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THE USE OF FUZZY LOGIC IN DETERMINING PRIMARY SCHOOL STUDENTS ACADEMIC ACHIEVEMENT IN SCIENCE COURSES

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ABSTRACT

This study investigates the use of fuzzy logic as an alternative to traditional assessment methods in evaluating the science achievement of primary school students. Conventional evaluations often rely on rigid threshold-based classifications, which may fail to capture nuances in student performance. In contrast, fuzzy logic enables flexible and multidimensional assessment. Employing a descriptive survey design, the science exam scores of 763 fourth-grade students in Kütahya, Turkey (2019–2020) were analyzed using both arithmetic means and a fuzzy logic model implemented in MATLAB. The model utilized triangular membership functions and a Mamdani-type inference system to classify student performance into nine distinct categories. The findings revealed a significant difference between the two methods, with fuzzy logic providing more detailed and adaptable classifications. By allowing students to simultaneously belong to multiple categories, the model offered a more sensitive reflection of individual performance. The study underscores the potential of fuzzy logic to enhance assessment precision in early science education—an area with limited existing research—and advocates for the integration of intelligent systems into educational evaluation practices.
Keywords: Fuzzy logic, academic achievement, artificial intelligence in education, science education.

İLKOKUL ÖĞRENCİLERİNİN FEN BİLİMLERİ DERSİNDEKİ AKADEMİK BAŞARILARININ BELİRLENMESİNDE BULANIK MANTIĞIN KULLANIMI

ÖZ

Bu çalışma, ilkokul öğrencilerinin fen başarılarını değerlendirmede geleneksel ölçme yöntemlerine alternatif olarak bulanık mantığın kullanımını araştırmaktadır Geleneksel değerlendirmeler genellikle katı eşik tabanlı sınıflandırmalara dayanır ve bu da öğrenci performansındaki incelikleri yakalayamayabilir. Buna karşın, bulanık mantık daha esnek ve çok boyutlu bir değerlendirme imkânı sunmaktadır. Tanımlayıcı tarama modeli kullanılan bu araştırmada, 2019–2020 eğitim-öğretim yılında Türkiye'nin Kütahya ilinde öğrenim gören 763 dördüncü sınıf öğrencisinin fen sınavı puanları hem aritmetik ortalamalar hem de MATLAB ortamında geliştirilen bir bulanık mantık modeliyle analiz edilmiştir. Modelde üçgen üyelik fonksiyonları ve Mamdani tipi çıkarım sistemi kullanılarak öğrenci performansları dokuz farklı kategoriye ayrılmıştır. Bulgular, iki yöntem arasında anlamlı bir fark olduğunu ortaya koymuş, bulanık mantığın daha ayrıntılı ve uyarlanabilir sınıflamalar sunduğunu göstermiştir. Öğrencilerin aynı anda birden fazla kategoriye ait olabilmesine olanak tanıyan bu model, bireysel başarıyı daha hassas yansıtmıştır. Çalışma, erken dönem fen eğitimi gibi araştırmaların sınırlı olduğu bir alanda, bulanık mantığın değerlendirme hassasiyetini artırma potansiyelini vurgulamakta ve eğitimde akıllı sistemlerin değerlendirme süreçlerine entegrasyonunu önermektedir.
Anahtar Kelimeler: Bulanık mantık, akademik başarı, eğitimde yapay zekâ, fen eğitimi.

Introduction

Education is a multifaceted process that not only fosters individuals' academic development but also facilitates their social and cultural integration by shaping desired behaviors through experience (Ertürk, 1972; Smith, Stanley, and Shores, 1957, as cited in Fidan, 1985). Education encompasses various disciplines, one of which is science education. This field aims to equip individuals with the ability to interpret and effectively use scientific knowledge. It also seeks to develop their skills in understanding, analyzing, and solving problems related to daily life and natural phenomena, enhance their scientific thinking, and apply their knowledge across diverse domains (Hançer Şensoy, and Yıldırım, 2003). Given its ever-evolving nature, science education necessitates evaluating students' learning processes through innovative approaches (Ministry of National Education [MoNE], 2024; Yunus, Yıldırım, and Kalaycı, 2021). Assessment and evaluation are essential tools for determining the extent to which intended learning outcomes are achieved during the instructional process. However, traditional assessment methods often classify students within rigid boundaries, failing to adequately consider individual differences (Çepni, 2015).

Traditional assessment systems are largely grounded in classical logic, which relies on binary distinctions and sharply defined thresholds. Within this framework, student performance is typically categorized into discrete outcomes (e.g., pass/fail or fixed grade intervals), leaving little room for transitional or partial achievement states. Such rigidity has been widely recognized as a limitation of classical assessment approaches, particularly in educational contexts where learning and performance develop gradually rather than dichotomously. Technological advancements have introduced numerous innovations to education, leading to the gradual replacement of traditional assessment methods with new techniques incorporating artificial intelligence. These innovative approaches contribute to achieving educational objectives yielding more granular and interpretable evaluation outcomes (Demir and Demir, 2025). One such prominent approach, utilized not only in education but also in fields like engineering, healthcare, and economics, is fuzzy logic (Dhokare et al., 2021). Fuzzy logic is renowned for its capacity to process complex and uncertain data, making it a powerful tool in educational research involving multiple variables. Within this context, it facilitates a more flexible and comprehensive evaluation of student achievement. Moreover, it enables the inclusion of multiple criteria in academic performance assessments, rather than focusing solely on quantitative data (Güler and Demirkaya, 2022).

Unlike classical logic, which operates on binary distinctions, fuzzy logic embraces a continuum of truth values. This allows assessments to consider a range of performance levels. It works with sets and concepts involving uncertainty, thereby offering a more flexible evaluation model (Bahadır, 2017; Zadeh, 1988; Zimmermann, 2001). While traditional assessment methods rely on rigid categorical classifications, fuzzy logic accommodates intermediary performance levels such as "partially successful," "moderately successful," or "highly successful" (Elmas, 2018). In this regard, the use of fuzzy logic in educational assessment allows for a more nuanced, adaptable, and realistic representation of student performance (Algshat, 2024). A literature review on the application of fuzzy logic in educational assessment reveals numerous studies directly contributing to the evaluation of academic achievement ((Ajoi, Gran, and Kanyan, 2020; Altunbaş ve Uyhan, 2024; Amelia, Abdullah, and Mulyadi, 2019; Bahadır, 2017; Bilici ve Özdemir, 2022; Bilici, Demiral ve Demir, 2025; Daud, Aziz and Sakib, 2011; Dhokare et al., 2021; Dülger, 2014; Ertuğrul, 2006; Güner ve Çomak, 2014; Hegazi, Almaslukh, and Siddig, 2023; Jan, Naqvi, and Ali, 2023; Kazancoglu ve Aksoy, 2011; Kazu ve Özdemir, 2009; Namlı, 2016; Özdemir ve Tekin, 2016; Petra and Aziz, 2021; Rojas, Espitia, and Bejarano, 2021; Yadav and Patel, 2022; Yıldız, Bal, ve Gülseçen, 2013). These studies have employed techniques such as fuzzy logic, fuzzy Analytic Hierarchy Process (AHP), and fuzzy Multi-Criteria Decision-Making (MCDM) to analyze student performance and related variables.

Other studies have indirectly contributed to academic performance evaluation by applying fuzzy logic in different educational contexts. These include assessments of teacher performance (Arslan, 2019; Arslan ve Zırhlıoğlu, 2021; Guruprasad, Sridhar, and Balasubramanian, 2016), evaluations of educational services (Altinsoy, Aktepe, ve Ersoz, 2023; Karakış, 2018; Mehra, Gupta, and Avikal, 2023; Özseven ve Çağman, 2021), learning strategies and methods (Balbal, 2016; Çebi, 2011; Deborah et al., 2015; Ergene, 2019; Ivan et al., 2017; Kazu ve Özdemir, 2009; Troussas, Krouska, and Sgouropoulou, 2020) exam evaluation (Ajol et al., 2020; Demirçelik, 2010; Taşkın, Üstün, ve Deliktaş, 2013; Taşkırdı ve Ünver, 2020), distance learning processes (Sinap, 2023; Rojas, Espitia, and Bejarano, 2021; Özseven and Çağman, 2021; Özdemir and Kalınkara, 2020; Amelia et al., 2019) learning process analysis (Akkaş, 2018; Bahadır, 2017; Çavdar, 2020; Öcal, 2015), pre-service teacher evaluations (Alptekin, 2011; Bakanay, 2009; Özdemir and Tekin, 2016), career guidance (Arı, 2009), foundational studies on fuzzy logic in education (Işıklı, 2010; Sanca, Artun, ve Okur, 2022), and research on the impact of technology on students (Memmedova, 2017). Selected examples from this body of research are discussed below.

Dhokare et al. (2021) developed a fuzzy logic-based model to evaluate students' academic performance during the COVID-19 pandemic, demonstrating its effectiveness in identifying performance levels. Similarly, Petra and Aziz (2021) focused on annual student performance analysis using fuzzy logic evaluation techniques; their model, implemented via MATLAB, was constructed based on selected performance criteria. In another study, Huang and Liu (2021) proposed a model integrating artificial intelligence algorithms and fuzzy logic to forecast and guide university students' employment and entrepreneurship trajectories. Gokmen et al. (2010) introduced a novel performance evaluation approach grounded in fuzzy logic systems, applying it in the Control Techniques Laboratory of Marmara University's Faculty of Technical Education, and compared its effectiveness with traditional evaluation methods.Voskoglou (2013) constructed a fuzzy logic model to assess students' knowledge and skills, representing their subject knowledge, problem-solving, and analogical reasoning abilities through fuzzy sets to perform both quantitative and qualitative analyses of group performance. Doz et al. (2022) explored integrating teachers assigned mathematics grades with the results of the Italian National Mathematics Knowledge Assessment (INVALSI) using a fuzzy logic framework to develop a new assessment model. Balovsyak et al. (2024) aimed to teach students in technical fields to perform image segmentation in railway transportation using fuzzy logic applications. In addition to fuzzy logic–based grading models, recent regional studies have applied fuzzy multi-criteria decision-making approaches to variables closely related to academic achievement. For instance, Türkmen et al., (2025) employed a Fuzzy Analytic Hierarchy Process (AHP) framework to model the determinants of exam anxiety, incorporating family-related, socio-environmental, and economic factors. Their findings highlight the multifaceted and interrelated nature of affective and contextual variables influencing student performance. Although the present study focuses on achievement assessment rather than affective factors, the inclusion of such studies contributes to a more comprehensive understanding of how fuzzy methodologies are being utilized in educational research within similar regional contexts.

A review of recent literature indicates that fuzzy logic has been increasingly adopted in educational performance evaluation due to its ability to handle uncertainty and capture subtle variations in learning outcomes. While its application has expanded considerably in higher education and secondary-level assessments, studies focusing on the evaluation of primary school students' performance remain relatively scarce. Assessing academic achievement in science education at the primary level is particularly critical, as it plays a key role in guiding students toward informed decisions regarding their future academic pathways. Therefore, enhancing sensitivity and reducing ambiguity in assessment processes is of paramount importance.

This study aims to offer educators and researchers an innovative perspective for achieving a more precise and comprehensive evaluation of student performance in science courses. Specifically, it examines the academic performance of fourth-grade primary school students through a fuzzy logic–based evaluation approach. The originality of this research lies in the development and validation of a fuzzy logic–based evaluation model specifically designed for primary school science education. Unlike previous studies that predominantly focus on higher education contexts or rely on simulated data, this study utilizes real classroom data obtained from fourth-grade students and integrates two separate examination scores into a single fuzzy-based academic performance indicator. Moreover, the proposed model incorporates expert-validated linguistic variables and triangular membership functions tailored to the primary education context. It also includes a comparative analysis of classical and fuzzy logic–based evaluation methods, empirically demonstrating the potential of fuzzy logic to enhance fairness, sensitivity, and diagnostic depth in educational assessment.

Finally, this study presents a practical and adaptable framework that can be extended to other subjects and educational levels, thereby bridging the gap between theoretical fuzzy logic models and real-world educational assessment practices. In line with these aims, the present study seeks to determine whether the two assessment approaches yield different evaluation outcomes for the same group of students. Accordingly, the research is guided by the following research question:

Is there a statistically significant difference between primary school students' science course performance evaluations when assessed using traditional methods and fuzzy logic–based approaches?

Method

Research Design

This study employed a descriptive survey design (Karasar, 2017). This design was selected to examine in detail the academic achievement of students in the science course.

Study Group

The population of this study consisted of the science course report-card grades of fourth-grade primary school students attending public primary schools in the central districts of Kütahya, Turkey, during the fall semester of 2019–2020. Because the research aimed to test the proposed fuzzy logic model on real and complete classroom data rather than on a probabilistic sample, a convenience sampling approach based on full enumeration of the accessible schools was adopted. Within this scope, the first- and second-exam science scores of 799 fourth-grade students from seven public primary schools located in the central districts of Kütahya were initially obtained.

The dataset was then pre-processed to ensure consistency and reliability. Records with missing or invalid scores for either of the two examinations were excluded, so that only students with complete and valid data for both exams were retained. After this screening, a final dataset of 763 students was used in the analyses. This sample size is well above the thresholds commonly recommended for parametric analyses in educational research and is comparable to, or larger than, the sample sizes reported in similar fuzzy logic–based assessment studies, thereby providing a sufficient basis for the paired-sample comparisons conducted in this study.

Data Collection

The fuzzy logic model developed in this study was tested using an authentic dataset comprising the science course examination scores of fourth-grade students enrolled in public primary schools in the central districts of Kütahya, Turkey, during the fall semester of 2019–2020. After the necessary permissions had been obtained from the Kütahya Provincial Directorate of National Education, students' first and second written science examination grades were collected from the selected schools in the form of official grade records that contained no personal or identifying information. The use of such existing institutional records as secondary data is a common and practical approach in educational research, as it allows researchers to work with large-scale, real classroom data while minimizing measurement error and protecting student confidentiality (Karasar, 2017). Prior to analysis, all data were anonymized, and only numerical examination scores were retained.

Data Analysis

Data analysis was carried out in two sequential stages. In the first stage, students' science examination scores were processed using Microsoft Excel to compute arithmetic mean scores and generate descriptive statistics. In the second stage, the same dataset was analyzed using MATLAB to implement the fuzzy logic–based evaluation model.

During the fuzzy logic analysis, appropriate membership functions and rule bases were defined, and student performance was evaluated through a structured, step-by-step procedure. Prior to analysis, all student data were anonymized to ensure confidentiality, and only numerical examination scores were included. The dataset was pre-processed to eliminate incomplete records and to confirm that each student had valid scores for both examinations, thereby ensuring data consistency and reliability across analyses.

The effectiveness of the proposed model was examined by comparing fuzzy logic–derived academic performance scores with traditional arithmetic averages. A paired-sample t-test was employed to determine whether the differences between the two assessment methods were statistically significant, with the significance level set at $p < .05$.

Research Ethics

Ethical approval for this study was granted by " T.C Kütahya Dumlupınar Üniversitesi Rektörlüğü Sosyal ve Bilimler Bilimsel Arastırma ve Yayın Etigi Kurulu, 21.05.2020, decision no: 20202\05. In addition, the necessary permissions for data collection were obtained from the Kütahya Provincial Directorate of National Education. All student data were fully anonymized before analysis, and no personal or identifying information was collected or processed.

Membership Functions and Defuzzification

In the fuzzy logic system developed for this study, triangular membership functions were adopted because of their simplicity and interpretability. A triangular fuzzy number, denoted as T = (x / y / z), is defined by three real numbers (x < y < z), where the interval [x, z] represents the support and y corresponds to the maximum degree of membership. The triangular fuzzy number T = (1 / n / m) is shown graphically in Figure 1.

The triangular membership function is determined using three variables, x, y, and z. The function is formally expressed in Equation 2.1 (Azam, Hasan, Hassan, and Abdulkadir, 2020):

$$\mu_{(x)} = \begin{cases} 0 \;\; If \quad x \leq l \; or \; x \geq m \\ \frac{x-l}{n-l} \quad If \;\; l < x \leq n \\ \frac{m-x}{m-n} \quad If \;\; n < x < m \end{cases} \tag{2.1}$$

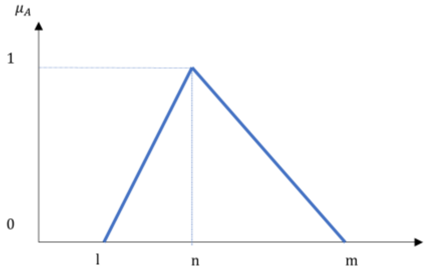

Figure 1. Graphical Representation of the Triangular Membership Function (Barlybayev et al., 2016). The triangular membership function reaches its maximum membership degree (1) at the central value and decreases linearly toward the lower and upper limits, illustrating how a score's degree of belonging to a fuzzy set changes across the interval.

Steps of Academic Performance Evaluation Using Fuzzy Logic

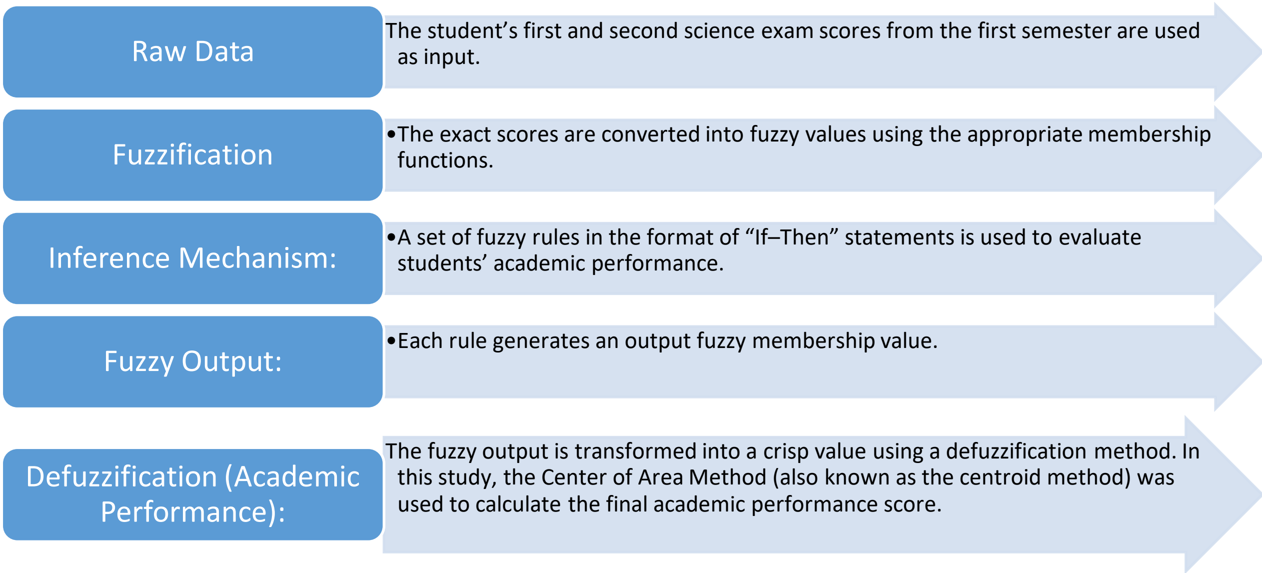

Figure 2. Science Exam Data of 4th Grade Primary School Students

Fuzzy Logic System Used to Evaluate Academic Performance

In this study, students' academic performance in the science course was evaluated using a fuzzy logic system based on the average of their first and second exam scores from a single semester. Accordingly, the input variables for the system were students' Exam 1 and Exam 2 scores in the science course. The output variable was the academic performance value computed using the fuzzy logic methodology. A Mamdani-type fuzzy inference system with two input variables and one output variable was used. The structure of this system, depicting the relationship between the inputs and the resulting output, is illustrated in Figure 3.

The fuzzy logic method for evaluating academic performance consists of three fundamental steps:

- Fuzzification of input and output variables
- Establishment of the rule base and selection of the inference method
- Defuzzification to obtain the final academic performance value

Fuzzification of Input and Output Variables for Determining Academic Performance

In the fuzzy logic system, where Exam 1 and Exam 2 scores are input variables, both input and output membership functions were divided into nine distinct intervals. During the fuzzification stage, each student's Exam 1 and Exam 2 scores were converted into corresponding membership degrees across the nine linguistic categories (Extremely Low to Extremely High). Table 1 presents sample fuzzification outputs for selected students, illustrating how individual scores are represented simultaneously within multiple fuzzy sets.

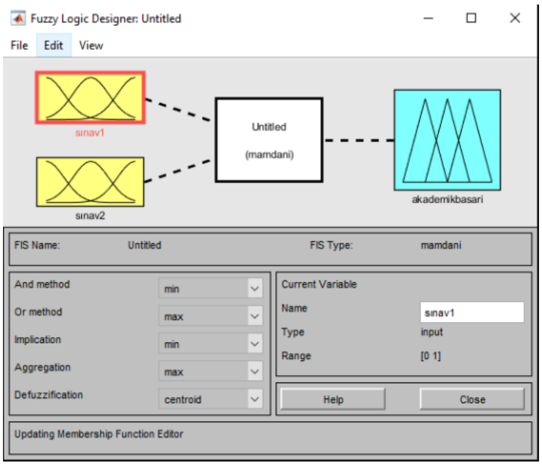

Figure 3. MATLAB Interface of the Mamdani-Type Fuzzy Inference System with Two Inputs (Exam 1, Exam 2) and One Output (Academic Performance). The Mamdani-type fuzzy inference system takes the two exam scores as input variables and produces a single academic performance value as output.

Figure 3 illustrates the structure of the fuzzy inference system. Based on this system, example fuzzification outputs for selected students are presented in Table 1.

Table 1.
Example Fuzzification Outputs for Selected Students

Student No.	**Exam 1**	**Exam 2**	**Membership in "Average"**	**Membership in "High"**	**Membership in "Very High"**
1	88	92	0%	40%	60%
2	76	80	0%	55%	45%
3	69	73	80%	20%	0%
4	56	63	100%	0%	0%
5	95	100	60%	0%	40%

Table 1 displays a numerical representation of the fuzzification output for a sample student, showing overlapping membership degrees across three adjacent linguistic categories ("Average," "High," and "Very High"). In Table 1, it is observed that Student No.1 has 0% of grades at the "average" level, 40% at the "High" level, and 60% at the "Very High" level.

Table 2.
Interval Values of Fuzzy Input and Output Variable Sets

Linguistic Variable	**Interval**
Extremely Low (EL)	(0, 0, 12.51)
Very Low (VL)	(0, 12.51, 25)
Low (L)	(12.51, 25, 37.51)
Below-Average (BA)	(25, 37.51, 50)
Average (A)	(37.51, 50, 62.51)
Above-Average (AA)	(50, 62.51, 75)
High (H)	(62.51, 75, 87.51)
Very High (VH)	(75, 87.51, 100)
Extremely High (EH)	(87.51, 100, 100)

This segmentation was designed to reduce measurement errors, increase precision, and enable a more reliable evaluation. An examination of student data revealed that scores were predominantly concentrated at or above 60. Input from classroom teachers and sample distribution characteristics were also considered when defining the membership function intervals.

The linguistic labels and corresponding triangular intervals for both input (Exam 1, Exam 2) and output (Academic Performance) variables are given in Table 2., and the types of membership functions applied are illustrated in Figure 4.

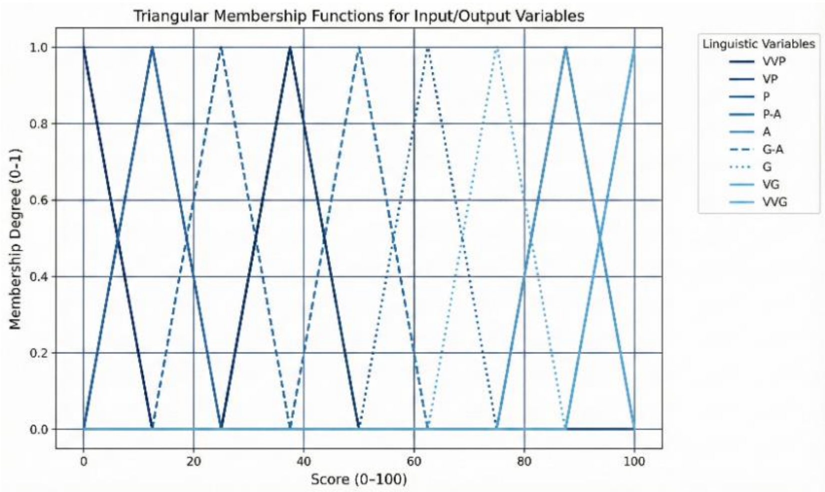

Figure 4. Triangular Membership Functions for Input/Output Variables. The nine overlapping triangular membership functions used for each variable, showing how adjacent linguistic categories share transition regions so that a single score can belong to more than one category with different degrees of membership.

Rule Base and Inference Process

The fuzzy rule base was constructed to evaluate students' academic performance by combining two input variables and mapping them onto a single output variable. The fuzzy rule base and membership function intervals were defined through an iterative process involving three experts: two experienced primary school science teachers (each with 10+ years of teaching experience) and one educational measurement specialist with expertise in fuzzy logic applications. The linguistic labels and interval boundaries were validated through expert consensus, considering the typical score distribution in Turkish primary education and the pedagogical significance of performance distinctions. A total of 81 rules were defined using the linguistic labels presented in Table 2. Each rule follows the standard *If–Then* structure of the Mamdani inference model. The general form of the rules is as follows:

If Exam 1 is (input1) and Exam 2 is (input2), then Academic Performance is (output).

Here, input1 and input2 represent the linguistic levels of the input variables (e.g., *Low, Average, High*), and output corresponds to the linguistic classification of the output. The rules were defined based on the logical relationship between performance levels in both exams.

A subset of representative rules is provided in Table 3.

In the fuzzy logic system, "If–Then" rules were constructed to evaluate students' academic performance. These rules utilize the membership functions of input and output variables based on students' exam results. For example:

If Exam 1 result is Average AND Exam 2 result is Very Low, THEN Academic Performance = Low

These rules reflect the principle that the overall performance outcome is influenced by both exam results, with higher weight given to consistent high performance across both inputs. The fuzzy inference engine uses these rule combinations to compute the output membership degrees before defuzzification.

Table 3
Table of Rules presents the complete rule matrix, in which each cell corresponds to the output linguistic category produced by a specific combination of Exam 1 and Exam 2 levels. The diagonal pattern reflects the principle that consistently high (or low) performance in both exams yields the correspondingly high (or low) academic performance output.

Exam1 Exam 2	**Extremely Low**	**Very Low**	**Low**	**Below Average**	**Average**	**Above Average**	**High**	**Very High**	**Extremely High**
Extremely Low	EL	EL	VL	VL	L	L	BA	BA	A
Very Low	EL	VL	VL	EL	L	BA	BA	A	BA
Low	VL	VL	L	VL	BA	BA	A	BA	BA
Below Average	VL	L	L	BA	BA	A	BA	BA	H
Average	L	L	BA	BA	A	BA	BA	H	H
Above Average	L	BA	BA	A	BA	BA	H	H	VH
High	BA	BA	A	AA	BA	H	H	VH	VH
Very High	BA	A	BA	AA	H	H	VH	VH	EH
Extremely High	A	BA	BA	H	H	VH	VH	EH	EH

Defuzzification of the Academic Performance Value

After the fuzzy logic evaluation is complete, the resulting fuzzy value must be converted into a crisp numerical score. This step, known as defuzzification, can be performed using various techniques. In this study, the centroid method, widely used in the literature, was selected (Mitsuishi, 2022). The crisp output value (z_0) was calculated using the formula in Equation 2.2:

$$z_0 = \frac{\int \mu(z).z\,dz}{\int \mu(z)\,dz} \quad (2.2)$$

Research Ethics

This study was conducted in accordance with research ethics and principles. Necessary permissions were obtained from the Kütahya Provincial Directorate of National Education prior to the data collection process. All student records were anonymized to ensure confidentiality, and only numerical examination scores without any identifying personal information were utilized in the analyses.

Findings

In this study, students' science course performance was evaluated using both the classical assessment approach based on arithmetic mean scores and the fuzzy logic–based evaluation method. The results obtained from these two approaches were subsequently compared using a paired-sample t-test.

The analysis revealed a statistically significant difference between the classical and fuzzy logic evaluation results, with the p-value falling below the .05 significance level. Although the mean scores produced by the two methods were relatively close, the statistical findings indicate a meaningful difference in the evaluation outcomes. The results showed that the classical method yielded slightly higher average scores compared to the fuzzy logic approach. Table 4 presents the descriptive statistics and t-test results comparing the classical and fuzzy logic–based evaluation methods. Table 5 provides a comparative presentation of the verbal evaluations of selected students' grades based on classical and fuzzy logic–based assessment approaches.

These examples demonstrate that fuzzy logic provides more flexible and detailed classifications compared to the classical method. Students near the category boundaries (e.g., between *Average* and *High*) are represented with partial membership degrees, reflecting the continuum of performance rather than rigid categorical distinctions.

Table 4
Comparison Between Classical and Fuzzy Logic Evaluation

t-test	Method	n	Mean ($\bar{x}$)	SD	t	p
Mean Score	Classical Method	763	86.01	13.45	0.33	< .001
	Fuzzy Logic Method	763	85.79	11.86		

Table 5
Comparison of Fuzzy and Classical Academic Performance Ratings for Selected Students

No	Exam1	Exam2	Classical Average	Classical categories	Fuzzy Score	Fuzzy categories
1	83	93	88	Very High	88.9	High, Very High
2	91	81	86	Very High	88.2	High, Very High
3	100	93	96.5	Very High	95.5	Very High, Extremely High
4	82	85	83.5	High	84	High, Very High
5	50	15	32.5	Extremely Low	28	Low, Below Average
6	70	64	67	Average	69.8	High Average, High
7	73	82	77.5	High	81.8	High, Very High
8	91	97	94	Very High	91.5	Very High, Extremely High
9	68	74	71	High	73.4	High Average, High
10	56	73	64.5	Average	68.6	High Average, High
11	40	69	54.5	Low	56.4	Average, Above Average
12	88	97	92.5	Very High	91.7	Very High, Extremely High

This section discusses the role of the five-point grading system used in the Turkish education system for classifying student achievement and the flexibility introduced by the fuzzy logic approach. In the conventional system, scores below 45 are considered *failing*; 45–54, *passing*; 55–69, *satisfactory*; 70–84, *High*; and 85–100, *excellent*. However, since primary school students often cluster in the higher performance categories, this fixed classification may not accurately reflect subtle differences in achievement. The fuzzy logic approach offers a more flexible and realistic evaluation by allowing partial membership across grade categories, providing a better representation of students' actual performance levels.

Fuzzy logic analysis indicated that while 498 students were classified as successful under classical logic, this number increased to 528 using fuzzy logic. Unlike classical methods with strict boundaries, fuzzy logic assigns students to multiple categories based on degrees of membership. For instance, a student can partially belong to both the "High" and "Very High" categories simultaneously.

To illustrate the difference between classical and fuzzy logic, consider two students: one with an academic performance score of 69 and another with 70.5. Under classical logic, the former falls into the "Satisfactory" category, while the latter is "High," despite a mere 1.5-point difference. Using fuzzy logic, the student scoring 69 might be assigned, for example, 20% membership in "Satisfactory" and 80% in "High," whereas the student with 70.5 might have 15% in "Satisfactory" and 85% in "High." This demonstrates that fuzzy logic enables a more sensitive and flexible evaluation of student performance compared to rigid classical methods.

Conclusion and Discussion

This study examined the flexibility offered by the fuzzy logic approach in educational assessment and its advantages over traditional methods. The findings reveal that fuzzy logic provides a more detailed and adaptable assessment of students' academic performance. Unlike conventional methods, fuzzy logic allows students to be classified into multiple, potentially overlapping, performance categories (e.g., "Average," "High," "Very High," and "Extremely High"), enabling more nuanced evaluations. Notably, the number of students classified as successful was higher when fuzzy logic was used compared to classical evaluation, particularly at the primary school level. This suggests that fuzzy logic can more precisely identify subtle differences in student achievement, especially among higher-performing students, due to its ability to distribute membership across different performance categories. An illustrative example is provided in Table 5.

As shown in Table 5, Students 2 and 3 were both classified as "Excellent" under the classical method. However, their academic performance yielded different characterizations with fuzzy logic. Specifically, Student 2 was associated with the "High" and "Very High" fuzzy sets, while Student 3 fell within the "Very High" and "Extremely High" sets. This observation highlights that although both students were placed in the same category (Excellent) by classical logic, fuzzy logic revealed qualitatively distinct performance levels. This differentiation demonstrates the higher sensitivity and granularity of the fuzzy logic approach in classifying academic performance.

Compared with similar studies involving different sample groups, the independent samples t-test findings in this research indicated a tendency favoring classical logic. This result aligns with Arslan and Zırhlıoğlu (2021) and Jafarkhani (2017), who also reported outcomes favoring classical methods. However, contrasting results favoring fuzzy logic have been reported in other studies (Dhokare et al., 2021; Ertuğrul, 2006; Ma and Zhou, 2000; Mehra, Gupta, and Avikal, 2023; Namlı, 2016; Uysal, 2010). For instance, Doz et al. (2022) found that their fuzzy evaluation method lowered students' grades, describing it as more stringent than traditional methods—a finding that contradicts the present study's results. Conversely, Quiroga et al. (2008) showed that fuzzy logic reduced false alarm rates while increasing fault detection sensitivity under fluctuating loads in an engineering context.

Recent studies conducted in similar educational contexts have demonstrated that high sensitivity in fuzzy evaluation systems can be achieved with substantially fewer rules when a limited number of input membership functions is employed. For instance, Türkmen and Killik (2024) proposed a parsimonious fuzzy assessment model using three input linguistic levels (e.g., Low, Moderate, High) while preserving a nine-level output scale, resulting in a compact 9-rule structure with effective discriminatory performance. In contrast, the present study adopts a higher-resolution input structure by employing nine linguistic membership functions for each exam score. This design choice was motivated by the distributional characteristics of primary school assessment data, particularly the observed ceiling effect and the pedagogical need to distinguish students clustered within upper score ranges. While this approach leads to a larger rule base (81 rules), it enables finer differentiation in borderline cases and supports diagnostic rather than purely classificatory assessment. Accordingly, the proposed model should not be interpreted as a more optimal or universally superior alternative, but rather as a context-sensitive framework prioritizing interpretive granularity over computational parsimony. In settings where computational efficiency is paramount, parsimonious designs such as those proposed by Türkmen and Killik (2024) may represent more appropriate solutions.

Such inconsistencies may stem from several factors, including sample size, the criteria for assessing primary school performance, or the use of nine fuzzy membership functions in this study. The sample's characteristics and size may have contributed to the results favoring classical logic. Specifically, in this study of 763 students, a large proportion was concentrated in the highest performance category (e.g., "Excellent" or "Extremely High"). This suggests that—despite a statistically significant difference—the mean scores between the classical and fuzzy logic evaluations were not substantially different for the majority of the cohort.

A more detailed analysis revealed that students classified as "Excellent" under classical logic were distributed across "High," "Very High," and "Extremely High" fuzzy sets when assessed using fuzzy logic. This finding, emphasizing the greater discriminatory power of fuzzy logic in performance assessment, is consistent with previous research (Arslan Namlı ve Senkal, 2018; Azimjonov, Hakan, ve Özbek, 2016; Bahadır, 2017; Bakanay, 2009; Daud et al., 2011; Kahrola, Kunwar, and Choudhury, 2015; Ma and Zhou, 2000; Öcal, 2015; Taylan ve Karagözoğlu, 2009; Yadav et al., 2014). This finding extends the work of Ma and Zhou (2000) and Bahadır (2017) by demonstrating that enhanced discriminatory power is particularly critical in contexts with ceiling effects—a phenomenon not adequately addressed in previous literature focused on normally distributed performance data.

Despite these contributions, some limitations should be acknowledged. First, the model was developed and tested within a specific context (fourth-grade science education in the central districts of Kütahya, Turkey), which may limit the generalizability of the findings to other educational levels, subjects, or regional settings. Second, although the nine-level membership structure provides enhanced discrimination, it also increases computational complexity and may require specialized software for practical implementation. Third, the model relies solely on written examination scores and does not incorporate other assessment dimensions such as practical work, projects, or oral presentations. Finally, the rule base was constructed through expert consensus rather than data-driven optimization techniques, which could be explored in future research. Overall, the fuzzy logic model can act as a complementary tool to traditional grading systems, fostering fairer, data-informed, and student-centered assessment practices in education. In this regard, developers and designers of educational software and student information systems—such as the e-School platform used by the Ministry of National Education—are encouraged to integrate fuzzy inference modules into existing grading and reporting tools. Embedding such a module would enable academic performance to be computed automatically through fuzzy logic alongside conventional averages, providing teachers and administrators with more sensitive and diagnostic information—particularly for students whose scores fall near grade-category boundaries—without requiring additional manual calculation.

Recommendations

Based on the findings of this study, several recommendations can be made for practitioners, teachers, and educational administrators seeking to implement fuzzy logic–based evaluation systems in real classroom environments. Teachers are encouraged to apply fuzzy evaluation particularly in borderline cases, such as when students' scores fall between grade thresholds, to ensure fairer and more balanced assessments. The fuzzy evaluation model can also be integrated into existing school information systems to automatically calculate academic performance using fuzzy inference mechanisms. To support effective implementation, teachers should receive training on basic fuzzy logic concepts and the interpretation of fuzzy outputs. Moreover, the model's capacity to identify partial memberships can be utilized for diagnostic purposes, allowing teachers to detect students who may need additional support before formal examinations.

Author Contribution

The first author, Şevval Demiral, contributed 40% to the planning, data collection, and writing of the study. The second author, Zehra Bilici, contributed 30% by providing supervision, guidance on the methodology, and critical review. The third author, Metin Demir, contributed 30% by assisting with data interpretation and editing of the manuscript.

Conflict of Interest

The researchers do not have any personal or financial conflicts of interest with other individuals or institutions related to the research.

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Genişletilmiş Özet

Giriş

Eğitim, bireylerin yalnızca akademik gelişimini desteklemekle kalmayıp aynı zamanda sosyal ve kültürel uyumlarını da kolaylaştıran çok boyutlu bir süreçtir. Bu sürecin önemli bir bileşeni olan fen eğitimi, bireylere bilimsel bilgiyi yorumlama ve etkili biçimde kullanma becerisi kazandırmayı; günlük yaşama ve doğal olaylara ilişkin problemleri anlama, analiz etme ve çözme yeterliklerini geliştirmeyi amaçlamaktadır. Öğretim sürecinde hedeflenen kazanımlara ne ölçüde ulaşıldığını belirlemede ölçme ve değerlendirme temel araçlardır. Ancak geleneksel değerlendirme yöntemleri çoğunlukla klasik mantığa dayanmakta; öğrenci performansını katı eşik değerleri ve ikili ayrımlar (geçti/kaldı gibi) üzerinden sınıflandırarak bireysel farklılıkları ve ara başarı düzeylerini yeterince yansıtamamaktadır. Özellikle öğrenmenin kademeli biçimde geliştiği bağlamlarda, bu tür kesin sınırlara dayalı sınıflandırmalar önemli bir sınırlılık oluşturmaktadır.

Bulanık mantık, belirsizlik içeren ve çok değişkenli verileri işleyebilme kapasitesiyle bu sınırlılıklara esnek bir alternatif sunar. Klasik mantığın ikili ayrımlarının aksine, bulanık mantık bir süreklilik içinde çok sayıda doğruluk değeriyle çalışır ve öğrencinin aynı anda birden fazla performans kategorisine kısmi üyelikle ait olabilmesine olanak tanır. Böylece "kısmen başarılı", "orta düzeyde başarılı" veya "yüksek düzeyde başarılı" gibi ara performans düzeyleri değerlendirmeye dâhil edilebilir. Alanyazın, bulanık mantığın eğitimde değerlendirme amacıyla giderek daha fazla kullanıldığını; ancak çalışmaların büyük ölçüde yükseköğretim ve ortaöğretim düzeyinde yoğunlaştığını, ilkokul düzeyindeki fen başarısının değerlendirilmesine yönelik araştırmaların sınırlı kaldığını göstermektedir. Oysa ilkokul düzeyinde akademik başarının hassas biçimde değerlendirilmesi, öğrencilerin ileriki akademik yönelimlerine ilişkin kararların şekillenmesinde kritik bir rol oynamaktadır.

Bu çalışma, ilkokul dördüncü sınıf öğrencilerinin fen dersindeki akademik performansını bulanık mantık temelli bir yaklaşımla incelemeyi ve geleneksel yöntemle karşılaştırmayı amaçlamaktadır. Araştırmanın özgünlüğü, ilkokul fen eğitimine özel olarak tasarlanmış, gerçek sınıf verilerine dayanan ve iki ayrı sınav puanını tek bir bulanık akademik başarı göstergesine bütünleştiren bir modelin geliştirilip doğrulanmasında yatmaktadır. Bu doğrultuda araştırma, "İlkokul öğrencilerinin fen dersi performansı geleneksel yöntemlerle ve bulanık mantık temelli yaklaşımlarla değerlendirildiğinde aralarında istatistiksel olarak anlamlı bir fark var mıdır?" sorusuna yanıt aramaktadır.

Yöntem

Araştırmada betimsel tarama modeli kullanılmıştır. Çalışma grubunu, 2019–2020 güz döneminde Türkiye'nin Kütahya ili merkez ilçelerindeki resmî ilkokullarda öğrenim gören dördüncü sınıf öğrencileri oluşturmaktadır. Araştırmanın modeli, olasılıklı bir örnekleme yerine erişilebilir tüm verilerin kullanılmasını gerektirdiğinden, tam sayıma dayalı uygun örnekleme yaklaşımı benimsenmiş; başlangıçta yedi ilkokuldan 799 öğrencinin fen sınavı puanları elde edilmiştir. Veri temizleme aşamasında, iki sınavdan herhangi birine ait puanı eksik veya geçersiz olan kayıtlar çıkarılmış ve analizlerde 763 öğrenciden oluşan nihai veri seti kullanılmıştır. Bu örneklem büyüklüğü, eğitim araştırmalarında parametrik analizler için önerilen ölçütlerin üzerinde olup benzer bulanık mantık temelli çalışmalarla karşılaştırılabilir düzeydedir.

Veriler, Kütahya İl Millî Eğitim Müdürlüğü'nden gerekli izinler alındıktan sonra, kişisel bilgi içermeyen birinci ve ikinci yazılı fen sınavı puanları biçiminde toplanmıştır. Veri analizi iki aşamada yürütülmüştür: ilk aşamada puanlar Microsoft Excel ile işlenerek aritmetik ortalamalar ve betimsel istatistikler hesaplanmış; ikinci aşamada aynı veri seti MATLAB ortamında geliştirilen bulanık mantık modeliyle analiz edilmiştir. Modelde, basitlik ve yorumlanabilirlik gerekçesiyle üçgen üyelik fonksiyonları tercih edilmiş; giriş (Sınav 1, Sınav 2) ve çıkış (akademik performans) değişkenleri dokuz dilsel kategoriye (Aşırı Düşük'ten Aşırı Yüksek'e) ayrılmıştır. İki girişli, tek çıkışlı Mamdani tipi bir çıkarım sistemi kurulmuş ve toplam 81 kural tanımlanmıştır. Kural tabanı ve üyelik fonksiyonu aralıkları, ikisi deneyimli fen öğretmeni ve biri ölçme-değerlendirme uzmanı olmak üzere üç uzmanın görüş birliğiyle belirlenmiştir. Durulaştırma işleminde alanyazında yaygın olarak kullanılan ağırlık merkezi (centroid) yöntemi kullanılmıştır. İki yöntemin sonuçları eşleştirilmiş örneklem t-testi ile karşılaştırılmış ve anlamlılık düzeyi $p < .05$ olarak alınmıştır.

Bulgular

Analizler, klasik ve bulanık mantık değerlendirmeleri arasında istatistiksel olarak anlamlı bir fark bulunduğunu ($p < .05$) ortaya koymuştur. İki yöntemin ortalama puanları birbirine yakın olmakla birlikte (klasik yöntem 86.01; bulanık mantık 85.79), klasik yöntem bir miktar daha yüksek ortalama üretmiştir. Bununla birlikte bulanık mantık, kategori sınırlarındaki öğrencileri kısmi üyelik dereceleriyle temsil ederek daha ayrıntılı ve esnek sınıflandırmalar sağlamıştır. Örneğin klasik yönteme göre "Mükemmel" kategorisinde toplanan öğrenciler, bulanık mantıkta "Yüksek", "Çok Yüksek" ve "Aşırı Yüksek" kümelerine dağılarak nitelik bakımından farklılaşmıştır. Klasik mantıkta başarılı sayılan öğrenci sayısı 498 iken, bulanık mantıkla bu sayı 528'e yükselmiştir. Bu bulgu, bulanık mantığın özellikle üst başarı düzeylerinde yer alan öğrenciler arasındaki ince farkları ayırt etmede daha duyarlı olduğunu göstermektedir.

Sonuç ve Tartışma

Bulgular, bulanık mantığın özellikle yüksek başarılı öğrencilerin yoğunlaştığı (tavan etkisi gözlenen) bağlamlarda öğrenci başarısındaki ince farkları ayırt etme gücünün geleneksel yönteme göre daha yüksek olduğunu göstermektedir. Klasik yönteme yakın ortalamalar elde edilmesi, örneklemin büyük bölümünün en üst başarı kategorisinde toplanmasıyla açıklanabilir. Çalışmanın klasik yöntem lehine eğilim gösteren sonucu, bazı çalışmalarla (Arslan ve Zırhlıoğlu, 2021; Jafarkhani, 2017) örtüşürken, bulanık mantık lehine sonuç bildiren çalışmalarla farklılaşmaktadır. Dokuz üyelik fonksiyonlu yüksek çözünürlüklü yapı, hesaplama karmaşıklığını artırmakla birlikte sınırdaki durumlarda sınıflandırıcı olmaktan çok tanılayıcı bir değerlendirmeye olanak tanımaktadır. Bu yönüyle önerilen model, evrensel olarak üstün bir alternatif olmaktan ziyade, bağlama duyarlı ve yorumlayıcı ayrıntıyı önceleyen bir çerçeve olarak değerlendirilmelidir.

Sonuç olarak, eğitimde bulanık mantık kullanımının öğrenci başarısının daha hassas ve gerçekçi biçimde değerlendirilmesine ve daha güvenilir kararlar alınmasına katkı sağladığı söylenebilir. Öğretmenlerin özellikle not eşiklerine yakın sınır durumlarda bulanık değerlendirmeden yararlanmaları, modelin okul bilgi sistemlerine entegre edilmesi ve kısmi üyeliklerin tanılayıcı amaçlarla kullanılması önerilmektedir. Çalışma, erken dönem fen eğitiminde akıllı sistemlerin değerlendirme süreçlerine entegrasyonu için diğer ders ve düzeylere de genişletilebilecek, uygulanabilir bir çerçeve sunmaktadır.