The Application of Fuzzy Cognitive Mapping in Education: Trend and Potential

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Abstract **– Fuzzy cognitive mapping (FCM) is a valuable tool for understanding complex issues due to its ability to express complex and uncertain knowledge domains with dynamic modelling capabilities. This study focuses on the application of FCM in education, using a bibliometric analysis and systematic review of publications in the Scopus database from 2000 to October 2023. Using keywords related to FCM and education, the study retrieved fifty-four publications for frequency analysis and citation metrics. This study showcases its results by leveraging standard bibliometric indicators, encompassing metrics such as publication growth, top-cited publications, country contributions, and preferred publication titles. Findings from the systematic review reveal the potential of FCM in providing explanatory, predictive, reflective, and strategic insights and solutions to numerous educational issues.**

Keywords **– Fuzzy cognitive mapping, educational applications, bibliometric analysis, systematic review.**

1. Introduction

As the real world is complex, Fuzzy Cognitive Mapping (FCM) assumes knowledge can be obtained from the perspectives of those relevant to a particular issue [1].

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FCM, developed by Kosko [1], is a dynamic method, either qualitative or semi-quantitative, used to structure expert knowledge, aiming to visually represent an individual's perception of a given situation [2]. The resultant diagram, referred to as a fuzzy cognitive map, is a method for knowledge representation and reasoning based on directed graphs. It illustrates a collection of interconnected concepts within a domain, depicting cause-and-effect relationships [3]. Kokkinos *et al.* [2] asserted that FCM graphs offer a loosely structured procedure to help the modeller and the expert or stakeholder provide their beliefs, insights, and conceptions about a specific subject. The connections and dependencies among these ideas or concepts are also made clear, illustrating how changes in one concept may impact others [2]. The main objective of FCM is to explore how these causal influences propagate throughout a system when it undergoes modification or intervention [4].

Despite its complexity, the developed model remains accessible to non-technical audiences, as each parameter carries a tangible meaning and can depict the quantitative and qualitative data gathered from stakeholders' perspectives [1], [5], [2]. Moreover, Van Vliet, Kok, and Veldkamp [6] state that FCM implementation is simple, customizable in parameterization, and offers flexibility in representation, accommodating multiple interconnected concepts or phenomena. They also suggested that FCM effectively addresses complex knowledge acquisition and management challenges, adeptly managing dynamic effects owing to its feedback structure. Moreover, it can deal with qualitative and quantitative inputs and outputs simultaneously, unlike the separate analyses of a situation using the conventional qualitative and quantitative approaches [6], [7].

1.1. Theoretical Foundations of FCM

FCM is founded on several core theories and concepts. Firstly, it is grounded in fuzzy logic, a mathematical framework introduced by Zadeh [8].

Fuzzy logic allows for the representation of vague and uncertain information using linguistic variables, expressing truth as a degree of membership in fuzzy sets. This approach adeptly captures the subjective and uncertain aspects of human knowledge and perception [9]. Secondly, the 'cognitive' aspect of FCM draws from cognitive science, which studies how individuals perceive, process, and interpret information. In the context of FCM, it is employed to develop and analyze causal models that simulate human decision-making processes [10]. Thirdly, the complex systems theory serves as another foundational pillar for FCM. This theory revolves around analysing systems with multiple interdependent and interconnected components, and FCM is a tool employed to model and scrutinize the relationships and interactions among these system components [11]. Lastly, FCMs are typically depicted as directed graphs or networks. The study and manipulation of these networks draw from graph theory, encompassing concepts such as nodes, edges, and path analysis [12].

1.2. FCM Approaches – Causal versus Dynamical

According to Felix *et al.* [3], the concepts, variables, or factors are depicted as nodes of the graph, and graph edges or connections representing the causal relationships between nodes are signed and weighted. Figure 1 depicts a sample fuzzy cognitive map. The following describes the two main approaches of how FCM is used [4], [13].

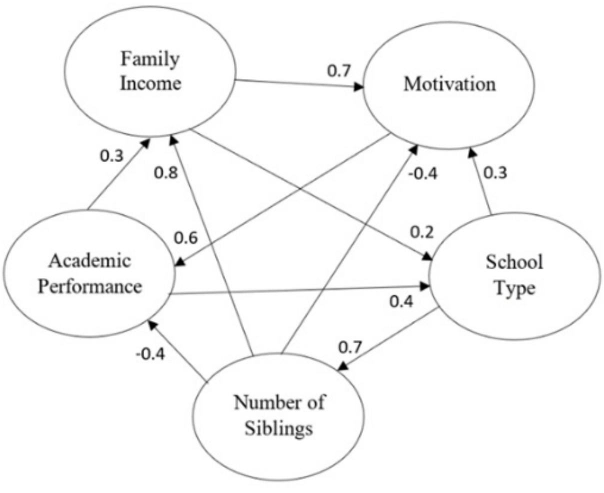

Figure 1. A sample fuzzy cognitive map

The first approach, known as the causal approach, is closely tied to the original FCM proposed by Kosko [1] and preserves the same mathematical formulation. The degree of connection between two nodes representing concepts, variables, or factors is indicated by a weight ranging from 0 to 1, reflecting the extent of uncertainty or fuzziness in the causal relationship.

A link value of 1 indicates absolute certainty that X causes Y.

As the value decreases, the certainty that X causes Y diminishes. The link between node X and node Y is marked with a positive sign to denote positive causation, which means that the occurrence of X will cause Y to occur or a negative sign to denote negative causation, which means that the occurrence of X will decrease the occurrence of Y. The states of nodes in the cognitive map are also made fuzzy, and any state can have a value from 0 to 1. The value shows how strongly a node is caused or activated by changes in other nodes. In other words, the nodes' values reflect how certain we are that changing one node would change another. These values do not represent the actual magnitude of the nodes.

The second approach, known as dynamical, uses the actual magnitude of the nodes. Hence, this approach examines how much (relatively) different nodes' magnitudes will be impacted by a change and how much they will be influenced or influence others. This article does not describe the mathematical formulations used in both approaches. Helfgott *et al.* [13] provide a detailed description of these formulations.

1.3. FCM Functions – Explanatory, Predictive, Reflective, Strategic

Referring to an article written in Italian by Codara Lino [14], FCM is classified into four functions. First, FCM can provide an explanatory function in which it rebuilds the assumptions underpinning the behavior of a given circumstance, provides insights into the reasons behind the stakeholders' decisions and behaviors, and identifies any distortions and limitations in the stakeholders' depiction of the circumstance. Second, FCM can offer a predictive capability to forecast future decisions and actions or to anticipate the reasoning a particular stakeholder may employ in response to new events. Third, FCM can serve a reflective function to help decision-makers ponder over the 'what-if' scenario and could lead to necessary interventions. Fourth, FCM can provide a strategic function by better depicting a challenging scenario.

2. FCM Applications

FCM stands out as a highly effective tool for modeling intricate processes. [15]. It is widely used in many fields [10], including computer sciences [16], [17]; engineering [18], [19]; medicine [20], [15]; commerce and management [21], [22], [23], [24]; robotics [25], [26]; environmental science [27], [28]; and education [29], [30].