Mapping Fuzzy Logic in Learning Environments

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Abstract: With the rapid development of science and technology in recent years, the application areas of fuzzy logic have also gained speed. Fuzzy logic is a frequently preferred approach in the educational process, and it can be said that scientific publications on this topic have recently gained momentum in the literature. In this context, the present study aims to shed light on the research forms of fuzzy logic approach in education. The Web of Science (WoS) database was used for data collection. The search reached 374 scientific publications on the topic after various exclusion procedures. The obtained data were visualized using the mapping technique. As a result of the research, it was found that the number of publications on this topic has generally increased from past to present. The analysis revealed that the most influential countries reporting on this topic are the United States, China, and Taiwan. In addition, National Cheng Kung University, Gazi University, Cornell University, and Marmara University have published the most publications. The authors with the most publications on the fuzzy logic approach are Reyna V.F., Castillo, O. and Huang, Y.M. The analysis of the journals showed that Computer Applications in Engineering Education and International Journal of Electrical Engineering Education are the journals that contribute the most to this topic. The concepts that appeared in the clusters of co-occurrences analysis are fuzzy logic, higher education, e-learning, data mining, matlab and education.

Keywords: Fuzzy Logic, Web of science, Learning environments.

Introduction

In some situations, in daily life, we avoid making precise definitions. For example, when we state the temperature of water, we use expressions like a little hot or a little cold instead of saying how many degrees it is. Or in our weather forecasts, we say that the weather is a little cold or a little hot. Depending on the age of the people we meet, we refer to them as old, middle-aged, adult or young without drawing clear boundaries. This situation reveals the fact that we make imprecise definitions for some situations we encounter in daily life.

The formulation and measurement of individual learning behavior in educational environments is possible through the collection of neurological data in information systems (Korkmaz, 2020; Korkmaz & Gülseçen, 2022). How to formulate ambiguous expressions mathematically is an important problem. With his 1965 work, Lotfi A. Zadeh introduced the concepts of fuzzy set and fuzzy logic to better understand systems with uncertainty (Altaş, 1999). Fuzzy logic was developed with the goal of better understanding situations that are not precise and has been used in many fields since its introduction in 1965. Fuzzy logic is a subfield of artificial intelligence that has the ability to think like a human and solve those thoughts by converting them into equations (Tiryaki & Kazan, 2007). Classical logic, which we encounter in our daily life and which we use frequently, has certain values. According to classical logic, an element belongs to a set or not (Dell'Aversana, 2017). In fuzzy logic, which is different from classical logic, an element can be an element of both sets at the same time. Fuzzy logic also allows us to operate in uncertain and approximate situations (Tiryaki & Kazan, 2007).

Fuzzy logic is used in many different fields/industries. Fuzzy logic applications are used in higher education (Ertuğrul, 2010), engineering (Değerli, 2009), business (Durgut et al., 2017), defense industry (Çakır et al., 2006), real estate (Özcan & Eldem, 2020), materials science (Filiz et al., 2014), soil science (Yakupoğlu et al., 2008), retail (Öztürk et al., 2017), and many other fields. Studies of fuzzy logic can also be found in education. Fuzzy logic is used in many disciplines such as engineering, mathematics, physics, computer science, automation, social sciences, biology, and economics. For example, Doz et al. (2022) used fuzzy logic in education as an assessment tool. In another study, fuzzy logic was also used in selecting the best student based on student performance (Ajoi et al., 2021). Fuzzy logic was used to create student models in educational games (Hamdoi, 2021). Fuzzy logic has also been used to determine student attitudes toward a particular lesson (Bakanay, 2009). Another study examined the effects of learning environments organized according to multiple intelligence domains determined by fuzzy logic on students' academic performance (Namlı, 2016).

The number of scientific publications on fuzzy logic is increasing day by day in many countries. Therefore, it can be said that the method of evaluating the publications on this topic has the potential to make an important contribution to the literature. In order to contribute to the related literature and fill the gap in the research field, an attempt was made to show the status of scientific publications on fuzzy logic in education. In this regard, the present study aims to highlight the publications forms of the fuzzy logic approach in the field of education. It can be stated that the results obtained in the study will be a source for researchers who want to study this topic, will guide them in defining different study topics, and will contribute to the production of original publications on this topic.

Method

In this study, publications on the topic of fuzzy logic in education were examined using the method of bibliometric analysis. Bibliometric analysis is the quantitative evaluation of various characteristics of scientific publications from different databases, such as author information of publications, the year of publication, the

journal in which the publication was published, and the publication information (Al & Tonta, 2004).

The data for this study were taken from the WoS (Web of Science Core Collection) database. An attempt was made to access relevant publications using the search query and filtering features of WoS. Only articles indexed in SCI-E, SSCI, A&HCI with the keyword fuzzy logic in the education category in the corresponding database were included in the study. There was no restriction on the language and period of publications. As a result of the filters, a total of 374 publications were identified and included in the analysis. The data obtained from the search were analyzed using the descriptive analysis technique. In addition, the visual mapping program VOSviewer was used to create relationships and density maps for different variables.

Results

Distribution of Publications by Years

As part of the research, the distribution of publications on the fuzzy logic approach in education published in the WoS database was first examined by year and number of citations. The corresponding findings are presented in Figure 1.
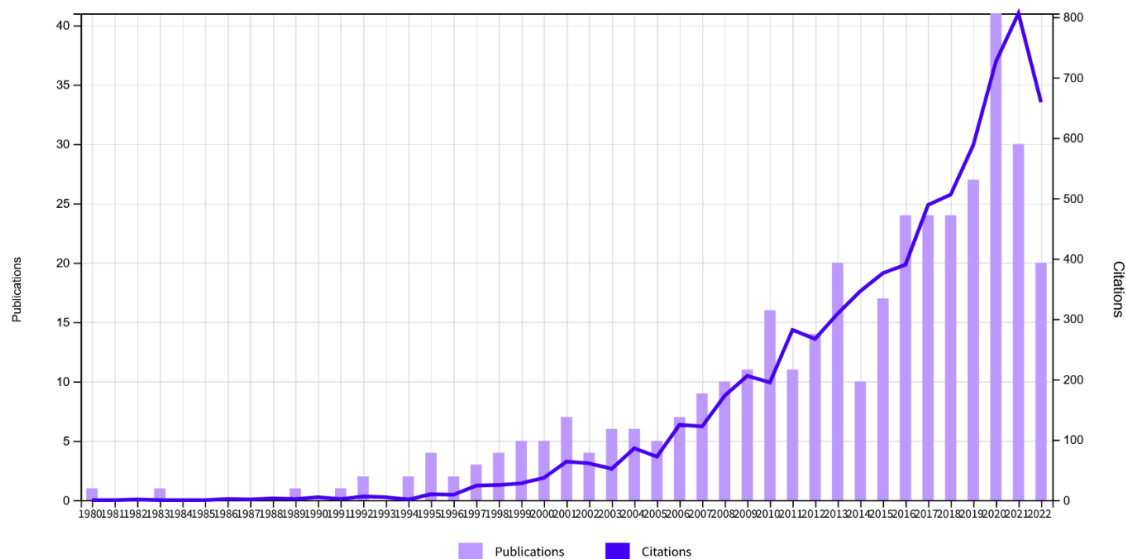

Figure 1. Times Cited and Publications over Time

When Figure 1 is examined, it is seen that the first publications on fuzzy logic in education appeared in the 1980s. It can be noted that the number of publications was low before 2000. However, the number of publications on fuzzy logic has generally increased over the years. It was found that the highest number of publications occurred in the last 5-6 years. The year 2020 was the year with the highest number of publications with 41 studies. On the other hand, it is noted that the number of citations has increased over the years. Since the study

was conducted in 2022, all publications and citation counts for that year are not yet indexed in WoS.

Distribution of Most Prolific Countries/Regions

The study also examined the top 10 most prolific countries/regions that have published articles on fuzzy logic. The results in this regard are shown in Figure 2. As shown in Figure 2, the USA is the most prolific country in terms of number of publications. It is followed by China, Taiwan, and Turkey with the highest productivity. The total number of publications in these countries accounts for about 56% of the publications on the topic.
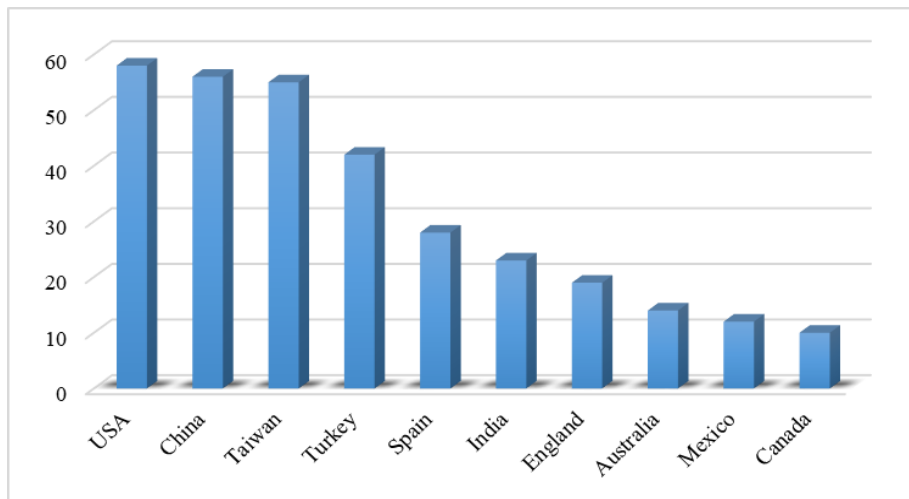

Figure 2. The 10 Most Prolific Countries/Regions

Distribution of Most Prolific Institutions

The study also examined the total number of publications by institutions that publish about fuzzy logic in education. Figure 3 provides data on the 10 most prolific institutions in this regard.
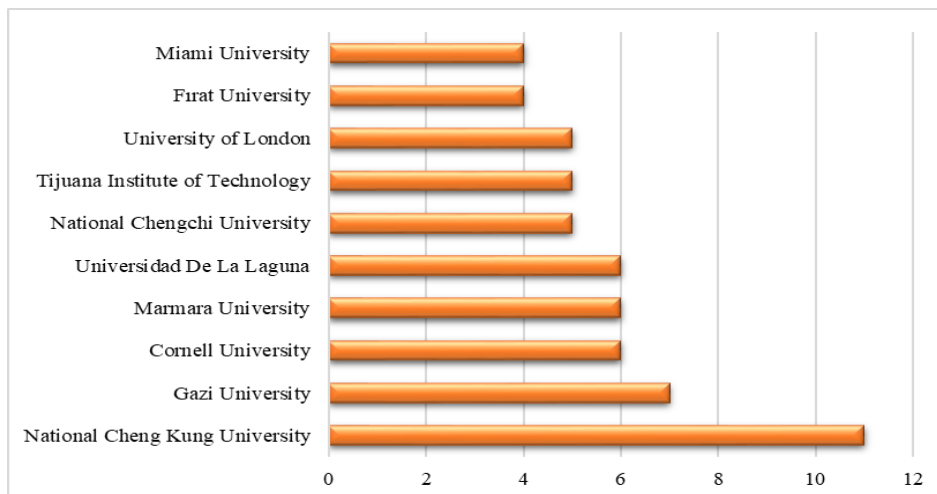

Figure3. The top 10 Most Prolific Institutions

When Figure 3 is examined, it is noticeable that National Cheng Kung University (Taiwan) and Gazi University (Turkey) are among the leading publishing institutions. After these institutions come respectively Marmara University (Turkey), Universidad De La Laguna (Spain) and National Chengchi University (Taiwan). Three of the 10 most productive institutions are in Turkey.

Journal Distribution of Publications

Within the scope of the research, it was examined in the journals that published the most about fuzzy logic in education. The data related to this are given in Figure 4.
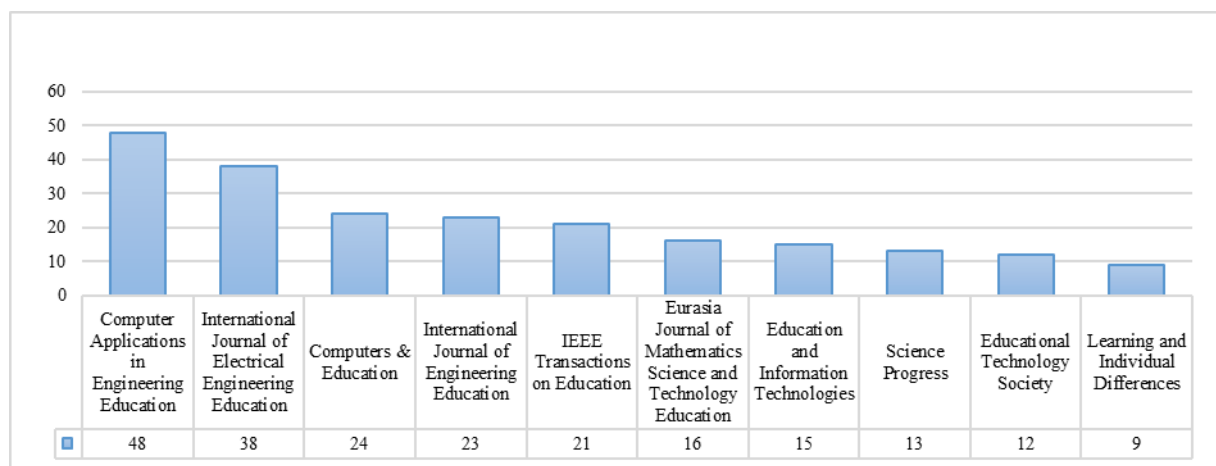

Figure 4. Journal Distribution of Publications

The distribution of publications by journal is shown in Figure 4. It can be seen that the journals "Computer Applications in Engineering Education", "International Journal of Electrical Engineering Education" and "Computers & Education" are in the foreground.

Distribution of Most Cited Publications

The study also examined information on the most frequently cited publications on the topic. Table 1 shows the top 10 most frequently cited publications. The total number of citations of the publications is 7065, the average number of citations is 18.89 and the H-index is 39.

According to the data in Table 1, the most cited publication belongs to Reyna & Brainerd (1995) with 789 citations. The second most cited publication (299 citations) and the fourth publication (174 citations) belong to the same authors. This indicates that these authors' publications have been widely recognized since the day they were published. The third most cited publication is Lykourentzou et al. (2009) belongs.

Table 1. The Top 10 Most Cited Publications

Rank	Title	Authors	Year	Citation
1	Fuzzy-trace theory - an interim synthesis	Reyna & Brainerd	1995	789
2	Numeracy, ratio bias, and denominator neglect in judgments of risk and probability	Reyna & Brainerd	2008	299
3	Dropout prediction in e-learning courses through the combination of machine learning techniques	Lykourentzou et al.	2009	178
4	The importance of mathematics in health and human judgment: Numeracy, risk communication, and medical decision making	Reyna & Brainerd	2009	174
5	Web usage mining for predicting final marks of students that use Moodle courses	Romero et al.	2013	155
6	Development of a web-based laboratory for control experiments on a coupled tank apparatus	Ko et al.	2001	145
7	Department-level cultures and the improvement of learning and teaching	Knight & Trowler	2000	139
8	An application of fuzzy AHP for evaluating course website quality	Lin H.F.	2010	136
9	Process mining techniques for analysing patterns and strategies in students' self-regulated learning	Bannert et al.	2014	134
10	Modeling and simulation of an adaptive neuro-fuzzy inference system (ANFIS) for mobile learning	Al-Hmouz et al.	2012	133

Author Collaboration Network

An author collaboration network has been established to detail the relationships of authors who publish on the fuzzy logic approach in education. The related network is shown in Figure 5.

When the co-author analysis of the studies on the topic is examined, it is seen that Reyna, V. F., Brainerd, C. J., Wolfe, Christopher R. and Widmer, Colin L. L. publish together. Again, cooperation was found between Brust-Renck P. G., Reyna, Valerie F., Widmer, Colin L. L, Wolfe, Christopher R., Weil, Audrey M. and Cedillos, Elizabeth M. As a result, it can be said that these authors have many publications on the fuzzy logic approach in education, have researched the subject in depth and contributed to the field.
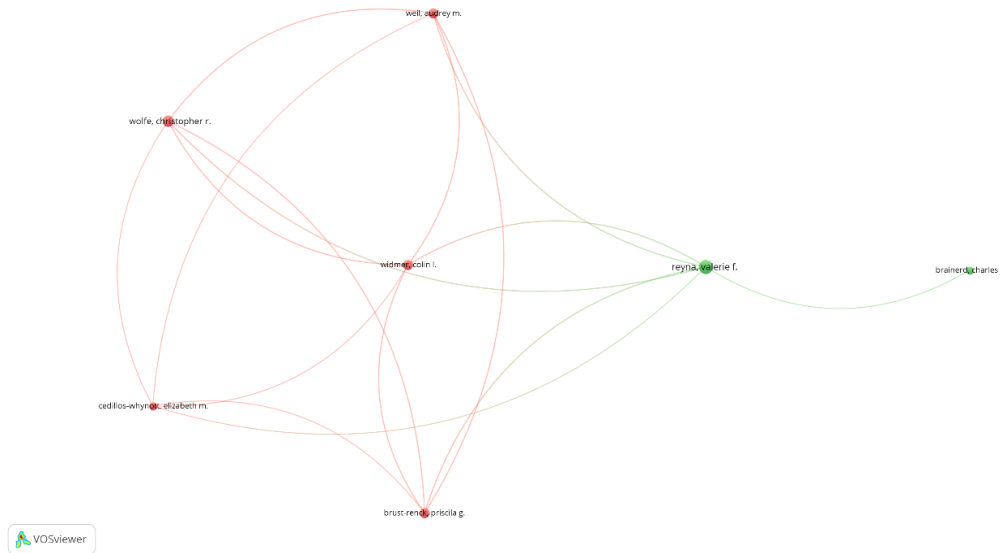
Figure 5. The Author Collaboration Network

Co-occurrences Analysis

It can be said that keyword analysis is important to define the knowledge structure of the fuzzy logic approach in education and to clarify the current questions on the topic. In this context, a network structure was created in which the relationships between the keywords were established. The corresponding findings are shown in Figure 6.
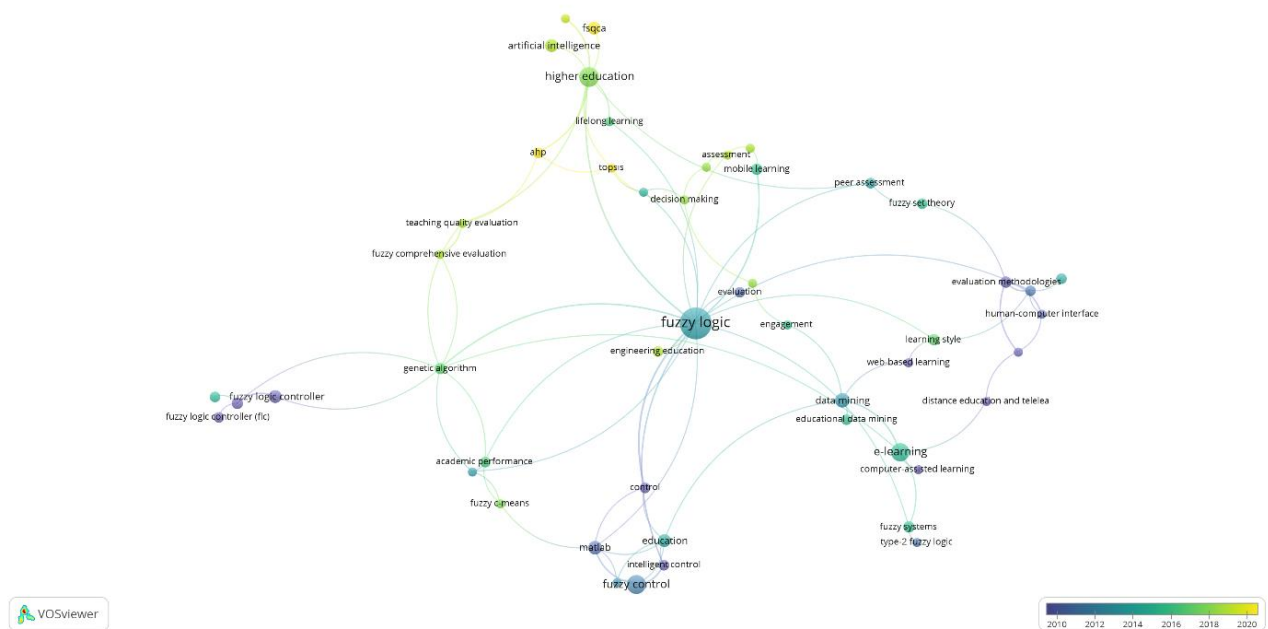

Figure 6. A Co-occurrence Network of Keyword

According to the keyword analysis, it shows that many keywords such as fuzzy logic, higher education, e-learning, data mining, matlab, fuzzy-trace theory, education, artificial intelligence, and genetic algorithm are commonly used. These words are the most common words and concepts explored with other clusters. Current topics are concepts such as artificial intelligence, higher education, AHP, topsis, fuzzy-set qualitative comparative, decision making, and teaching quality evaluation.

Discussion

In this study, the scientific publications published in the WoS database on the topic of fuzzy logic in education were examined by means of a content and bibliometric analysis. For this context, the distribution of publications by years, citation counts, countries/regions, and institutions was first examined. Then, information was provided on the journals that have published the most on the topic and on the most cited publications. In addition, bibliometric analysis methods, an author collaboration network, and keyword analysis (co-occurrences) were used to examine publications on the topic of fuzzy logic in education.

According to the research results, it should be noted that the first publications on this topic appeared in the 1980s and the number of publications before 2000 was relatively small. The main reason for this may be the limited resources, lack of communication facilities and the internet network at that time (Radu et al., 2021). In the following years, it was observed that the number of fuzzy logic researches in education increased in connection with the development of ICT in general, but this increase was not regular. In this case, it can be said that the interest in this topic has increased over the years and the topic has been extended to different areas. In the literature, similar to our research findings, it was found that the number of publications on this topic published annually increased significantly (López-Guauque & Gil-Lafuente, 2020; Merigó, Gil-Lafuente & Yager, 2015; Radu et al., 2021). It can be stated that fuzzy logic research has increased significantly, especially in the last decade (López-Guauque & Gil-Lafuente, 2020). Therefore, it can be said that fuzzy logic is an ever-evolving interdisciplinary topic and is used in the fields of computer science, automation, engineering, mathematics, and physics. Similarly, Yu, Xu & Wang (2018) examined the researches of Chinese scholars on fuzzy theory and found that the researches on this topic were mainly focused on computer science and engineering. However, especially in recent years, there has been more research on the application of fuzzy theory in many fields such as social sciences, biology and economics (Yu, Xu & Wang, 2018).

An analysis of the distribution of publications on fuzzy logic in education by country/region showed that the USA is the most productive country. This is followed by China, Taiwan and Turkey as the most productive countries. It can be said that the number of scholars in the USA and China is high and they have made important contributions to the literature in recent years. On the other hand, Radu et al. (2021) stated that the countries with the most publications in the field of fuzzy logic are China, India and the USA. At the beginning, the USA was the most influential country, thanks to Lotfi Zadeh, the father of fuzzy logic (Merigó, Gil-Lafuente & Yager, 2015). However, López-Guauque and Gil-Lafuente (2020) also noted that the contributions of the U.S. have declined

relatively recently, but that China continues to lead in the number of contributions. Similarly, Yu, Xu & Wang (2018) noted that fuzzy theory has received increasing attention from Chinese scholars over the past 30 years. It can be said that the subject has gained momentum and made visible contributions to the scientific literature in recent years, especially in Asian countries. The main reason for this may be the rapid increase in the number of academics and researchers in these countries and the increasing investment of these countries in this technology (Radu et al., 2021).

Publications and researches on fuzzy logic are conducted by many institutions and research centres from different countries and continents around the world. In the study, National Cheng Kung University (Taiwan) and Gazi University (Turkey) stand out among the institutions that publish the most on fuzzy logic in education. The study also found that three of the 10 most productive institutions are from Turkey. On the other hand, Radu et al. (2021) found that the most influential institutions in fuzzy logic research are Islamic Azad University, Tijuana Institute of Technology, and National Institutes of Technology, respectively. Similarly, it was found that the most effective and productive institution in the field of fuzzy logic in the literature is Islamic Azad University (Laengle et al., 2021; López-Guauque & Gil-Lafuente, 2020). In another study, it was found that many institutions in China, Taiwan and Spain have a very good position in this field (Merigó, Gil-Lafuente & Yager, 2015). It can be said that most of the most influential institutions publishing on fuzzy logic are located in Asian countries (Radu et al., 2021). However, if we look at the studies on fuzzy logic, we find that the subject is interdisciplinary and used by many researchers from different institutions in the world.

The study also examined the distribution of publications on fuzzy logic in education in journals. It was found that Computer Applications in Engineering Education, International Journal of Electrical Engineering Education, and Computers & Education are the journals with the most publications on this topic. Therefore, it can be concluded that these journals are among the important journals in the field of computer science and engineering. In the literature, it was found that IEEE Transactions on Systems Man and Cybernetics, IEEE Transactions on Fuzzy Systems, Information Sciences and Fuzzy Sets and Systems are among the most influential journals in fuzzy logic research (Laengle et al., 2021; López-Guauque & Gil-Lafuente, 2020; Merigó, Gil-Lafuente & Yager, 2015; Radu et al., 2021).

According to the results of the research, the most cited publications on fuzzy logic in education are from Reyna & Brainerd (1995). These authors are well-known authors who have published on this topic. The most frequently cited and influential publication on fuzzy logic in the literature is the article by Zadeh (Laengle et al., 2021; López-Guauque & Gil-Lafuente, 2020; Merigó, Gil-Lafuente & Yager, 2015; Radu et al., 2021; Yu, Xu & Wang, 2018). Zadeh prepared numerous scientific publications on the principle and structure of fuzzy logic and is the leading author in this field (Keskenler & Keskenler, 2017). When the co-author analysis of the publications on the subject is examined, it is seen Reyna, V. F., Brainerd, C. J., Wolfe, Christopher R. and Widmer, Colin L. L. publish together. Brust-Renck P. G., Reyna, Valerie F., Widmer, Colin L. L, Wolfe, Christopher R., Weil, Audrey M. and Cedillos, Elizabeth M. are examples of outstanding author collaborations. Therefore, it can be said that these authors have many publications on the fuzzy logic approach in education, have thoroughly

researched the topic, and have contributed to the field.

As part of the study, an analysis of the words used was also carried out in order to identify the frequently recurring terms and to take into account the content analysis of the publications on the subject (Talan, 2021). It was found that many keywords such as fuzzy logic, higher education, e-learning, data mining, matlab, fuzzy trace theory, education, artificial intelligence, and genetic algorithm are frequently used. The current keywords were also studied in terms of identifying the current research topics on this topic. In this regard, it is noteworthy that the current topics are concepts such as artificial intelligence, higher education, AHP, topsis, fuzzy set quality comparison, and teaching quality assessment. On the other hand, the study by Laengle et al. (2021) revealed that the most popular keywords on this topic are fuzzy logic, fuzzy sets, fuzzy control, and fuzzy numbers.

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