



Comparing Teachers' Critical Thinking Skills in Terms of the School Types through Classical Logic and Fuzzy Logic

Çiğdem Apaydin¹, Abdullah Kargin^{2*}, Sevilay Şahin³

¹Akdeniz University, Faculty of Education, Educational Administration Department, Antalya, 07058, Turkey

²Department of Mathematics, Gaziantep University, Gaziantep 27310, Turkey

³Department of Educational Sciences, Gaziantep University, Gaziantep 27310, Turkey

Emails: cigdemapaydin@akdeniz.edu.tr; kargin@gantep.edu.tr; kargin@gantep.edu.tr

Abstract

This study is an attempt to explore the value of the teachers' critical thinking skills with fuzzy expert systems. The study employed this system to obtain an objective and authentic evaluation in an abstract or ambiguous assessment. The working group consisted of 275 teachers working in public schools in Antalya central districts during the 2021-2022 academic year. This study deployed The Critical Thinking Appraisal (CTA) developed by Özelçi (2012). In the first stage, the data obtained from the teachers' critical thinking skill scale were analyzed through classical logic. Validity (explanatory and confirmatory factor analysis) and reliability analyzes (Cronbach Alpha) were performed during data analysis. Besides, the data regarding the teachers' critical thinking skill scale were also examined through the fuzzy logic approach. Different results emerged when comparing both methods. The findings revealed that the result on the fuzzy logic approach, which underpins artificial intelligence applications and which is used in various decision-making applications, is more consistent and objective. This study may shed light onto the researchers to obtain results that are more objective by conducting studies based on fuzzy logic-based survey. Besides, the validity and reliability analyzes made through the classical method with a similar method may also be carried out through the fuzzy logic method. These new results may be compared with those of the classical method. Thus, the objectivity of classical validity and reliability analyzes may also be examined.

Keywords: Critical Thinking; Teachers; School Type; Classical Logic; Fuzzy Logic; Fuzzy Survey; Fuzzy Matlab

1. Introduction

Teaching critical thinking skills (CTS) has become a fundamental and frequently emphasized educational goal in conjunction with acquiring knowledge in the age of artificial intelligence. Considering today understands of democratic and globalizing society, it is most likely that critical thinking is an essential competence to have. Critical thinking (CT) is a higher-level thinking skill that involves problem solving, decision-making and creative thinking [1]. Therefore, it is of great significance to teach students critical and effective thinking competencies since countless information is easily accessible [2]. Their peers or parents cannot teach critical thinking skills to students strongly; instead, trained and knowledgeable instructors are needed to impart these proper knowledge and skills [3]. Therefore, teachers must first enjoy critical thinking skills [4-5].

CTS is a competency that is hard to identify and that has complex definitions without a single, universally accepted definition [6]. Despite all the criticism, educators hold similar views regarding the need for CTS in a time when new knowledge is rapidly increasing in the contemporary world [5], [7]. As is seen, the specific boundaries of the CTS cannot be clearly drawn.

Pe'piot, Cheikhrouhou, Fürbringer and Gardon asserted that precise measurements in a place where there is a human element might be questionable in terms of the accuracy and reliability of evaluating different people in the same group [8]. Therefore, this study employed fuzzy logic to evaluate critical thinking skills. Fuzzy logic is used in situations in which uncertainty and ambiguity prevail and when it is necessary to reduce the impact of subjectivity [9]. This study deployed a Likert-type scale to evaluate teachers' critical thinking skills in terms of the types of schools they work in and compare the

findings regarding teachers' critical thinking skills and those obtained through classical logic in terms of school types by measuring this scale with fuzzy logic.

One of the higher-level thinking skills, critical thinking is a set of skills that allow producing arguments, inferences, deductions, conclusions, and evaluations based on the information [10]. CT is the ability to understand assumptions, make claims supported by evidence and make conclusions warranted by the evidence presented [5]. Hence, CT is disciplined thinking governed by intellectual standards such as clarity, precision, accuracy, relevance, consistency, logical correctness, completeness, and fairness [11]. Individuals with these characteristics can evaluate and weigh information to make informed decisions [12].

CT helps the individual make wise decisions through teaching them to think more carefully, clearly and logically related to significant life decisions. In this vein, the individual can make inferences in problem solving and decision-making processes, increase the probability of desired results, take probabilities into account, and use cognitive skills or strategies [2]. The basic components of CTS are listed as interpretation, analysis, evaluation, inference, explanation and self-regulation [13]. Therefore, CTS enables the individual to consciously carry out democratic processes in social life and prevents society from being harmed due to wrong choices resulting from poor critical thinking [11]. Critical thinking also helps individual's live better lives and make contributions that are more positive to society with conscious and informed decisions.

In recent years, critical thinking has been among the primary goals of education to provide individuals with the thinking and reasoning skills necessary to solve the problems they encounter in their daily lives [14]. Critical thinking corresponds to the levels of analysis, synthesis and evaluation in the field of education [15]. Teachers hold a significant mission in acquiring these skills. It is paramount for teachers to have CTS in terms of professional competence and educational reforms [16-18]. Teachers play a significant role in the development of competencies such as CTS, which is among higher-level thinking skills [19]. Future teachers need to be skilled critical thinkers so that they can promote students' critical thinking skills [20]. Various studies revealed that teachers have a limited understanding of critical thinking [21-23]. Thus, previous studies suggested that teachers from different disciplines understand the significance of CTS, but cannot fully grasp what it really means. Besides, there is a dearth of studies on investigating teachers' perceptions, practices and their levels of CTS. It is remarkable that teachers ready for their responsibilities regarding the education of the new generation. Therefore, they need to possess CTS in the processes of organizing, implementing and evaluating their practices in school and to encourage their students for being good critical thinkers. They also need to first develop their own CTS to promote students' CTS [24]. It is also vital to develop methods for evaluating teachers' CTS. On this wise, teachers may both increase their own critical thinking competencies and that they may be more effective in teaching students CTS. Numerous current studies were grounded on pre-service teachers' critical thinking skills [25-29], [14]; few focused on teachers' critical thinking skills [30] in-service. This indicates the lack of research on maintaining and developing CTS in teachers' professional lives.

Although the emphasis on critical thinking has led to a significant amount of research on critical thinking skills, little information is available on identifying teachers' critical thinking skills. Upon analyzing the relevant literature, studies on measuring teachers' CTS [31-35] are mostly built on Aristotle's logic perspective, which is classical logic. The evaluations made with Aristotelian logic may be insufficient or incomplete as the boundaries of CTS are difficult to draw sharply. Thus, this study used fuzzy logic to evaluate teachers' critical thinking skills in terms of school types.

It is most probable to encounter uncertainties at almost every moment of life. However, classical logic is often inadequate in explaining these uncertainties since a situation or proposition must be either absolutely true (used for elements with a membership degree of 1) or false (used for elements with a membership degree of 0) in classical logic. Situations other than this cannot be expressed logically and mathematically. In other words, a situation involving uncertainty cannot be expressed with classical logic. To illustrate, an apple must be either red or not red in classical logic. However, in classical logic, shades of red cannot be expressed as the color of an apple. There is no equivalent in classical logic for situations such as the color of an apple being dark red or light red.

Zadeh defined the concept of fuzzy sets [36] in 1965 to explain uncertainties mathematically. Unlike classical logic, fuzzy logic is used to explain how true the situation or importance is instead of analyzing whether a situation or proposition is absolutely true or false. In other words, fuzzy logic requires that the membership values of an element in a set do not have to be 0 or 1 as in classical logic. Fuzzy logic uses the continuum values local values between 0 and 1, including 0 and 1. Namely, the membership of the elements can be graded in fuzzy logic. Thus, the uncertainties may be expressed mathematically. The color of the apple being red with a membership degree of 0.9 (meaning 90% red) or being red with a membership degree of 0.01 (meaning 1% red) is a simple example of membership grading in fuzzy logic. Therefore, fuzzy logic is used in many decision-making practices in almost every branch of science [37-40]. It also contributes to obtaining more objective results in solving many problems compared to classical methods. In addition, fuzzy logic theory underpins popular artificial intelligence applications with its increasing use day by day.

2. Preliminaries

Özelçi developed critical Thinking Appraisal (CTA) [41]. The tool consists of five factors (willingness to gather information, self-regulation, inference making ability, evidence-based decision making, and openness to causality) and 19 items. The willingness to gather information factor consists of four items (4,8,12,19), self-regulation (6,13,15,16,18) five items, inference making ability (2,9,10) three items, evidence-based decision making (5,11,17) three items, and openness to causality (1,3,7,14) four items. The scale is rated on a 5-point Likert type (1 = Strongly disagree, 5 = Strongly agree). Items 1, 3, 5, 7, 11, 14, 16 and 17 are reverse items. Cronbach's alpha values regarding the factors were depicted respectively as willingness to gather information ($\alpha = .70$), self-regulation ($\alpha = .64$), inference making ability ($\alpha = .52$), evidence-based decision-making ($\alpha = .54$) and openness to causality ($\alpha = .56$). The Cronbach's alpha coefficient for CTA was identified as .75. In addition, Cronbach's alpha values for each of the 5 factors were as follows: willingness to gather information ($\alpha = .46$), self-regulation ($\alpha = .64$), inference ($\alpha = .49$), evidence-based decision making ($\alpha = .61$) and openness to causality ($\alpha = .53$), respectively. Confirmatory factor analysis was performed to test the accuracy of the scale including 19 items and 5 factors.

The fit indexes of the model obtained from the path analysis were examined through the Lisrel 8.71 package program and that the five-factor model's RMSEA (root mean square error of approximation), NFI (normed fit index), NNFI (non-normed fit index), CFI (comparative fit index), SRMR (standardized root mean squared residual) were at acceptable levels (Kaplan, 1995). The fit indices of the model obtained from the confirmatory factor analysis related to the critical thinking attitude scale were analyzed and the chi-square value ($\chi^2 = 267.03$) and degrees of freedom ($df = 142$), $p = 0.00 < 0.05$) were identified. The fit index values were found to be RMSEA = .06, NFI = .88, NNFI = .92, GFI = .91, CFI = .93, AGFI = .88, SRMR = .07, and RMR = .07. On analyzing the fit values of the measurement tools, χ^2/sd , RMSEA, NFI, NNFI, GFI, CFI, AGFI, SRMR and RMR values for CTA were determined to show satisfactory fit (Byrne & Campbell, 1999; Bentler, 1980; Schermelleh-Engel, Moosbrugger and Müller, 2003). Accordingly, it is most likely that all fit values confirm the factor structure of the scale.

Definition 1: [36] Let \mathcal{B} be the universal set. A fuzzy set \mathcal{A} on \mathcal{B} is defined by

$$\mathcal{A} = \{(a, \mu_{\mathcal{A}}(a)): a \in \mathcal{B}\}.$$

Here, $\mu_{\mathcal{A}}(a)$ is membership function such that

$$\mu_{\mathcal{A}}: \mathcal{B} \rightarrow [0,1].$$

Definition 2: [46] A triangular fuzzy number $\tilde{n} = [k_1, l_1, m_1]$ is a special fuzzy set on the real number set \mathbb{R} , whose membership function is defined as follows

$$\mu_{\tilde{n}}(a) = \begin{cases} (a-k_1)/(l_1-k_1), & \text{if } (k_1 \leq a < l_1) \\ 1, & \text{if } (a = l_1) \\ (m_1-a)/(m_1-l_1), & \text{if } (l_1 < a \leq m_1) \\ 0, & \text{if otherwise} \end{cases}$$

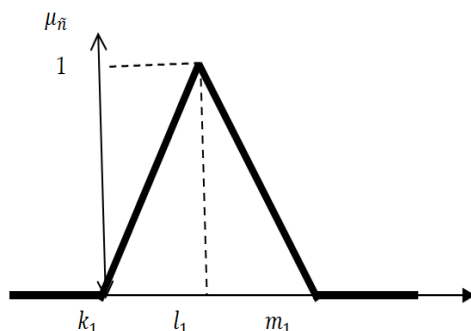


Figure 1. $\tilde{n} = [k_1, l_1, m_1]$ triangular fuzzy membership function [46]

3. Classical Method

3.1 Research problem

This study employed a Likert-type scale to measure teachers' critical thinking skills in terms of the types of schools they work in, and the data were examined through fuzzy logic to obtain the teachers' critical thinking skills, and these findings were compared those of classical logic. Hence, answers to the following sub-problems were sought;

1. What are the teachers' critical thinking skill levels across the types of schools in terms of classical logic approach?
2. What are the teachers' critical thinking skill levels across the types of schools in terms of fuzzy logic approach?

3. Is there a significant difference between the teachers' critical thinking skill scores in terms of fuzzy and classical logic approaches?

3.2 Working Group

The working group held 275 teachers working in public schools in the central districts of Antalya during the 2021-2022 academic year. The maximum variation sampling and convenience sampling/criterion sampling techniques chose the participants.

Among the participants, 144 (52.4%) are females and 131 (47.6%) were males. 195 (70.6%) of the participants have a bachelor's degree, 76 (27.6%) a master's degree and 3 (1.1%) doctorate degree. The teaching experience of the participants range from 1 to 38 years, with an average of 15 years. The age distribution is between 22 and 62 with an average of 40.

Table 1: Information regarding school types

Variables	Sub-groups	N	%
School type	HL ₁ -Private High School	29	10.5
	HL ₂ -Science High School	67	24.3
	HL ₃ -Anatolian Religious High School	34	12.4
	HL ₄ -Thematic High School	33	12
	HL ₅ -Project Vocational High School	23	8.4
	HL ₆ -Vocational and Technical Anatolian High School	37	13.5
	HL ₇ -Multi-Program Vocational and Technical Anatolian High School	22	8.0
	HL ₈ -Anatolian High School	30	10.9

29 of the teachers work at private high schools, 67 at science high schools, 34 at Anatolian religious high school, 33 at thematic high schools, 23 at project vocational high schools, 37 at vocational and technical Anatolian high schools, 22 at multi-program vocational and technical Anatolian high schools and 30 at Anatolian high schools. (Table 1).

3.3 Classical Findings

Table 2 displays the evaluation results on teachers' critical thinking skills through using the classical survey method in terms of eight different types of schools.

Table 2: Result of Classical Survey

	Mean (out of 5)	Mean (out of 100)
IL ₁	,83	6,67
IL ₂	,9	8
IL ₃	,86	7,24
IL ₄	,96	9,22
IL ₅	,85	7,07
IL ₆	,97	9,46
L ₇	,98	9,67
IL ₈	,99	9,86

Table 2 depicts that HL₁ (Private High School) had the lowest mean value ($\bar{X} = 3,83$), and HL₈ (Anatolian High School) had the highest mean value ($\bar{X} = 3,99$) in terms of the teachers' critical thinking skills. The values related to teachers' critical thinking skills across eight different school types were identified from the highest to the lowest as HL₈ ($\bar{X} = 3,99$), HL₇ ($\bar{X} = 3,98$), HL₆ ($\bar{X} = 3,97$), HL₄ ($\bar{X} = 3,96$), HL₂ ($\bar{X} = 3,9$), HL₃ ($\bar{X} = 3,86$), HL₅ ($\bar{X} = 3,85$) and HL₁ ($\bar{X} = 3,83$).

4. Fuzzy Method

This section presents basic information in relation to fuzzy matlab applications. Besides, new artificial intelligence applications were offered through using the fuzzy matlab to measure teachers' critical thinking skills in terms of the types of schools they work in.

4.1 Fuzzy Matlab Application

In the fuzzy matlab application, the process is shown in Figure 2.

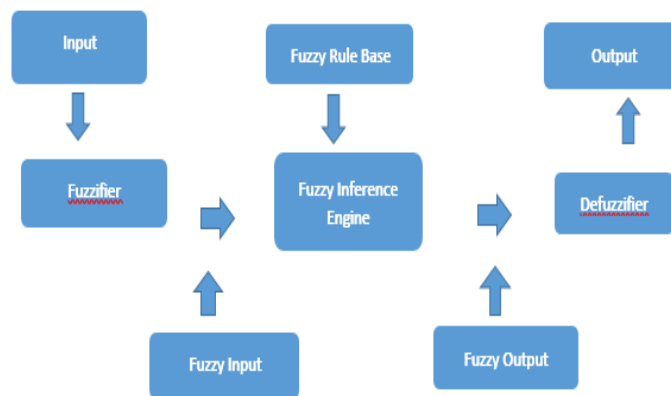


Figure 2. Fuzzy Matlab Algorithm

We present the fuzzy Logic Designer in Figure 3.

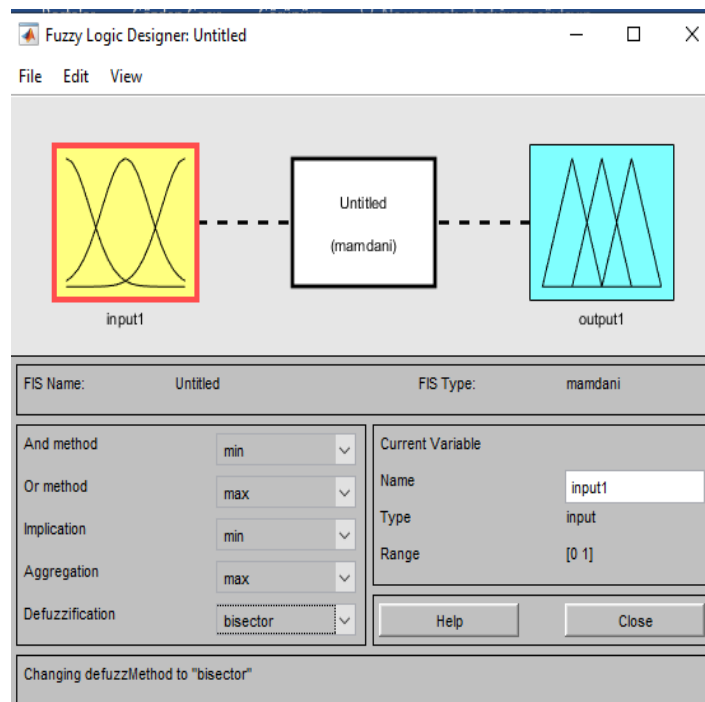


Figure 3. Fuzzy Logic Designer

We suggest the inputs for this application in Table 3 and Figure 4 (inputs at Fuzzy Matlab Applications).

Table 3: Inputs for this fuzzy matlab application

Input	Abbreviation
Evidence Based Decision Making	EBDM
Openness to Causality	OTC
Self-Regulation	SR
Inference Making Ability	IMA
Willingness to gather Information	WTGI

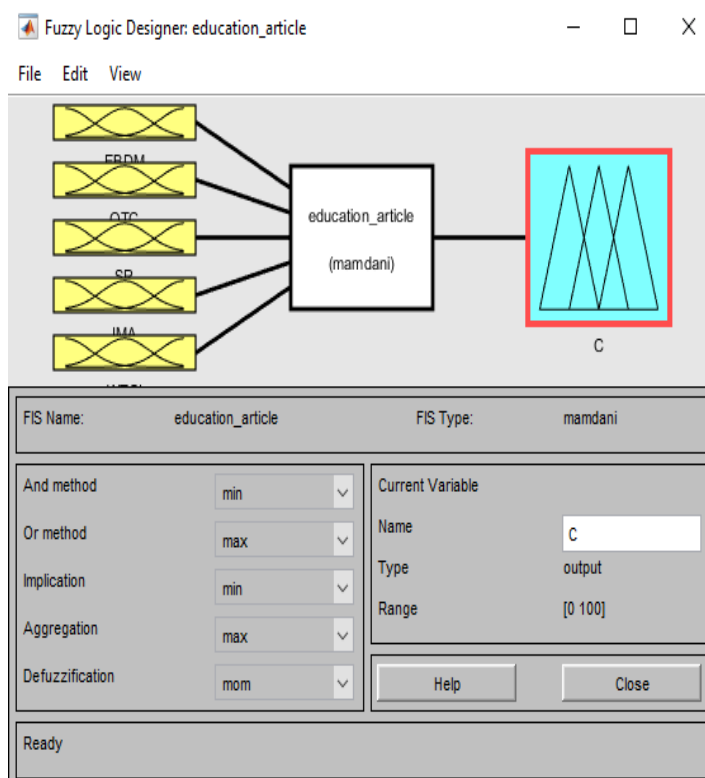


Figure 4. Inputs for Fuzzy Matlab Algorithm

The fuzzy membership functions of these inputs and the representation of these functions as fuzzy numbers were summarized in Table 4, Table 5, Table 6, Table 7, Table 8 and Figure 5, Figure 6, Figure 7, Figure 8, Figure 9 (triangular fuzzy numbers at Fuzzy Matlab Applications).

In this section, we use the triangular fuzzy numbers as fuzzy number.

Table 4: Fuzzy Membership Functions of input EBDM

Fuzzy Membership Functions	Abbreviation	Fuzzy Number
Little	L	[0, 0, 40]
Medium	M	[15, 50, 85]
High	H	[65, 100, 100]

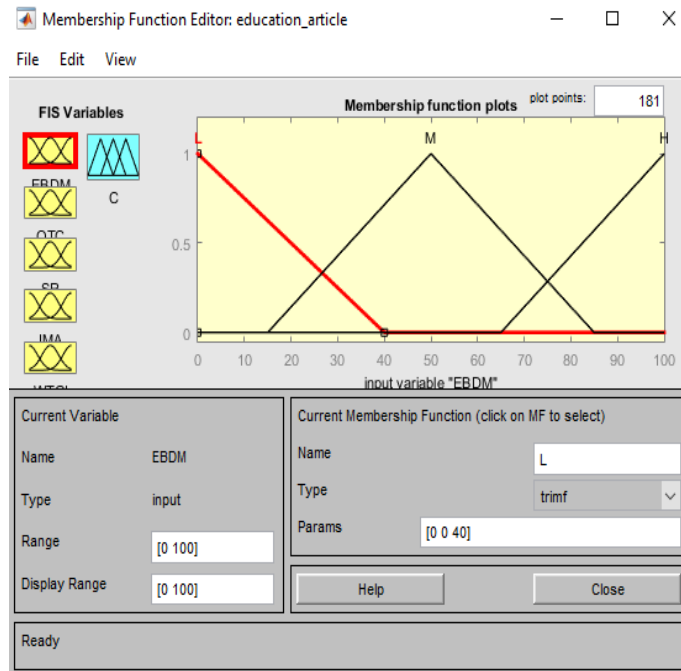


Figure 5. Fuzzy Membership Functions of input EBDM

Table 5: Fuzzy Membership Functions of input OTC

Fuzzy Membership Functions	Abbreviation	Fuzzy Number
Little	L	[0, 0, 40]
Medium	M	[15, 50, 85]
High	H	[65, 100, 100]

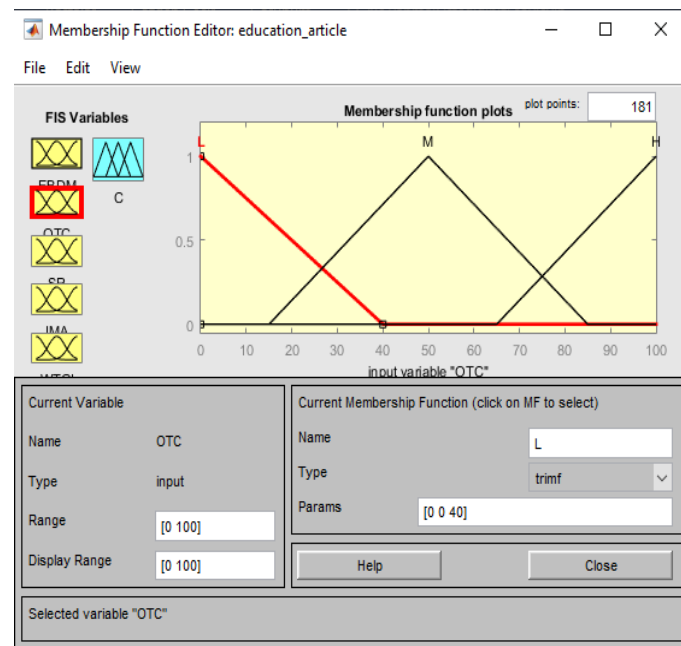


Figure 6. Fuzzy Membership Functions of input OTC

Table 6: Fuzzy Membership Functions of input SR

Fuzzy Membership Functions	Abbreviation	Fuzzy Number
Little	L	[0, 0, 40]
Medium	M	[15, 50, 85]
High	H	[65, 100, 100]

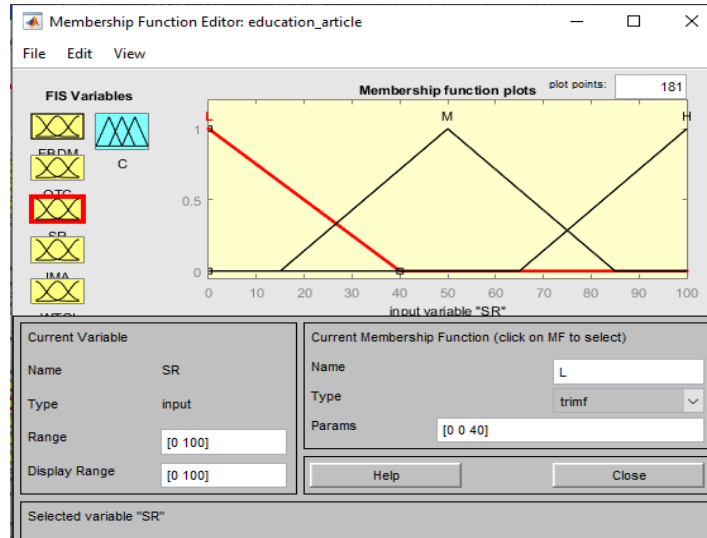


Figure 7. Fuzzy Membership Functions of input SR

Table 7: Fuzzy Membership Functions of input IMA

Fuzzy Membership Functions	Abbreviation	Fuzzy Number
Little	L	[0, 0, 40]
Medium	M	[15, 50, 85]
High	H	[65, 100, 100]

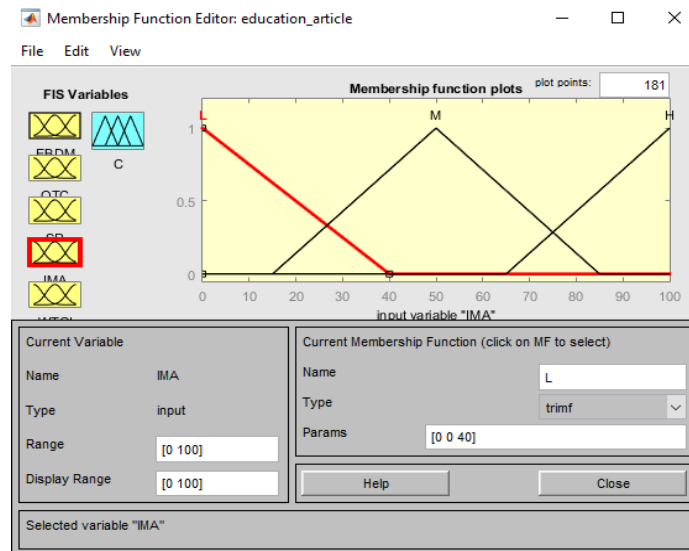


Figure 8. Fuzzy Membership Functions of input IWA

Table 8: Fuzzy Membership Functions of input WTGI

Fuzzy Membership Functions	Abbreviation	Fuzzy Number
Little	L	[0, 0, 40]
Medium	M	[15, 50, 85]
High	H	[65, 100, 100]

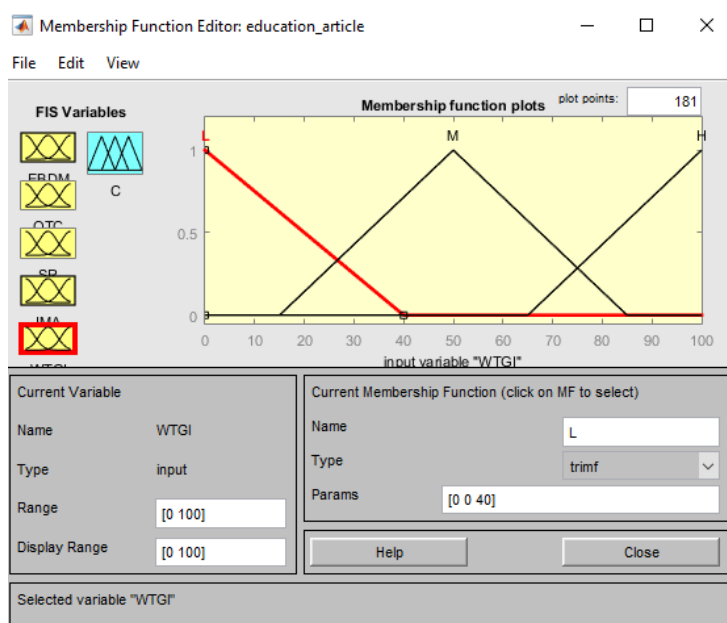


Figure 9. Fuzzy Membership Functions of input WTGI

Table 9 signifies the output for this fuzzy matlab application.

Table 9: Output for this fuzzy matlab application

Output	Abbreviation
Conclusion	C

The triangular fuzzy membership functions of this output were depicted in Table 10 and in Figure 10.

Table 10. Fuzzy Membership Functions of Output S

Fuzzy Membership Functions	Abbreviation	Fuzzy Number
Little	L	[0, 0, 40]
Medium	M	[15, 50, 85]
High	H	[65, 100, 100]

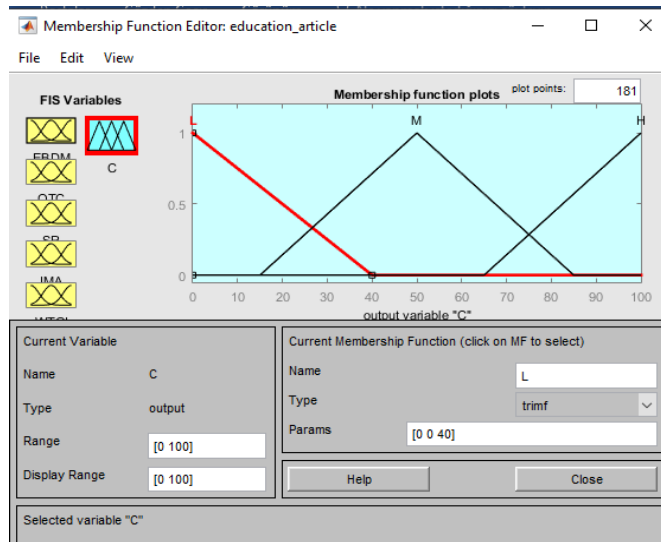


Figure 10. Fuzzy Membership Functions of output C

As in Figure 11, we obtain 243 rules for fuzzy matlab application.

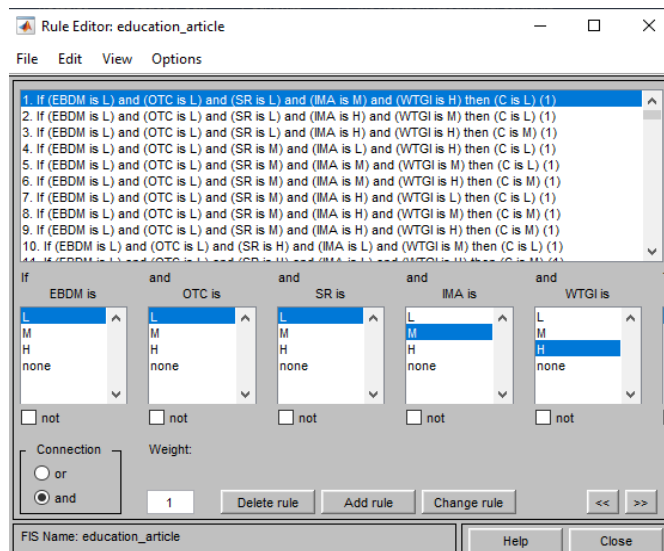


Figure 11. Fuzzy Rules in Fuzzy Matlab Application

The results with fuzzy matlab rules at Fuzzy Matlab Application were shown in Figure 12.

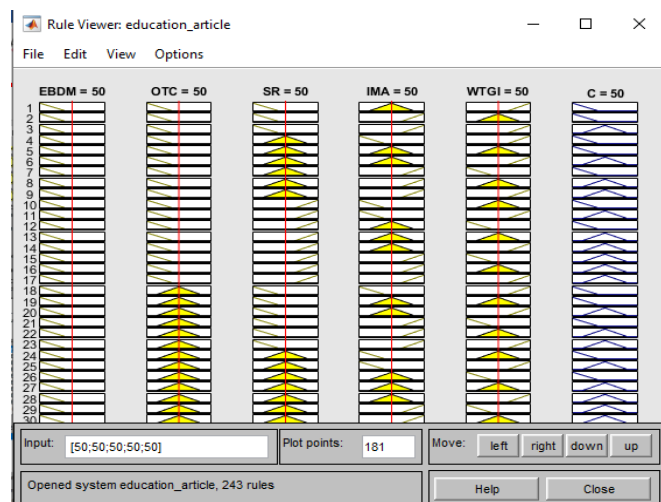


Figure 12. Results with Fuzzy Matlab Rules

4.1 Fuzzy Findings

Table 11 indicates the teachers' critical thinking skill levels in terms of the type of school they work in through using the mean size of the data obtained from the fuzzy survey. In addition, Table 11 also covers the results for the fuzzy matlab application.

Table 11: Results for Fuzzy Survey

School type	Mean (out of 5)	Mean (out of 100)
HL ₁	4,28	86,6
HL ₂	3.61	72.2
HL ₃	3,50	70
HL ₄	4,50	90
HL ₅	2,50	50
HL ₆	4,31	86.1
HL ₇	4,31	86.1
HL ₈	4,17	83.3

Table 11 demonstrates the results on teachers' critical thinking skills in terms of eight different types of schools. Specifically, teachers' fuzzy matlab results suggested the teachers' critical thinking skill levels in terms of school types. Accordingly, HL5 ($\bar{X} = 2.50$) (Project Vocational High School) had the lowest mean value, while HL4 had the highest ($\bar{X} = 4.50$) (HL4=Thematic High School) regarding the teachers' critical thinking skills. The values related to the teachers' critical thinking skills in terms of eight different school types were ranked from the highest to lowest as HL4 ($\bar{X} = 4.50$), H6=H7 ($\bar{X} = 4.31$), HL1 ($\bar{X} = 4.28$), HL8 ($\bar{X} = 4.17$), HL2 ($\bar{X} = 3.61$), HL3 ($\bar{X} = 3.50$) and HL5 ($\bar{X} = 2.50$).

5. Data Analysis

Data analysis was carried out in two stages. In the first stage, the data obtained from the teachers' critical thinking skill scale were analyzed through classical logic. Validity (explanatory and confirmatory factor analysis) and reliability analyzes (Cronbach Alpha) were also performed during data analysis.

In the second stage, the data obtained from the teachers' critical thinking skills scale were analyzed through the fuzzy logic approach. Matlab fuzzy logic module was used for the fuzzy logic approach. A structure with five entrances and one exit was designed. Triangle membership function was used as the membership function and centroid method as the defuzzification method. Table 12 suggests a comparison of the data regarding the classical logic and those from the fuzzy logic.

6. Comparison Method

This study designed a fuzzy logic-based system by using the Fuzzy Logic Toolbox in the Matlab program to evaluate teachers' critical thinking skills in terms of the types of schools they work in. The study deployed Mamdani type fuzzy inference model and found a sharp output value obtained after the defuzzification process. The output value was determined as the teacher's critical thinking skill score. More than one system trial was made and the most appropriate one was selected

Table 12: Comparison of Classical Survey and Fuzzy Survey

	Classical Survey Mean	Fuzzy Survey Mean
HL ₁	3,83	4,28
HL ₂	3,9	3,61
HL ₃	3,86	3,50
HL ₄	3,96	4,50
HL ₅	3,85	2,50
HL ₆	3,97	4,31
SL ₇	3,98	4,31
HL ₈	3,99	4,17

When we compare the classical survey results presented in Table 2 with the fuzzy survey results in Table 11, we get those shown in Table 12 and Table 13.

Table 13: Comparison of Classical Survey and Fuzzy Survey Results

Survey Type	Rank of Critical Thinking Skills of Teachers'
Classical Survey	HL ₈ , HL ₇ , HL ₆ , HL ₄ , HL ₂ , HL ₃ , HL ₅ , HL ₁
Fuzzy Survey	HL ₄ , HL ₁ , HL ₆ = HL ₇ , HL ₈ , HL ₂ , HL ₃ , HL ₅

Table 12 and Table 13 show that critical thinking skills of teachers working in Anatolian high schools ranked first in the classical survey, while the fourth according to the evaluation made through the fuzzy survey. Likewise, the data regarding the classical survey revealed that the critical thinking skills of teachers working in private high schools ranked last, while they ranked second in the evaluation with the fuzzy survey. Critical thinking skills of teachers working in thematic high schools ranked fourth in the evaluation with a classical survey and first with a fuzzy survey. As seen, the results differ across the classical survey and the fuzzy survey.

7. Conclusion

This study explored the mean value of teachers' critical thinking skills in terms of the types of schools through using the fuzzy MATLAB application and averaging the dimensions of the data obtained from the fuzzy survey. Since fuzzy survey and fuzzy MATLAB provide a more comprehensive and objective evaluation, the fuzzy survey result is more consistent than the classical survey. The items are ranked on strongly agree, disagree, somewhat agree, disagree, and strongly disagree for the classic survey, while the fuzzy survey requires an evaluation between 0 and 100. The classical survey evaluates in 5 categories, while the fuzzy survey evaluates in 100 categories. For instance; the classical survey welcomes the range of 4.20-5.00 as strongly agree, the fuzzy survey and fuzzy MATLAB have a separate membership value for each real number in the range of 4.20-5.00. Namely, the fuzzy questionnaire considers each value as a different category instead of adding some values to a category. Therefore, it may be wise to mention that the result obtained from the fuzzy survey is more acceptable and realistic compared to that of of the classical survey. In this regard, the results on a fuzzy survey suggested that the critical thinking skills of teachers working in thematic high schools were ranked first, those working in private high schools ranked second, and those in multi-program and general vocational and technical Anatolian high schools ranked third. Teachers working in vocational and technical high schools were among the first three. In other words, the critical thinking skills of teachers working in vocational and technical high schools were higher than those of teachers working in other schools.

Heyman and Daly [47] and Ovdiiichuk [48] affirmed that vocational teachers need various strategies to prepare students for today's complex and globalized business environment (today's workplace), and thus critical thinking is an indispensable skill for them. Therefore, they should constantly improve their own critical thinking skills to teach these skills effectively [48]. Some studies [49-50] demonstrated that vocational and technical teachers' critical thinking is of critical importance for students to become competent professionals. Pithers [51] found that vocational and technical teachers had average critical thinking skills in terms of the critical reasoning test.

This study proved that the vocational and technical teachers' critical thinking skills were higher than those working in other schools were. This paves the way for the fact that vocational and technical teachers' work-oriented style by doing and experiencing makes them more proactive and positively affects their problem-solving competencies. Because vocational and technical high schools in Turkey consist of vocational and technical high schools that implement various programs (focusing on a profession, multi-program, accepting with an exam, etc.). To exemplify, a thematic high school is a Vocational and Technical Anatolian High School that implements programs in a specific vocational field (e.g. aircraft maintenance and technologies, etc.) and in at most three complementary branches. Multi-program vocational and technical Anatolian high schools are formed by the combination of more than one school program in one school. Multi-program high schools implement: a) Programs that prepare for higher education, b) Programs that prepare for both profession and higher education, c) Programs that prepare for life and business. The cognitive competencies of teachers working in vocational and technical schools in Turkey may also be affected in line with the objectives of the schools.

This study compared teachers' critical thinking skills in terms of the school types they work in. Another study may compare teachers through the fuzzy MATLAB application in different dimensions. Three different triangular fuzzy membership functions were used for each dimension in the fuzzy MATLAB application, and five for the outputs. As the number of these triangular fuzzy membership functions increases, results that are more precise may emerge. Besides, triangular fuzzy membership function was used for inputs and outputs in fuzzy MATLAB application. Researchers may obtain more results that are objective by conducting studies based on fuzzy logic-based survey. Researchers can also use other membership functions appropriate for their problems (trapezoidal fuzzy membership function, Gaussian fuzzy membership function, etc.). In addition, centering was performed with the Mandami method in the fuzzy MATLAB application. Researchers may also employ other centering processes appropriate to their problem (medium, mom, lom, etc.) or Sugeno management if appropriate. Moreover, the validity and reliability analyzes made with classical methods may be conducted with the fuzzy logic method. These new results may be compared with those of the classical method. Thus, the objectivity of validity and reliability analyzes may be reviewed.

Funding: “This research received no external funding”

Conflicts of Interest: “The authors declare no conflict of interest.”

References

- [1] C. Cortázar, M. Nussbaum, J. Harcha, D. Alvares, F. López, J. Goñi, and V. Cabezas, “Promoting critical thinking in an online, project-based course,” *Computers in Human Behavior*, vol. 119, pp. 1–18, 2021. doi: 10.1016/j.chb.2021.106705.
- [2] D. F. Halpern, *Thought and Knowledge*, Psychology Press, 2014.
- [3] S. D. Schaferman, “An introduction to critical thinking,” 1991. [Online]. Available: <https://facultycenter.ischool.syr.edu/wp-content/uploads/2012/02/Critical-Thinking.pdf>
- [4] B. Rott and T. Leuders, “Mathematical competencies in higher education: Epistemological beliefs and critical thinking in different strands of pre-service teacher education,” *Journal for Educational Research Online*, vol. 9, no. 2, pp. 115–136, 2017.
- [5] N. El Soufi and B. H. See, “Does explicit teaching of critical thinking improve critical thinking skills of English language learners in higher education? A critical review of causal evidence,” *Studies in Educational Evaluation*, vol. 60, pp. 149–162, 2019. doi: 10.1016/j.stueduc.2018.12.006.
- [6] I. Y. Subbotin and M. G. Voskoglou, “An application of the generalized rectangular fuzzy model to critical thinking assessment,” 2016. [Online]. Available: <https://arxiv.org/ftp/arxiv/papers/1601/1601.03065.pdf>
- [7] L. M. Marin and D. F. Halpern, “Pedagogy for developing critical thinking in adolescents: Explicit instruction produces greatest gains,” *Thinking Skills and Creativity*, vol. 6, pp. 1–13, 2011. doi: 10.1016/j.tsc.2010.08.002.
- [8] G. Pépiot, N. Cheikhrouhou, J.-M. Fürbringer, and R. Glardon, “A fuzzy approach for the evaluation of competences,” *Science Direct*, pp. 336–353, 2008.
- [9] S. Djenadic, M. Tanasijevic, P. Jovancic, D. Ignjatovic, D. Petrovic, and U. Bugaric, “Risk evaluation: Brief review and innovation model based on fuzzy logic and MCDM,” *Mathematics*, vol. 10, no. 811, pp. 1–26, 2022. doi: 10.3390/math10050811.
- [10] F. A. D’Alessio, B. E. Avolio, and V. Charlesa, “Studying the impact of critical thinking on the academic performance of executive MBA students,” *Thinking Skills and Creativity*, vol. 31, pp. 275–283, 2019. doi: 10.1016/j.tsc.2019.02.002.

- [11] G. Bassham, W. Irwin, H. Nardone, and J. M. Wallace, *Critical Thinking: A Student's Introduction*, 5th ed., McGraw Hill, 2011.
- [12] R. H. Bruning, G. J. Schraw, and M. M. Norby, *Bilişsel Psikoloji ve Öğretim*, Z. N. Ersözülü and R. Ülker, Eds., Nobel, 2014.
- [13] P. Facione, "Critical thinking: What it is and why it counts," *Insight Assessment*, 2007.
- [14] E. Sönmez, E. Kabataş Memiş, and Z. Yerlikaya, "The effect of practices based on argumentation-based inquiry approach on teacher candidates' critical thinking," *Educational Studies*, vol. 47, no. 1, pp. 59–83, 2021. doi: 10.1080/03055698.2019.1654364.
- [15] M. Caceres, M. Nussbaum, and J. Ortiz, "Integrating critical thinking into the classroom: A teacher's perspective," *Thinking Skills and Creativity*, vol. 37, pp. 1–18, 2020. doi: 10.1016/j.tsc.2020.100674.
- [16] F. Aryani, M. Rais, and H. Wirawan, "Reflective learning model in improving student critical thinking skills," *Global Journal of Engineering Education*, vol. 19, no. 1, pp. 19–23, 2017.
- [17] M. B. Burgoyne and K. Chuppa-Cornell, "If I tried this idea again: Developing faculty professional growth through reflective practice," *Reflective Practice*, vol. 19, no. 6, pp. 818–831, 2018.
- [18] A. Olga, V. Zinaida, M. Fedotova, and M. Smirnova, "Critical thinking and teacher training development," *Revista Espaciosa*, vol. 41, no. 9, pp. 1–8, 2020.
- [19] R. Paul and L. Elder, "Critical thinking: The nuts and bolts of education," *Optometric Education*, vol. 33, pp. 88–91, 2008.
- [20] R. L. Williams, "Targeting critical thinking within teacher education: The potential impact on society," *The Teacher Educator*, vol. 40, no. 3, pp. 163–187, 2005. doi: 10.1080/08878730509555359.
- [21] P. Andreucci-Annunziata, A. Riedemann, S. Cortés, A. Mellado, M. T. del Río, and A. Vega-Muñoz, "Conceptualizations and instructional strategies on critical thinking in higher education: A systematic review of systematic reviews," *Frontiers in Education*, vol. 8, 2023.
- [22] L. Pretorius, G. P. Van Mourik, and C. Barratt, "Student choice and higher-order thinking: Using a novel flexible assessment regime combined with critical thinking activities to encourage the development of higher order thinking," *International Journal of Teaching and Learning in Higher Education*, vol. 29, no. 2, pp. 389–401, 2017.
- [23] P. Stapleton, "A survey of attitudes towards critical thinking among Hong Kong secondary school teachers: Implications for policy change," *Thinking Skills and Creativity*, vol. 6, pp. 14–23, 2011.
- [24] L. Elder and R. Paul, "Critical thinking: Why we must transform our teaching," *Journal of Developmental Education*, vol. 18, no. 1, pp. 34–35, 1994.
- [25] T. Ecevit and F. Kaptan, "The efficiency of argument-based inquiry practices in science teacher candidate education," *Journal of Theoretical Educational Science*, vol. 15, no. 4, pp. 721–757, 2022.
- [26] M. M. Grosser and B. J. J. Lombard, "The Relationship between culture and the development of critical thinking abilities of prospective teachers," *Teaching and Teacher Education*, vol. 24, no. 5, pp. 1364–1375, 2008, doi: 10.1016/j.tate.2007.10.001.
- [27] C. M. Mowling and S. K. Sims, "The metacognition journey: Strategies for teacher candidate exploration of self and student metacognition," *Strategies*, vol. 34, no. 2, pp. 13–23, 2021, doi: 10.1080/08924562.2020.1867268.
- [28] C. Pena and I. Almaguer, "The use of online discussions to foster critical thinking in a Teacher Education Program," *International Journal of Instructional Media*, vol. 39, no. 1, pp. 25–33, 2012.
- [29] D. L. Schussler and L. Bercaw, "Peering through a Looking Glass: Deconstructing Teacher Candidate Assumptions Using Dispositions," *The Teacher Educator*, vol. 57, no. 2, pp. 113–135, 2022, doi: 10.1080/08878730.2021.1946228.
- [30] H. Zhang, R. Yuan, and X. He, "Investigating university EFL teachers' perceptions of critical thinking and its teaching: Voices from China," *Asia-Pacific Education Research*, vol. 29, no. 5, pp. 483–493, 2020, doi: 10.1007/s40299-020-00500-6.
- [31] R. Kumar and R. James, "Evaluation of critical thinking in higher education in Oman," *International Journal of Higher Education*, vol. 4, no. 3, pp. 33–43, 2015.

- [32] M. Lloyd and N. Bahr, "Thinking critically about critical thinking in higher education," *International Journal for the Scholarship of Teaching and Learning*, vol. 4, no. 2, pp. 1-18, 2010.
- [33] L. Ma and N. Liu, "Teacher belief about integrating critical thinking in English teaching in China," *Journal of Education for Teaching*, 2022. [Online]. Available: <https://www.tandfonline.com/doi/epdf/10.1080/02607476.2022.2044267?needAccess=true&role=button>
- [34] J. Ro, "Critical thinking in the national curriculum and teacher education in South Korea: a missing link," *Teachers and Teaching*, 2023. [Online]. Available: <https://www.tandfonline.com/doi/pdf/10.1080/13540602.2023.2172393>
- [35] T. Sugiarti, I. Kaniawati, and L. Aviyanti, "Development of assessment instrument of critical thinking in Physics at Senior High School," *Journal of Physics: Conference Series*, vol. 812, no. 1, pp. 012-018, 2017.
- [36] L. Zadeh, "Fuzzy Sets," *Inform and Control*, vol. 8, pp. 338-353, 1965.
- [37] A. Emniyet and M. F. Şahin, "Fuzzy normed rings," *Symmetry*, vol. 10, no. 10, p. 515, 2018.
- [38] N. Okumuş, "Sürdürülebilir Kalkınma Kapsamında Türkiye'de Çevre Ekonomisine Yönelik Yapılan Harcamaların Değerlendirilmesine Yönelik Yeni Bir Yaklaşım," *Gaziantep Üniversitesi Sosyal Bilimler Dergisi*, vol. 24, no. 1, pp. 242-251, 2025.
- [39] V. Uluçay and M. Şahin, "Intuitionistic fuzzy soft expert graphs with application," *Uncertainty Discourse and Applications*, vol. 1, no. 1, pp. 1-10, 2024.
- [40] T. M. Al-shami and A. Mhemdi, "Generalized frame for orthopair fuzzy sets: (m, n)-Fuzzy sets and their applications to multi-criteria decision-making methods," *Information*, vol. 14, no. 1, p. 56, 2023.
- [41] Y. S. Özgelçi, *Factors affecting critical thinking attitude: A study on classroom teacher candidates* (Doctoral thesis), Adnan Menderes University Social Sciences Institute, Aydın, Turkey, 2012.
- [42] D. Kaplan, "Statistical power in structural equation modeling," in *Structural Equation Modeling: Concepts, Issues and Applications*, H. R. Hoyle, Ed. London: Sage Publications, 1995, pp. 100-117.
- [43] B. M. Byrne and T. L. Campbell, "Cross-cultural comparisons and the presumption of equivalent measurement and theoretical structure: A look beneath the surface," *Journal of Cross-Cultural Psychology*, vol. 30, no. 5, pp. 555-574, 1999.
- [44] P. M. Bentler, "Multivariate analysis with latent variables: Causal modeling," *Annual Review of Psychology*, vol. 31, no. 1, pp. 419-456, 1980.
- [45] K. Schermelleh-Engel, H. Moosbrugger, and H. Müller, "Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures," *Methods of Psychological Research Online*, vol. 8, no. 2, pp. 23-74, 2003.
- [46] D. Dubois and H. Prade, *Fuzzy sets and systems: Theory and applications*. Academic Press, 1980.
- [47] G. A. Heyman and E. R. Daly, "Teaching critical thinking in vocational-technical and occupational classes," *New Directions for Community Colleges*, vol. 77, pp. 103-108, 1992.
- [48] V. Ovdiiichuk, "Critical thinking of IT teachers as important component of their professional competence," *Scientific Journal of Polonia University*, vol. 45, no. 2, pp. 105-113, 2021.
- [49] M. J. Bezanilla, H. Galindo-Domínguez, and M. Poblete, "Importance of teaching critical thinking in higher education and existing difficulties according to teachers' views," *Multidisciplinary Journal of Educational Research*, vol. 11, no. 1, pp. 20-48, 2021, doi: 10.4471/remie.2021.6159.
- [50] M. Krüger, "Design Thinking for German vocational schools? Discovering an innovative approach by testing in teacher education," *Open Education Studies*, vol. 1, no. 1, pp. 209-219, 2019, doi: 10.1515/edu-2019-0015.
- [51] R. Pithers, "Vocational teachers' critical thinking skills," *Australian and New Zealand Journal of Vocational Education Research*, vol. 6, no. 1, pp. 86-99, 1998.