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Use of Fuzzy Logic in Determining the Academic Success of Secondary School Students in Mathematics Class[a]

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Abstract

The research data consists of the exam notes of the first term 1st and 2nd Mathematics course of the 2023-2024 academic year in Kütahya. The study consists of the exam scores of 876 students studying in 4 secondary schools in the center of Kütahya. To study a fuzzy logic-based two-input and single-output system was designed using Fuzzy Logic Toolbox in the Matlab program. In total, nine fuzzy rules were created. Academic success was evaluated first using the classical method and then using the designed fuzzy-based model. According to the results obtained, it has been observed that there is a highly positive relationship between the fuzzy logic method and the classical logic method. The academic success score obtained by the fuzzy logic method was less than that obtained by the classical logic method for grades 5 and 7. However, it was obtained that the fuzzy logic method was more than the classical logic method for grades 6 and 8. In conclusion, it was reached in favor of fuzzy logic because the fuzzy logic method gives more flexible results

Keywords: Fuzzy logic, mathematics lesson, academic success, Matlab, artificial intelligence

Ortaokul Öğrencilerinin Matematik Dersindeki Akademik Başarılarının Belirlenmesinde Bulanık Mantık Kullanımı

Öz

Araştırma verileri Kütahya ili 2023-2024 Eğitim-Öğretim yılı matematik dersi 1. Dönem 1. ve 2. sınav notlarından oluşmaktadır. Çalışma, Kütahya ili Merkezinde bulunan 4 ortaokulda öğrenim gören 876 öğrencinin yazılı puanından oluşmaktadır. Ortaokul öğrencilerinin matematik dersi akademik başarılarının belirlenmesi için Matlab programında Fuzzy Logic Toolbox kullanılarak bulanık mantık temelli iki girişli ve tek çıkışlı bir sistem tasarlanmıştır. Toplam 9 tane bulanık kural oluşturulmuştur. Ortaokul öğrencilerinin matematik dersi akademik başarısı ilk olarak klasik yöntemle daha sonra bulanık mantık yöntemiyle değerlendirilmiştir. Elde edilen sonuçlara göre, bulanık mantık yöntemi ve klasik mantık yöntemi arasında pozitif yönlü yüksek ilişki olduğu görülmüştür. Bulanık mantık yöntemiyle elde edilen başarı puanlarının ortalaması 5 ve 7. sınıflarda klasik mantık yöntemiyle elde edilen matematik dersi akademik başarı puanlarının ortalamasından daha düşük olduğu, 6 ve 8. sınıflarda bulanık mantık yönteminin ortalamasının klasik mantık yöntemi ortalamasına göre daha yüksek olduğu görülmüştür. Bulanık mantık ve klasik mantık karşılaştırılması sonucunda bulanık mantık yöntemi daha esnek sonuçlar verdiği için bulanık mantık lehine bir sonuca ulaşılmıştır.

Anahtar Kelimeler: Bulanık mantık, matematik dersi, akademik başarı, Matlab, yapay zekâ.

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1. Introduction

Nowadays, the use of mathematics in daily life is increasing. Even though mathematics is taught as a subject, it is always in life. It is used in many areas, such as time calculations and price calculations. Mathematics is included in all of life, not just a short part of it. While mathematics is crucial for us, many students do not like it. Many students believe that they cannot do it. The first lesson that students fear most and want to avoid throughout their education life. The reason why students are afraid of mathematics is the attitude developed by the students. (Taşdemir, 2009, pp. 90). Not only the student's attitude toward mathematics is effective, but also the teacher's attitude toward mathematics is effective (Karakaş Türker and Turanlı, 2008, pp. 20). In this study, the fuzzy toolbox in the Matlab program on the computer, one of the mathematical models, the input variables are students' 2023-2024 academic year 1st term mathematics course exam scores of secondary school students, and the output variable is the mathematical success, then fuzzy logic modeling method is applied. In this study, fuzzy logic and classical logic methods were compared to determine the academic success of secondary school students in mathematics.

The research aims to examine the academic success of secondary school students in mathematics using the fuzzy logic method and to create a model of their academic success. When the literature was analyzed, studies were found on the use of fuzzy logic in education and the evaluation of academic success and performance. However, studies have yet to be found using fuzzy logic to determine the academic success of secondary school students in mathematics. Instead of using judgments such as successful or unsuccessful in determining the academic success of students, how successful and how unsuccessful they were analyzed in detail. How do we determine the academic success of secondary school students in mathematics using the fuzzy logic method? The question will be answered.

1.1. Fuzzy Logic

Fuzzy logic is a preferred concept in the decision-making process in situations that are unclear and involve uncertainty (Zadeh, 1965, pp. 338-339). According to fuzzy logic, the membership degree does not need to be 1 for an object to be a member of a set, and the membership degree does not need to be 0 not to be a member of the set. It can take different degrees into the set. Additionally, the same variable in a fuzzy set can also be an element of another set (Bahadır, 2017, pp. 29). In simple words, in the fuzzy logic approach, a gray image is a different approximation of a black and white image (Klir and Yuan, 1995, pp. 374). Fuzzy logic is a mathematical term, although it is used by many researchers in different fields, such as chemical science, the healthcare industry, and agriculture. Because of using fuzzy logic, many things have become easier, and this has helped to save time, money, and energy (Makkar, 2018, pp. 357). Everything is not good or ugly. They can be some good or some ugly. These definitions are more suitable for daily life (Özmen, 2019, pp. 111).

1.1.1. Basıc Structure Of Fuzzy Logic System

Fuzzy logic explains the basic structure of a system. It consists of a rule base, database, input, fuzzification, inference mechanism, defuzzification, and output sections. The basic structure of fuzzy logic is shown in Figure 1.

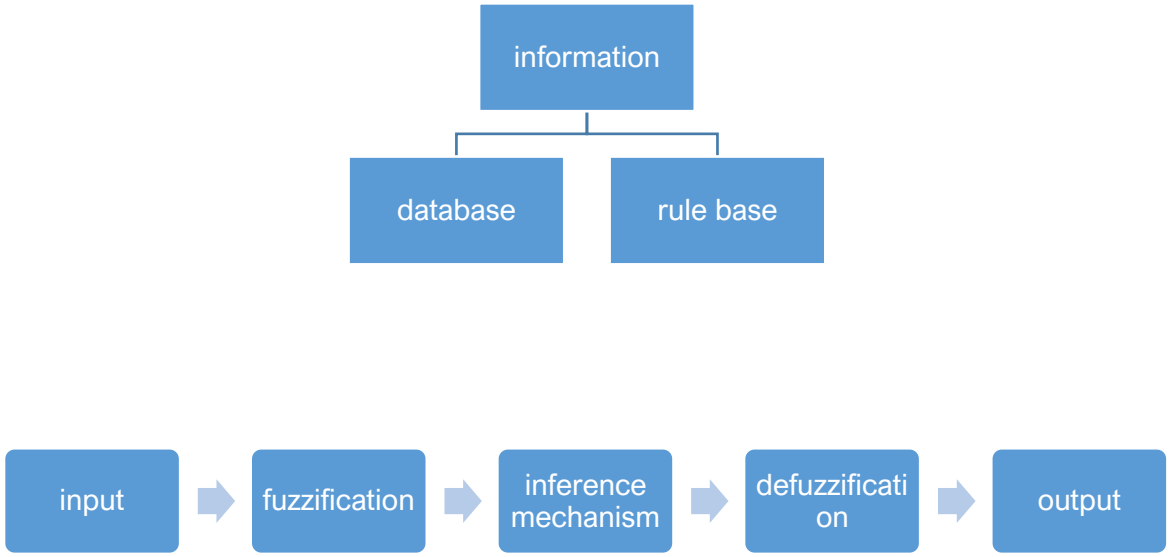


Figure 1. Basic Structure of Fuzzy Logic System

1.1.2. Fuzzy Membership Functions

When the literature was examined, it was seen that different membership functions were used depending on the problem situation. The most well-known membership functions are triangle-type membership functions, trapezoidal membership functions, and Gaussian membership functions (Arslan Namlı, 2016). Triangle Type Membership Function is given in Figure 2. The mathematical expression of the triangle membership function is as follows:

$$\mu_A(x,a,b,c) = \begin{cases} \dfrac{x-a}{b-a}, a \le x \le b \\ \dfrac{c-x}{c-b}, b \le x \le c \\ 0, others \end{cases}$$

Figure 2. Triangle Type Membership Function (Dönmez, 2012, pp. 59).

The Trapezoidal Membership Function is given in Figure 3. The mathematical expression of the trapezoidal membership function is as follows:

$$\mu_A = \begin{cases} \dfrac{x-a_1}{a_2-a_1}, a_1 \le x \le a_2 \\ 1, a_2 \le x \le a_3 \\ \dfrac{a_4-x}{a_4-a_3}, a_3 \le x \le a_4 \\ 0, x > a_4 \; or \; x < a_1 \end{cases}$$

Figure 3. Trapezoidal Membership Function (Dönmez, 2012, pp. 59).

Gaussian Membership Function is shown in Figure 4. The mathematical expression of the Gaussian membership function is as follows:

$$\mu_A(x; m, \sigma) = \exp\left(\frac{(x-m)^2}{\sigma^2}\right)$$

Figure 4. Gaussian Membership Function (Dönmez, 2012, pp. 60).

In the research, the Gaussian membership function was used in the fuzzy logic system.

2. Method

In this study, the academic success of secondary school students was examined using the descriptive survey model and the quantitative research method. The survey model aims to describe the existing situation in the past or present (Karasar, 2023, pp. 109).

The research consists of data from the 1st and 2nd exam scores of the 1st term mathematics course of 876 secondary school students studying in Kütahya in the 2023-2024 academic year. Information about the data collection tool used, recorded data, and the data analysis process are given below.

2.1. Methodology

The data used in the study were obtained from 876 middle school students' 1st-semester Mathematics course first and second exam scores during the 2023-2024 academic year in Kütahya. 2023-2024 academic year first term 1st and 2nd mathematics course exam scores were received from 4 secondary schools in the center of Kütahya. The collected data are combined in the Excel program, descriptive statistics are made in the Spss program, and the input value of the students' 1st and 2nd exam scores is the output variable of the students' academic success in the Matlab Fuzzy Logic program. A rule base was created by defining set variables, membership degrees, and membership functions for input and output values. The scores obtained by both methods and the results were compared using t-test and Pearson Correlation. The arithmetic average of the 1st and 2nd exam scores of 876 students was calculated according to classical logic. It was calculated using fuzzy logic using Matlab Fuzzy Logic Toolbox. Firstly, the 1st exam grades and the 2nd exam grades were entered as input values. Students' academic success is the output variable. A rule base was created for variables, membership degrees, and membership functions for input and output values. Finally, a total of 9 rule bases have been created. The rule table is given in Table 1. Linguistic variables and input variables of the exam scores are given in Table 2 and Table 3. The output variables of linguistic variables are given in Table 4.

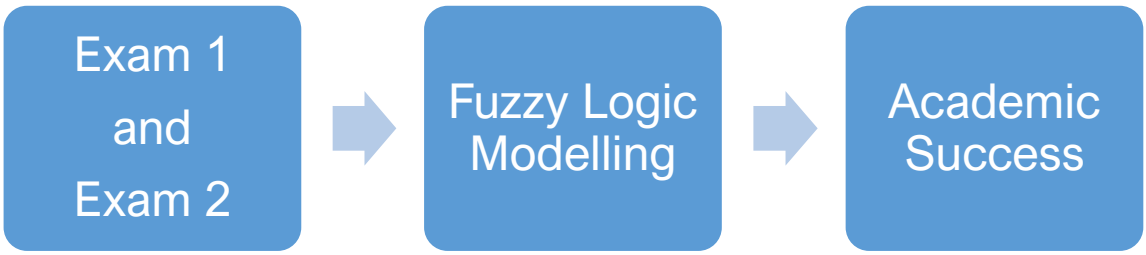


Figure 5. Fuzzy Logic Modelling

The following rule base has been created for the student's academic success according to the membership levels and the scores they received from the first exam and second exams of the first semester of the mathematics course. The rule base is shown in Table 1. For the rule base used in the system, 3 rules were entered for both the 1st and 2nd exam scores, and a total of 9 rules were created. The rules are given in Table 1.

Table 1. Rule Table

Exam 1/ Exam 2	Bad	Intermediate	Good
Bad	VVB	B	IG
Intermediate	VB	I	VG
Good	IB	G	VVG

1. If (Exam1 = Bad) and (Sınav2 = Bad) then (academic success = VVB)
2. If (Exam1 = Bad) and (Sınav2 = Intermediate) then (academic success = B)
3. If (Exam1 = Bad) and (Exam2 = Good) then (academic success = IG)
4. If (Exam1 = Intermediate) and (Exam2 = Bad) then (academic success = VB)
5. If (Exam1 = Intermediate) and (Exam2 = Intermediate) then (academic success = I)
6. If (Exam1 = Intermediate) and (Exam2 = Good) then (academic success = VG)
7. If (Exam1 = Good) and (Exam2 = Bad) then (academic success = IB)
8. If (Exam1 = Good) and (Exam2 = Intermediate) then (academic success = G)
9. If (Exam1 = Good) and (Exam2 = Good) then (academic success = VVG)

```
Details:
                         Description
        ________________________________________________________________
1       "Exam1==Bad & Exam2==Bad => Academic Success=VVB (1)"
2       "Exam1==Intermediate & Exam2==Bad => Academic Success=VB (1)"
3       "Exam1==Bad & Exam2==Intermediate => Academic Success=B (1)"
4       "Exam1==Good & Exam2==Bad => Academic Success=IB (1)"
5       "Exam1==Intermediate & Exam2==Intermediate => Academic Success=I (1)"
6       "Exam1==Bad & Exam2==Good => Academic Success=IG (1)"
7       "Exam1==Good & Exam2==Intermediate => Academic Success=G (1)"
8       "Exam1==Intermediate & Exam2==Good => Academic Success=VG (1)"
9       "Exam1==Good & Exam2==Good => Academic Success=VVG (1)"
```

Figure 6. Rules of Input and Output Values in Matlab Program

Table 2. Fuzzy Input Variable Set (1st exam)

Linguistic Variables	Variables
Bad	(17,5 0)
Intermediate	(17,5 50)
Good	(17,5 100)

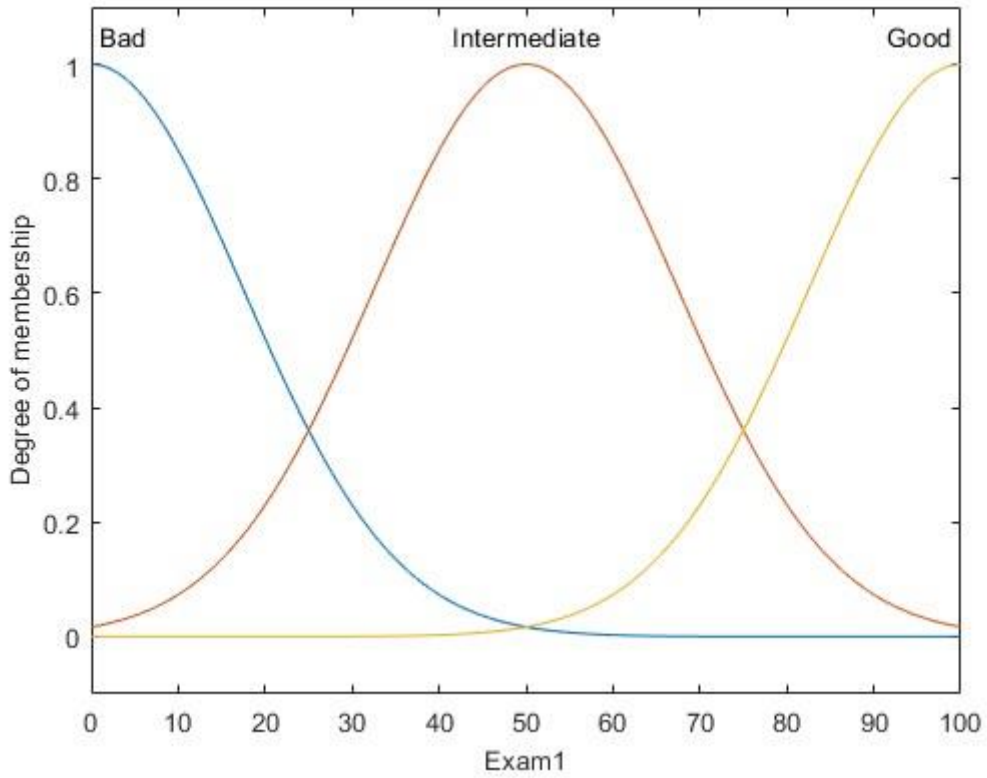


Figure 7. Membership Functions Defined for Exam 1 Score

Table 3. Fuzzy Input Variable Set (2nd exam)

Linguistic Variables	Variables
Bad	(17,5 0)
Intermediate	(17,5 50)
Good	(17,5 100)

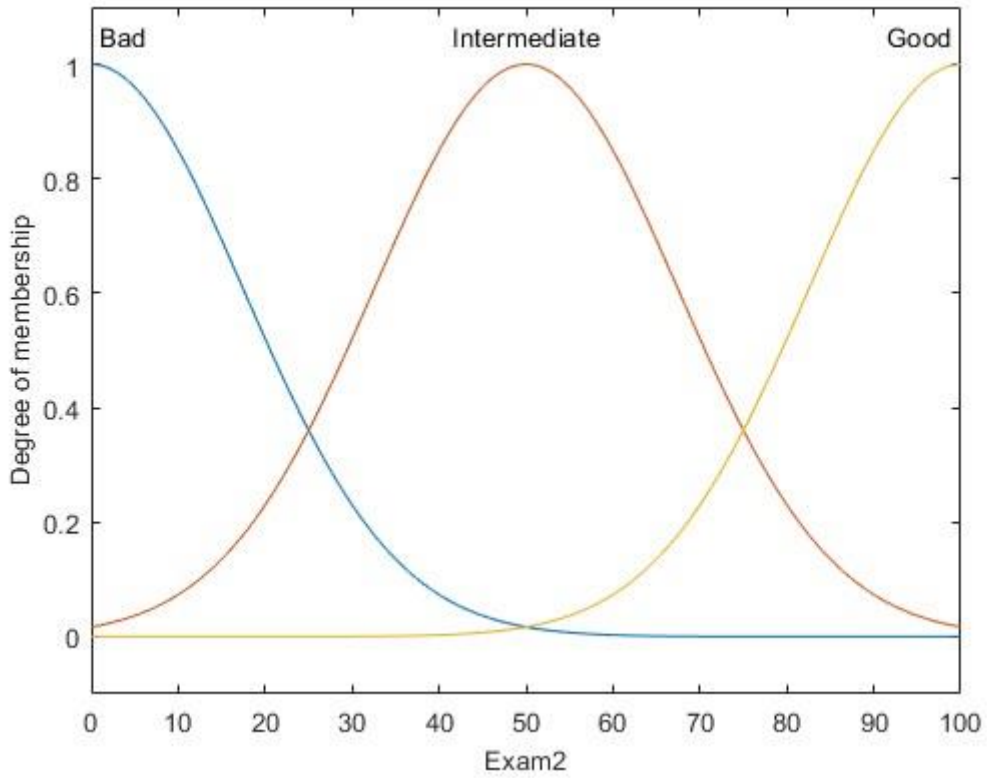


Figure 8. Membership Functions Defined for Exam 2 Score

Table 4. Fuzzy Output Variable Set

Linguistic Variable	Variables
Very Very Bad (VVB)	(4,2 0)
Very Bad (VB)	(4,2 12,5)
Bad (B)	(4,2 25)
Intermediate Bad (IB)	(4,2 37,5)
Intermediate (I)	(4,2 50)
Intermediate Good(IG)	(4,2 62,5)
Good (G)	(4,2 75)
Very Good (VG)	(4,2 87,5)
Very Very Good (VVG)	(4,2 100)

3. Conclusion

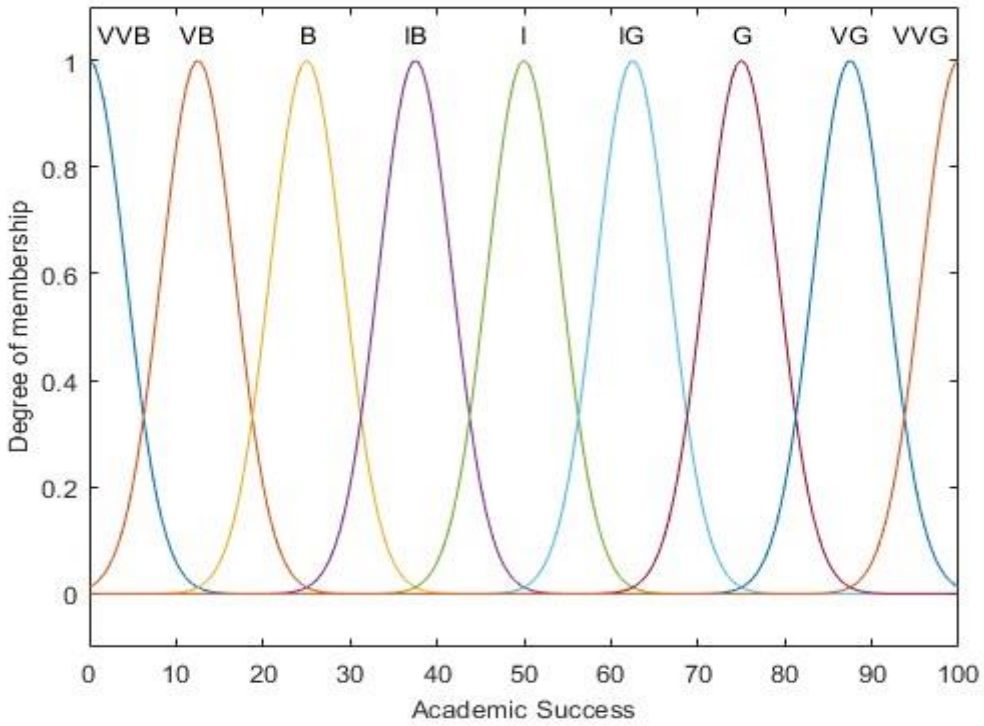


Figure 9. Membership Functions Defined for Academic Success

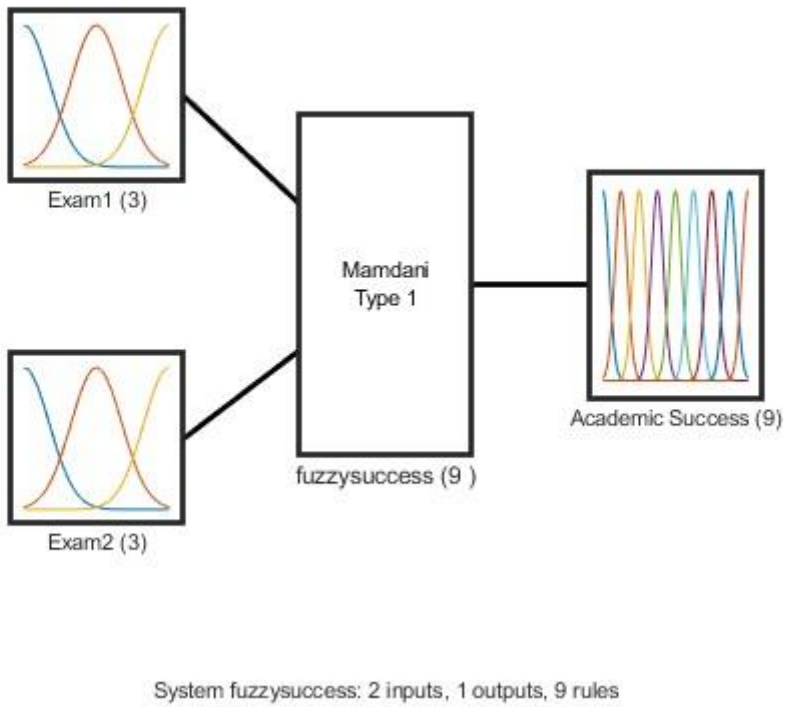


Figure 10. Mamdani Type Fuzzy Logic Mechanism with Two Inputs and One Output

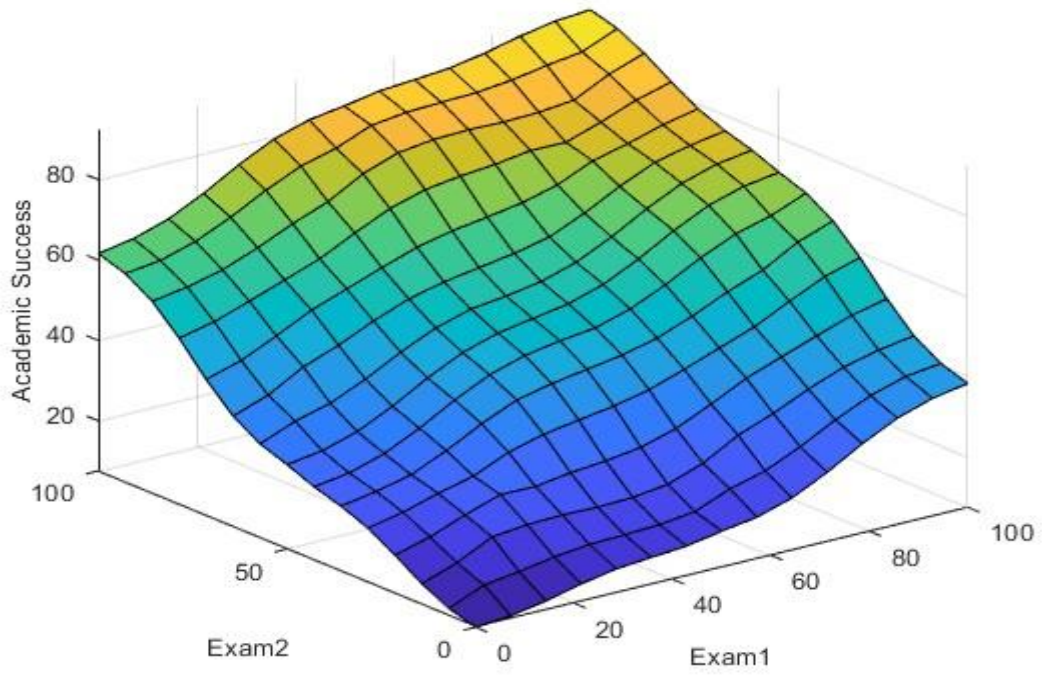


Figure 11. Surface Viewer

In the model obtained, output values were found in the fuzzy logic system for each input variable.

Table 5. Comparison of Scores Obtained According to Classical and Fuzzy Logic Methods (Grade 5)

Method	N	$\bar{x}$	Std. Error Mean	Max	Min
Classical Logic	218	68,22	1,72	99	1
Fuzzy Logic	218	66,36	1,54	92,30	8,17

Table 6. Comparison of Scores Obtained According to Classical and Fuzzy Logic Methods (Grade 6)

Method	N	$\bar{x}$	Std. Error Mean	Max	Min
Classical Logic	230	54,72	1,51	100	8,50
Fuzzy Logic	230	55,76	1,39	92,44	13,41

Table 7. Comparison of Scores Obtained According to Classical and Fuzzy Logic Methods (Grade 7)

Method	N	$\bar{x}$	Std. Error Mean	Max	Min
Classical Logic	187	59,59	1,96	100	3
Fuzzy Logic	187	56,98	1,83	92,44	9,13

Table 8. Comparison of Scores Obtained According to Classical and Fuzzy Logic Methods (Grade 8)

Method	N	$\bar{x}$	Std. Error Mean	Max	Min
Classical Logic	241	56,85	1,95	100	1,50

Fuzzy Logic	241	56,90	1,75	92,44	8,24

Descriptive statistical calculations were made for the results obtained using classical logic and fuzzy logic methods. According to Table 5, the average of the scores obtained using the classical method ($\bar{x}$ = 68,22) was higher than those obtained using the fuzzy method ($\bar{x}$= 66,36). It was observed that the highest score according to the fuzzy logic method was 92,30, and the highest score according to the classical logic method was 99. The lowest score for the fuzzy logic method was 8,17, and the lowest for the classical logic method was 1.

According to Table 6, the average of the scores obtained using the fuzzy method ($\bar{x}$= 55,76) was higher than those obtained using the classical method ($\bar{x}$=54,72). It was observed that the highest score according to the fuzzy logic method was 92, 44, and the highest score according to the classical logic method was 100. The lowest score for the fuzzy logic method was 13,41, and the lowest for the classical logic method was 8,50.

According to Table 7, the average of the scores obtained using the classical method ($\bar{x}$= 59,59) was higher than those obtained using the fuzzy method ($\bar{x}$=56,98). It was observed that the highest score according to the fuzzy logic method was 92, 44, and the highest score according to the classical logic method was 100. The lowest score for the fuzzy logic method was 9,13, and the lowest for the classical logic method was 3.

According to Table 8, the average of the scores obtained using the fuzzy method ($\bar{x}$= 56,90) was higher than those obtained using the classical method ($\bar{x}$=56,85). It was observed that the highest score according to the fuzzy logic method was 92,44, and the highest score according to the classical logic method was 100. The lowest score for the fuzzy logic method was 8,24, and the lowest for the classical logic method was 1,50.

In addition, t- test was calculated. T- test results are given below in Table 9, Table 10, Table 11, and Table 12.

Table 9. T-Test for Scores Obtained According to Classical and Fuzzy Logic Methods (Grade 5)

Method	N	T	Df	P
Classical-Fuzzy Logic	218	7,46	217	,00

According to Table 9, the t-test result shows that there is a significant difference between these variables, as the p-value is less than 0,05. (t(217)=7,46; p<,05).

Table 10. T-Test for Scores Obtained According to Classical and Fuzzy Logic Methods (Grade 6)

Method	N	T	Df	P
Classical-Fuzzy Logic	230	-3,84	229	,00

According to Table 10, the t-test result shows that there is a significant difference between these variables, as the p-value is less than 0,05. (t(229)=3,84; p<,05).

Table 11. T-Test for Scores Obtained According to Classical and Fuzzy Logic Methods (Grade 7)

Method	N	T	Df	P
Classical-Fuzzy Logic	187	9,49	186	,00

According to Table 11, the t-test result shows that there is a significant difference between these variables, as the p-value is less than 0,05. (t(186)=9,49; p<,05).

Table 12. T-Test for Scores Obtained According to Classical and Fuzzy Logic Methods (Grade 8)

Method	N	T	Df	P
Classical-Fuzzy Logic	241	-,16	240	,86

According to Table 12, the t-test result shows that there is not a significant difference between these variables, as the p-value is more than 0,05. (t(240)= ,16; p>,05).

According to both methods, students have improved in maths courses. Generally, their score has increased; therefore, there isn't a significant difference between both methods. Because students have prepared exams for high school, they have studied regularly.

Pearson Correlation Analysis Fuzzy- Classical Logic test results are given below:

Table 13. Pearson Correlation Analysis Fuzzy- Classical Logic

Grade	N	R	P
5	218	,99	,00
6	230	,98	,00
7	187	,99	,00
8	241	,99	,00

Pearson correlation determines the direction and magnitude of the relationship between normally distributed data (Arslan, 2019, pp. 54). The Pearson product-moment correlation coefficient was used to calculate normally distributed continuous variables. According to Table 13, there was a strong positive and significant relationship between the students' success using the fuzzy logic and classical logic methods for every grade. Grades 5, 7, and 8 are [r = 99; p<,01]. According to grade 6 is [r = ,98; p<,01].

Table 14. Average of Students' Scores According to Fuzzy Logic and Classical Logic Methods

Grade Level	Students	Exam 1	Exam 2	Classical Logic	Fuzzy Logic
7	S1	100	95	97,5	91,27
7	S2	95	100	97,5	92,02
7	S3	100	100	100	92,44
6	S4	100	89	94,5	88,90
6	S5	89	100	94,5	90,97
6	S6	29	64	46,5	50,21
6	S7	28	72	50	55,58
5	S8	42	55	48,50	50,38
8	S9	28	66	47	51,21
8	S10	60	43	51,5	49,25

According to Table 14, while the average of the two exams of S1 and S2 students according to the classical logic method was 97,5 their scores according to the fuzzy logic method were not equal and were calculated as 91,27 for S1 and 92,02 for S2. The reason for this difference is that

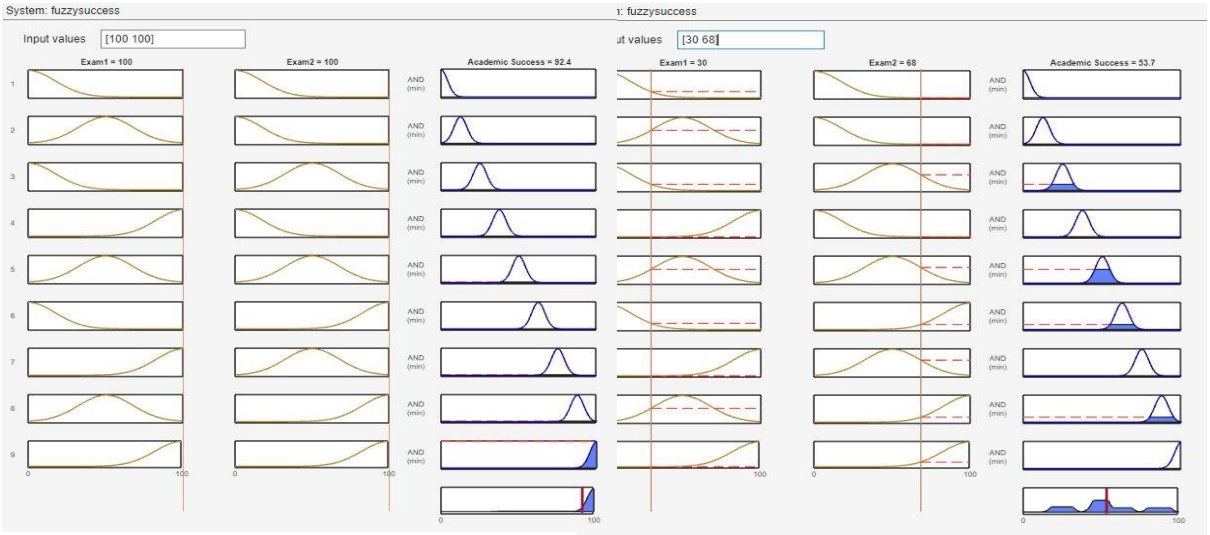
student S1 has a decreased score on the 2nd exam. Although S2's score was lower than S1's in the first exam, S2's score increased in the second exam. According to classical logic, the success of both students is the same, but S2 increases S2's score constantly; S2 isn't in the same success situation as S1. According to the fuzzy logic method, it was seen that student S2 received a higher score than student S1 because S2 showed improvement in the course. Student S3's both exam scores are 100, and according to classical logic, the average is 100. Even if the student's exam average is 100, the student does not know everything about the subject. According to the fuzzy logic method, the student's score is 92,44. Instead of thinking that the student knows everything about the subjects in the exam, S3 can be thought that the student knows the subjects very well, but S3 does not have all the information about the subject. Although the averages of students S4 and S5 are equal according to the classical logic method, there is a difference according to the fuzzy logic method. The reason is that while S4 was getting a high score in the first exam and decreased S4's score in the second exam, the S5 student showed a regular improvement and increased the student's scores, so it can be thought that the student has a higher average than the fuzzy logic method. S6 is not successful in the course according to classical logic but is successful according to fuzzy logic. The improvement S6 was supported by using fuzzy logic. The S7 exam score has increased. By supporting the development of the student, the average of fuzzy logic is higher than classical logic. S8 and S9 failed the course according to classical logic, but they have increased scores, so they were improved by fuzzy logic. The fuzzy logic average is higher than the classical logic method. S10 has a decreased score, so the student's classical logic score is higher than the fuzzy logic score. Students' motivation might be increased by using fuzzy logic. The research was conducted according to different grade levels by selecting students from different grade levels.

Table 15. Cronbach Alpha

Score	**Cronbach Alpha**
Classical Fuzzy Logic	,99

Cronbach Alpha was used to measure validity and reliability. Cronbach Alpha is ,99 in this research.

Students' Scores According to Fuzzy Logic Method is given in figure 12.



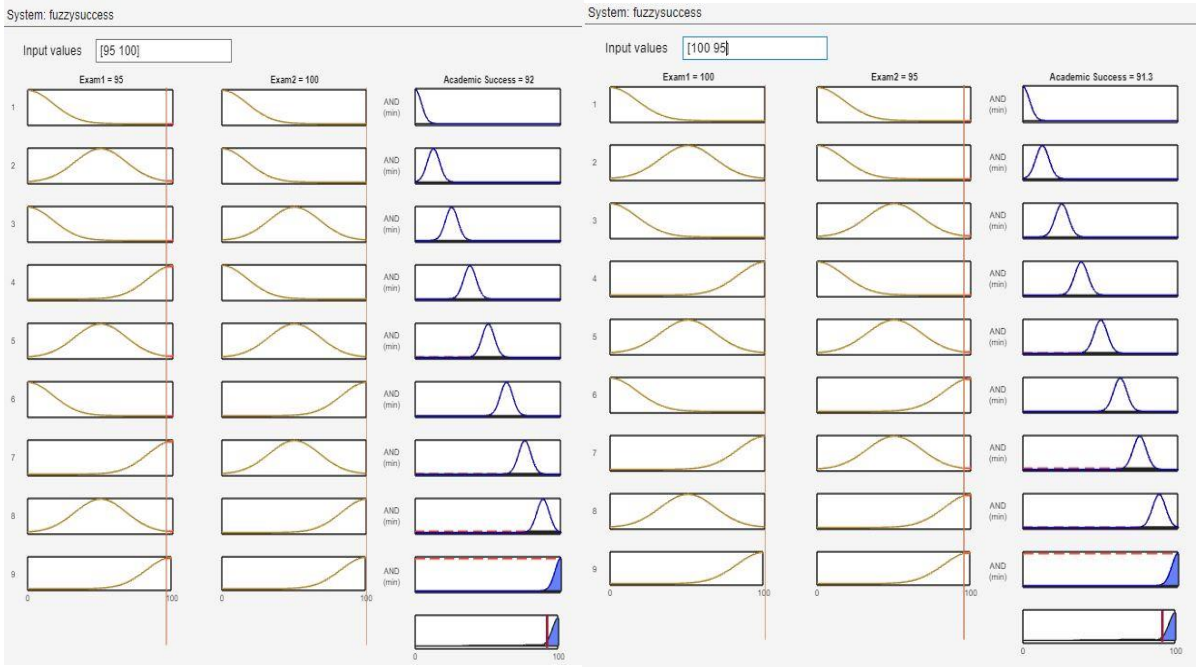


Figure 12. Defuzzification Result of Some Student Scores

4. Disscussion

According to classical logic, An element is or is not an element. It is clear and certain. For example, if a student's mathematics course grade is below 50, the student is unsuccessful, and if a student's score is above 50, the student is successful. If the student's score is 49, the student is unsuccessful, and if the student's score is 50, he is successful. There is only one point difference between them. Therefore, classical logic is inflexible. The classical logic method makes a limited classification. The use of fuzzy logic may be preferred to recover classical logic from limited classification (Ertuğrul, 2006, pp. 174).

In the study, the correlation value giving the relationship between the data obtained by fuzzy logic and the classical method was found to be ,99 for grades 5, 7 and 8. The correlation value giving the relationship between the data obtained by fuzzy logic and the classical method was found to be ,98 for grade 6. It has been observed that there is a highly positive relationship between the fuzzy logic method and the classical logic method. The academic success of primary school students in science courses were compared with the fuzzy logic method and the classical logic

method. Evaluation with the fuzzy logic method is more accurate and flexible, so the conclusion was reached favor of using fuzzy logic (Demiral, 2022, pp. 64). Teacher performances were compared with fuzzy logic and classical logic methods. It was concluded that there was a significant difference between the scores obtained as a result of the research. Therefore, a conclusion was reached in favor of classical logic (Arslan, 2019, pp. 59). The effect of high school students on mathematics success by taking active participation and absence were compared with fuzzy logic and classical logic methods. Both methods were found to be similar 80%. (Uyhan and Gök, 2022, pp. 869). As a result of the evaluations, it is seen that there are differences between the scores calculated by the two methods. The method of classical logic is strictly based on rules. According to the classical logic method, the student is successful or unsuccessful in the course. The fuzzy logic method provides results by providing flexibility in the evaluation process. The success of the student is examined in detail as a very very bad, very bad, bad, intermediate bad, intermediate, intermediate good, good very good, very very good. According to the results of the study, a conclusion was reached in favor of the fuzzy logic method, which evaluates the academic success of secondary school students in mathematics, providing more flexible and reliable results. According to the fuzzy logic method, in cases where the 1st exam score is low and the 2nd exam score is higher, the positive progress in the student's success compared to the classical logic method does not show any effect in the calculation, while fuzzy logic supports the student's development and it has been observed that the student's academic success score is higher. It is thought that the increase in scores due to the calculations made using the fuzzy logic method has a significant effect on the calculation and increases the students' motivation toward the course. The fuzzy logic average is higher than the classical logic average in evaluating the success of preservice teachers (Öcal, 2015, pp. 51). Fuzzy marks are higher than the non-fuzzy marks (Daud et al., 2011). In addition, although the average of the student whose exam score was 100 in both exams was calculated as 100 according to the classical logic method, it was calculated as 92,4 according to the fuzzy logic method. This is the case because a student with an average of 100 knows everything about the subject and course, but it can be wrong because the student does not know everything. The students' average is 1 according to classical logic and 8,17 according to fuzzy logic. They are unsuccessful but may help the student develop a positive attitude toward the course with fuzzy logic. It was concluded that while some of the students were unsuccessful in the course according to classical logic, they were successful in the course according to fuzzy logic. Performance determined by fuzzy system is more realistic than the classical system (Alam and Pandey, 2017, pp. 7). It has been observed that the use of the fuzzy logic method can be applied successfully and easily in evaluating the academic success of secondary school students in mathematics.

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