarios are particularly useful for the area of medical decisions and problem-solving; typically, these are complex and potential outcomes have a degree of uncertainty. Within the context of this work, FCM methodology is used to create abstract models and suggest different scenarios within a particular case study that impose various inputs, events, facts and behaviours which may lead to different outcomes.

This chapter introduces Fuzzy Cognitive Maps as a methodology for case based learning. It briefly describes Fuzzy Cognitive Maps, how they could be used as a teaching tool using case learning scenarios and specifically explores Medical Decision Case Scenarios.

About Fuzzy Cognitive Maps

Concept mapping is an established technique for representing knowledge in graphs. It was developed by Novak in the 1960s, applied over a 12 year period and reported much later (Novak, 1998). In essence, it is an individual's diagrammatic interpretation of ideas, since it connects two or more concepts by words and expressions that describe their relationship. It has been used in education for more than 25 years to promote learning and understanding of difficult concepts. According to a recent systematic review (Daley & Torre, 2010) concept maps foster in the learner the development of meaningful learning, critical thinking and problem solving. They reported that in medical education, through concept maps, students are able to integrate basic and clinical science information as well as demonstrate more integrated holistic thinking patterns. This is an essential element in medical decision making.

On the other hand, a *cognitive map* is a graphical representation that specifically indicates causal relationships between concepts. It is a directed graph of nodes (concepts) that are connected by edges (directional lines) that represent positive or negative causal relationships. For example, concept A has a positive causal relationship to concept B when an increase in Concept A causes an increase in Concept B. Alternately, when concept A has a negative causal relationship to concept B then an increase in Concept A will cause an decrease in Concept B. Cognitive maps were developed by political scientist Robert Axelrod (1976). In his design the edge values between concepts were +1 (positive causality), -1 (negative causality), or 0 (no causality). This implies that cognitive maps represent formal, bivalent, true or false logical relationships. In many sciences where there is a great degree of uncertainty in the knowledge base (for example, in social sciences, medical sciences, and business), concepts are, for the most part, not related by such crisp (0,1) relationships. There is a degree of causality in relationships between concepts that experts can best describe in linguistic terms. Such terms are: “sometimes”, “not likely”, “very likely”, “always”, “never” etc. These linguistic terms may correspond to fuzzy values *between* 0 and 1 (as opposed to crisp) through membership functions. Additionally, in these sciences experts do not always agree on the degree of causality; so, for example, one expert may consider the causal relationship between two concepts as "very likely", a second expert as "likely", while a third one "very likely". The mathematical field of Fuzzy Logic allows mathematical operations between membership functions so that this collective knowledge is represented in a more complex concept mapping tool, the Fuzzy Cognitive Map.

A Fuzzy Cognitive Map (FCM) is a flexible soft computing tool that is based on a synergistic cooperation of Fuzzy Logic and Neural Network methodologies and it has been successfully applied in a large variety of disciplines. FCMs model the world as a collection of concepts and causal relations between concepts that are created exploiting the experience and knowledge of experts. In a graphical illustration, an FCM appears as a signed, weighted graph with feedback that consists of nodes and weighted arcs (Kosko, 1986), as shown in Figure 1.

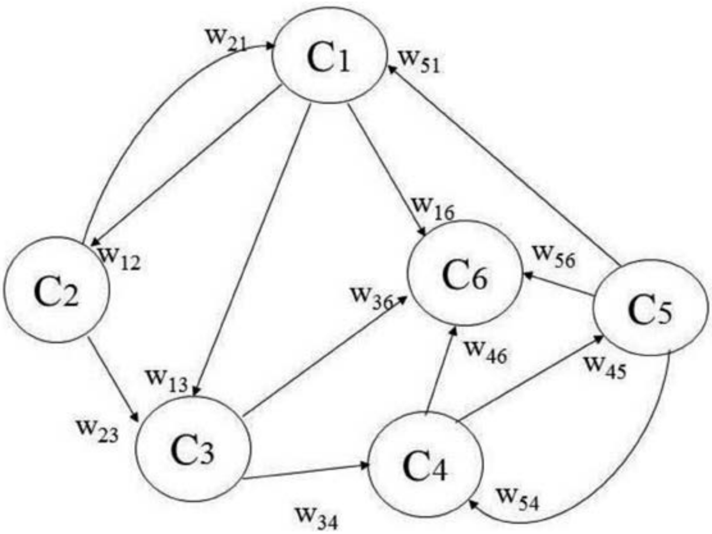

Figure 1. A Fuzzy Cognitive Map comprised of nodes (C_i) and weights (W_{ij})

Nodes are concepts that are key elements used to describe the behaviour of the system being modelled. The concepts can be events, actions, goals, values, or trends of the system being modelled by the FCM. FCMs are considered as fuzzy feedback models of causality, where the weighted interconnections between concepts represent the existing causality between the corresponding entities, thus creating an interconnected network of interrelated concepts, like an abstract mental model. A weighted arc value W_{ij} from causal concept C_i to affected concept C_j describes the degree by which the first concept influences the latter, either positively or negatively. Feedback interconnections are permitted along with 'if-then' inferencing. This allows FCMs to model complex, nonlinear, dynamic systems such as medical and patient systems.

Medical decisions can be complex because they may involve a number of possible diagnoses and/or management options, a large amount of data to be handled, determination if the existing data and information is sufficient or if further testing is required and, finally, consideration of the risk of complications. Therefore, approaches that model medical decisions are complex ones which frequently involve a significant number of variable factors including changing characteristics, unexpected events, new facts, and combinations of alarm situations.

Medical Decision Support Systems (MDSS) have been introduced to provide consultation and support to medical professionals automatically. Typically they are developed by using methodologies that resemble human-like decision-making procedures. FCMs have been used successfully to design and implement Medical Decision Support Systems because these use a human-like reasoning approach and can handle information which is vague, incomplete, complementary and/or conflicting.

Due to the way in which an FCM MDSS is constructed, it is a suitable tool for formalising understandings of conceptual and causal relationships (Kosko, 1993). Such a FCM MDSS can be used to teach reasoning and decision-making skills and to prepare students to become problem-solving clinicians. This can be achieved by two separate tasks.

In the first task, the students themselves are the ‘experts’ and draw their own fuzzy cognitive map of the decision process after reading up/learning all relative theoretical material. Linguistic Causal relationships between concepts are established by each student. Comparisons of maps and discussion lead to a ‘group of experts’ version of the map. The aggregated FCM designed by the group of students is then compared to an actual FCM MDSS designed, approved and used in everyday practice by clinicians.

In the second task, medical learning scenarios are established using the dynamic nature of FCMs inherently in the structure and operation of the MDSS. We will explain and illustrate these in the next section.

Learning Based on Fuzzy Cognitive Maps

Fuzzy Cognitive Mapping can be used as a teaching tool because it is an illustrative approach that enables learners to enhance their comprehension of a field being studied. FCMs are suitable for illustrating cases because of the way they are developed – that is, the concept-nodes and the interrelations between them (weights) are determined by subject matter experts using their background knowledge and experience. An FCM represents the key concepts, the causal directions among them and their relationship using linguistic variables.

A learning procedure using FCMs starts with the learner studying the relevant subject matter and then understanding the causal relationships between key concepts by drawing cognitive maps with linguistic connections between concepts chosen by the learner. Each learner creates his/her map based on their comprehension of the subject matter. Learners in groups discuss, argue and finally aggregate their opinions and maps into a final concluded map with linguistic connections. The teacher provides an FCM that has been designed by field experts and has proved its merit in practice. Then learners, in consultation with the teacher, are able to compare the learner map and the subject matter experts’ maps concerning concepts included and interconnections between concepts. This procedure is shown in Figure 2, where the feedback discussion and comparison approach has great importance for enhancing learners' knowledge and understanding.

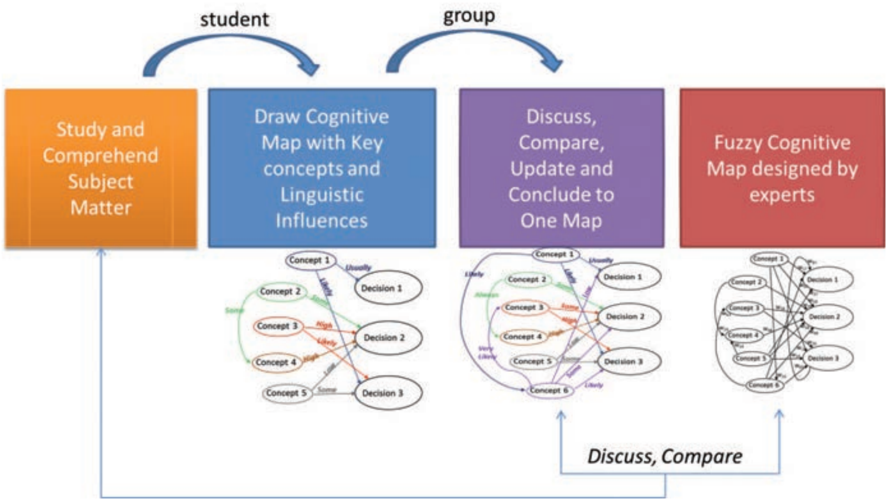

Figure 2. Learning through case problem understanding and solving

For every case, the FCM designed by experts is a reference one which allows comparison and manipulation by the learners. Therefore, a learner who is using the FCM-based teaching tool has already studied the corresponding field and is able to increase his/her comprehension by testing it with the FCM tool. The learner is able to understand the problem and 'decipher' the relative concepts/variables of the FCM tool by activating/deactivating them (following the procedure shown in Figure 3). The learner is able to choose different initialisation values for the concepts and in this way to test and run different scenarios. When a case problem is given to the learner s/he should activate the appropriate concepts by applying their existing knowledge to the specific case and following the influence that this has on the output concepts (outcomes) of FCM. Then, s/he may make one or more modifications to the initial values of the input concepts or alter the activation level among the concepts and this may lead to different outcomes. In this way, the learner can implement various scenarios based on real or hypothetical suggestions and can perceive the behaviour and notice any differences resulting from a change.

From a pedagogical viewpoint, this complementary method of learning offers the opportunity to apply the theoretical knowledge in virtual situations that characterise real cases. And, because a variety of cases can be simulated, the use of an FCM as a simulation/testing tool can enhance learning through experiment.

On the other hand, any instructor could use the FCM tool as a means to check or create didactic scenarios and evaluate learners' knowledge. An instructor could use FCMs as an assessment tool for various didactic scenarios (i.e. cases with varying parameters). Since FCMs are sensitive to changes – they produce different outcomes for slight changes – the instructor could use an FCM tool to assess or to check the correctness of a didactic scenario, to quantify the degree of interaction between the concepts/variables with each other, and to choose the most appropriate scenario for using during the learning process. More specifically, an instructor is able to evaluate possible cases that illustrate different circumstances by activating different concepts.

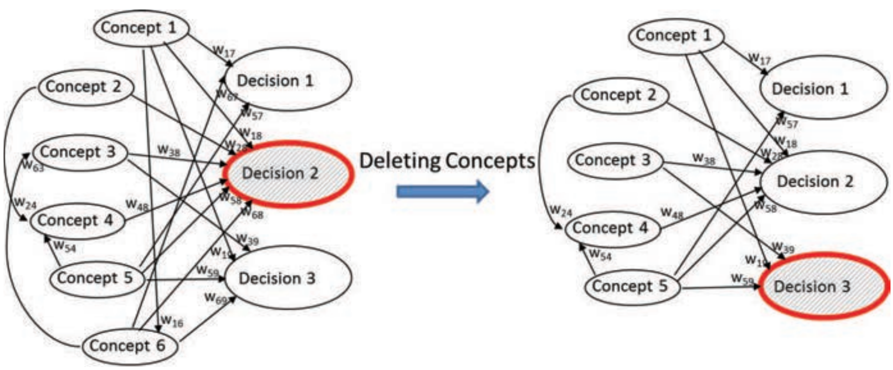

Figure 3. Illustrative scenario testing by deactivating concept 6 and observing that the decision is changed from 'Decision 2' to 'Decision 3'

Another pedagogical aspect of the FCM tool is that it can support instructors in evaluating learners. As a learner evaluation tool the proposed method accords with modern strategies of teaching and training that require the learner to be active and able to discover knowledge through practice and experiential learning methods.

FCMs have been implemented for a wide variety of fields and they are highly applicable to the domain of medicine. Many FCM models have been developed for medical decision support in a variety of situations, namely; making a decision, concluding to a diagnosis, characterising tumours or providing a clinical guideline. Fuzzy Cognitive Map Medical Decision Support Systems (FCM MDSSs) have been successfully used for differential diagnosis in speech and language pathology (Georgopoulos, Malandraki, & Stylios, 2003), making decisions during labour (Stylios, Georgopoulos, Malandraki, & Chouliara, 2008; Stylios & Georgopoulos, 2010), decision-making choices in external beam radiation therapy (Georgopoulos & Stylios, 2008), emergency room triage (Georgopoulos & Stylios, 2013a) and post-triage decisions (Georgopoulos & Stylios, 2013b), and many other medical applications.

The above mentioned FCM MDSSs have been developed to assist medical professionals' decisions. However, due to their design, they could also be applied to the education process in order to allow further and deeper understanding of the specific medical decision process. Therefore, for an inexperienced clinician or learner, this tool can be valuable as it can assist him/her, as well as enhancing the learning experience.

Case Learning Scenarios Based on FCM Models

In case based teaching and learning scenarios, each case represents a particular problem/situation that may lead to specific decision or set of possible decisions made by medical personnel (e.g. doctors, nurses, speech and language pathologists, etc.). The FCM MDSSs are initiated by subject matter experts that determine the main concepts and the weighted interrelation among concepts through a reasoning process similar to the one that they would normally use to reach a decision.

Scenarios within these cases are built by manipulating various parameters of the FCM MDSS model to reflect changes by adding, deleting and altering concepts and/or by updating the interconnections among them. The results of each change are revealed by new values of the outcome concepts as well as by any nodes that are directly or indirectly affected by the change introduced by the scenario.

This type of learning model allows integration of theoretical knowledge with in-depth exploration of the decision-making process as well as critical analysis of 'what-if' situations. These speculation-based scenarios prepare medical professionals for clinical practice by allowing them to experience a much wider range of potentially critical situations than is possible within a more traditional education setting. At the same time this particular kind of case-based process allows medical professionals to follow the impact various changes can have both on the final outcome and on the intermediate values of components of the model.

The use of FCMs for case learning scenarios has important characteristics:

- They are easy to understand, develop and apply since they are designed in a highly intuitive manner.
- FCMs have a high level of information integration allowing a wide variety of types of information to be represented using discrete and continuous scales.
- They can easily be adjusted for new information and new situations.
- The availability of feedback and non-linearities within the system model uncovers potentially critical situations that may arise.

How FCM MDSS Learning is Applied to Obstetrics

The rich scenario building capabilities of FCM MDSSs are particularly well suited to use in the field of medicine. In the section we will discuss in detail how it is applied in the area of Obstetrics and specifically during the delivery.

The target audience is young doctors during their specialisation training to become obstetricians. These obstetrics learners are able to manipulate parameters that are measurements or events and follow them through to the output decision (outcome). They can then compare their own decision with that advocated by the MDSS and, at the same time, explore ‘what-if’ scenarios.

The FCM MDSS case model is run using a series of pre-set sets of parameter values representing the various cases initially set up by the instructors and aiming to mirror the authentic clinical reasoning process; these can easily be expanded with scenarios simulating evolving patient situations. The scenarios are defined by the instructors to ensure specific learning outcomes, as well as by learners to explore their own ‘what-if’ questions.

During the crucial stage of labour, obstetricians continuously evaluate the entire health situation of the mother and the child. As time progresses, or with the appearance of an event, they take into consideration a wide variety of factors in order to make a decision. Their decisions may be related to the well-being of the infant who is close to full-term delivery or to the risk to the maternal health when continuing with the pregnancy would outweigh the risk to the infant being delivered.

Therefore, is it vital that an obstetrician is able to decide on the basis of physical measurements whether to continue with a natural delivery or to proceed with a Caesarean section. These measurements will include fetal heart rate (FHR), the interpretation of the cardiotocograph (CTG) that monitors the fetal heart rate and the mother’s contractions, and other essential indicators and metrics. In essence, any decision is based on ‘weighing’ the risks of maternal and/or fetal health complications.

One particular case study is concerned with the decision to carry out an emergency Caesarean section when there is a fetal distress – that is, there are vital signs that the fetus is not well, either before or during childbirth. Factors to be taken into consideration include abnormal CTG and/or acidosis and/or cord prolapse and/or abruption, obstructed labour, prolonged labour, or delivery at maternal risk compared with that from a routine, elective Caesarean section. In most real situations these factors are intrinsically fuzzy. Accordingly obstetricians use linguistic terms to characterise them – terms such as "stable", "moderate", "intense", "increased" etc.

Obstetricians consider a variety of maternal indications and fetal indications. The labour surveillance monitoring has three main components: fetal condition, progress of labour, and maternal conditions. Fetal health condition is mainly reflected in the interpretation of the Fetal Heart Rate (FHR) signal and some other physiological measurements or observations such as the colour of liquor (meconium) and vaginal examinations. Progress of labour is based on physiological examinations (descent of head, dilation of the cervix), measurement of the strength and frequency of uterine contractions, quantity and kind of drugs given to augment/induce the labour, and the elapsed time. Maternal conditions measured include pulse rate and blood pressure.

Medical Decision Support Systems – and particularly those based on Fuzzy Cognitive Maps – are well suited for labour modelling because clinicians are not always in agreement on the importance of each individual parameter, especially in situations involving induction or augmentation of labour. Clinical disagreements can also exist about what constitutes excessive FHR because of uterine activity and what management strategies to undertake when it occurs (Simpson & Miller, 2011). As a result, FCM scenario-based MDSS are particularly well-suited for training medical clinicians.

So the specific FCM MDSS case study for obstetrics has been developed to model the way in which the obstetrician decides between a normal delivery or a Caesarean section. It is a dynamic procedure where the obstetrician evaluates whether either the mother or the fetus is at serious risk and, therefore, if s/he must intervene by stopping the physiological delivery and performing an emergency Caesarean section instead of continuing with natural delivery. According to evidence-based practice, labour abnormalities and unnecessary Caesarean birth are associated with risks to the mother and baby. On the other hand, excessive uterine activity may have a negative effect on fetal oxygenation during labour and fetal acid-base status at birth (Simpson & Miller, 2011). A similar decision support system developed by Warrick *et al.* (2010) focuses on hypoxia detection based on recordings of the uterine pressure and fetal heart rate, both of which are routinely monitored during labour. The variability of these factors makes it essential to reach the best decision for both mother and baby.

The FCM MDSS takes into consideration factors based on the main parameters that an obstetrician evaluates. These parameters constitute the 13 concepts of the FCM case study model for obstetrics, which are:

- Concept 1: Decision for Normal Delivery
- Concept 2: Decision for Emergency Caesarean section
- Concept 3: Fetal Heart Rate (FHR) evaluation
- Concept 4: Meconium (Colour of liquor: from clear, to mild blood staining, to heavier bleeding)
- Concept 5: Time duration of labour in comparison to progress of the delivery
- Concept 6: Contractions of the uterus (strength and frequency)
- Concept 7: Medication (quantity of oxytocin given to mother)
- Concept 8: Diastole of Cervix (measurement)
- Concept 9: Evaluation of Cervix commendation (4 linguistic values)
- Concept 10: Position of placenta (3 linguistic values)

- Concept 11: Position of fetus (5 linguistic values)
- Concept 12: Contra-indication
- Concept 13: Fetal weight estimation (3 linguistic values)

These concepts are depicted in Figure 4. It is important to note that concepts are interrelated and these interrelationships have been included in the FCM-MDSS model according to clinical evidence-based best practice.

Given the different values that concepts 3-13 may take and the interrelationships among concepts, scenarios are built on cases by varying the parameters appropriately to reflect changes. In Figure 4 yellow squares are used to indicate that Concepts 3, 4, 7 and 8 are susceptible to change. The values of these concepts are manipulated by the learner to match the case scenario and then the FCM MDSS for labour is allowed to run step by step. The changes to the various concepts are observed as the FCM algorithm evolves. The final outcome is either Caesarean section or Normal delivery.

As well as these critical parameters, the learner has the ability to review or obtain additional information by accessing relevant material stored in the system. For example by selecting the small square on the concept 'Medication', recent literature on oxytocin dosage (Clark *et al.*, 2009) can be accessed directly from the publisher's website, as shown in Figure 5. This or other selections would have been added by the teacher as reference materials. Similarly, for fetal heart rate evaluation the latest literature on classification categories of FHR can be reviewed (Coletta *et al.*, 2010).

Due to the fact that in complex systems, such as medical systems, there can be unexpected events, the FCM scenario-based MDSS allows the possibility of trigger/alarm events that may alter the outcome unexpectedly. Such an event is, for example, Concept 3(Fetal Heart Rate (FHR) evaluation) as indicated by the red triangle in Figure 4. These trigger events occur while the user is running the FCM scenario-based MDSS and as a result may affect a number of concept values, as well as the outcome. This provides the learner with the opportunity to observe how dynamic, high-risk and unusual case scenarios evolve, allowing learning in a safe environment without placing actual patients at risk.

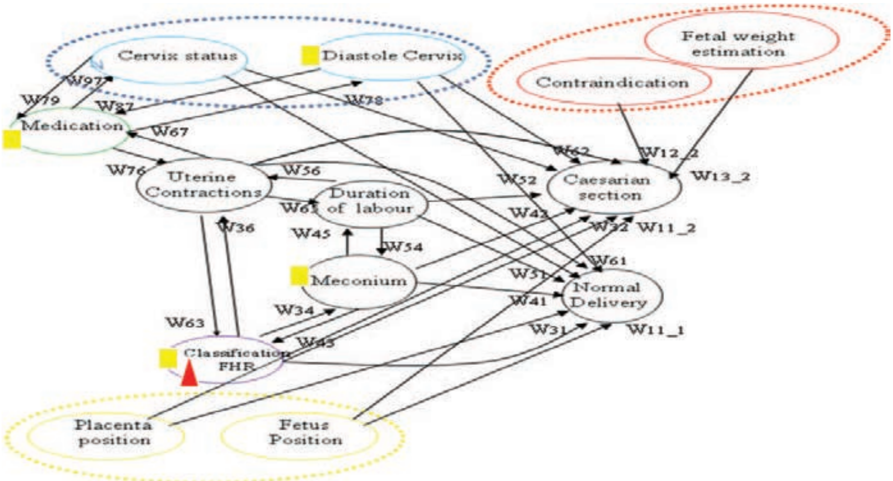

Figure 4. FCM Scenario-Based MDSS with alarm triggers for Labour Decision Support

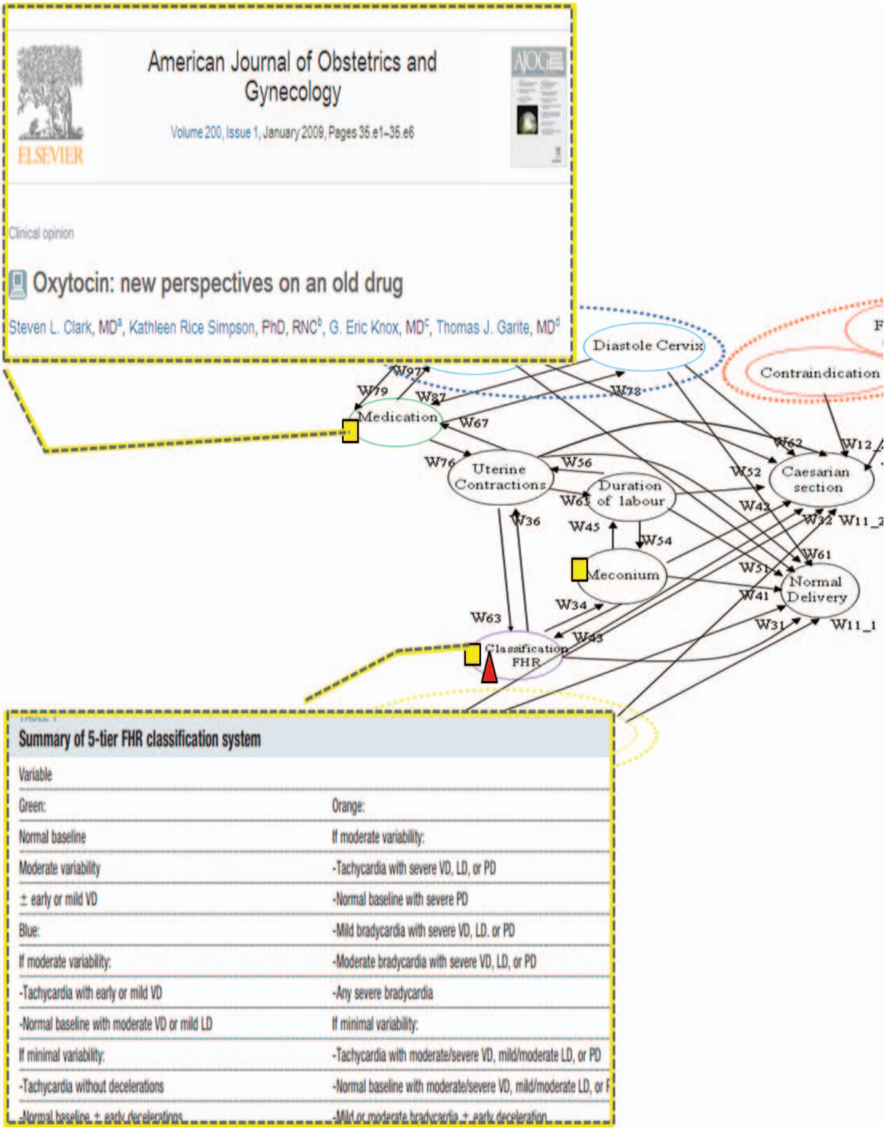

Figure 5. Access to relevant resource material (Clark et al., 2009; Coletta et al., 2010) during scenario learning in FCM MDSS for Labour Decision Support

Illustration of the Impact of Changes in Measurements

An example learning scenario is presented here for a particular patient, a pregnant woman where complications occur during labour:

- A 32 year old patient at 40 weeks gestation period in the first stages of labour is observed with temperature 36.7◦C, blood pressure 120/80 mm Hg, pulse rate of 110 beats/min and has clear liquor draining. The fetal heart rate according to the monitor is 155 beats per minute. The estimated birth weight is 3 kg.
- All these indications would lead to a normal delivery and thus, the FCM MDSS for labour is run and concludes to the decision of Normal labour.
- But according to the scenario, during the labour procedure the liquor becomes meconium stained while the other parameters would initially remain the same; at this point a careful examination of factors that are influenced by this change would be required. Presence of meconium is an indication of fetal distress.
- Within the FCM Scenario-based MDSS this can be used as a trigger event altering the FHR to 114 beats/min that implies that the fetus is in distress; thus, the FCM MDSS would now advocate an emergency Caesarean delivery.

Therefore, for the learner, running such a scenario reinforces the connection between meconium staining and fetal heart rate and the possibility of an adverse outcome for the baby by proceeding with normal delivery.

Conclusions and Pedagogical Goals

Fuzzy Cognitive Mapping is an essential tool that could be used for case based and scenario learning and could be established as a complementary tool during any learning procedure. It is a versatile tool that could be useful for the learner as a way to represent and evaluate his/her knowledge by simulating cases. For the instructor it is a means to check or create didactic scenarios based on real cases. In addition, the FCM tool can be used for testing of learners because it allows the instructor to monitor students/learners and evaluate their understanding by simulating cases that are based on real events using their knowledge and principles.

A Medical Decision Support System combines the human clinical experience acquired through practice with widely-accepted, systematic, analytic approaches. Here, previously designed Fuzzy Cognitive Map Medical Decision Support System (FCM MDSS) reflecting the medical decision making process are enhanced by variety of scenarios by using a '"what-if' approach and/or trigger events to understand how a decision is made and what conditions need to be addressed in order to avoid adverse patient events.

This type of learning model allows integration of theoretical knowledge with in-depth exploration of the decision making process as well as critical analysis of 'what-if' situations. In medical education Fuzzy Cognitive Map learning tools contribute to learners being able to:

- recognise symptoms and factors correlated with the problem,
- make critical judgment and identify the importance and impact of each factor on how changes of a factor impact an end result as well as intermediate values of components in the model,
- practise and test their skills under unusual or adverse conditions without putting patients at risk due to the ability to dynamically present trigger events,
- set up their own scenarios.

Although this chapter describes the application of FCM as a case scenario based learning tool in the medical field, it is important to note that the methodology is general and can easily be adapted appropriately to other disciplines. These include business and social sciences where FCMs have also been used extensively for solving a variety of critical problems.

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