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Prediction of students' perceptions of problem solving skills with a neuro-fuzzy model and hierarchical regression method: A quantitative study

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Abstract

Traditionally, students' various educational characteristics are evaluated according to the grades they get or the results of their answers to the scales. There are some limitations in making an evaluation based on the results. The fuzzy logic approach, which tries to eliminate these limitations, has recently been used in the field of education. While applying the fuzzy logic method to education, students' qualifications are determined qualitatively without using formulas in calculating student performance. However, fuzzy systems lack learning abilities. By combining fuzzy rules and neural networks, the evaluation tool will have greater adaptability to changing conditions. Thus, an educationally robust and easy-to-use assessment tool will be obtained. In this study, in the first stage, students' perceptions of problem solving skills, which is one of their educational characteristics, were modeled with the ANFIS approach, which is one of the neuro-fuzzy systems apart from traditional methods, through creative problem solving features. ANFIS is an adaptive network that allows neural network topology to be combined with fuzzy logic. It not only incorporates the benefits of both strategies but also eliminates some of their drawbacks when used alone. The inputs of the research were determined as students' creative problem-solving characteristics and the output was their perceptions of problem-solving skills. As a second step, statistical methods (correlation and hierarchical regression) were used to examine whether there was a relationship between students' PoPS skills and CPS characteristics. Afterwards, students' artificial PoPS skill scores obtained with ANFIS in the first step and real PoPS skill scores obtained from their answers to the scale were compared. 360 students from Turkey took part in the study. Depending on the findings of the study, real PoPS scores and artificial ANFIS PoPS scores do not statistically differ significantly. Therefore, the ANFIS results based on creative problem solving features accurately predict students' PoPS scores. Additionally, there is a clear relationship between PoPS talents and CPS features. One of the study's most startling conclusions is that the environment, which is accepted as one of the components affecting creative problem solving in this

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research, predicts students' perceptions of problem solving skills. These results also prove that the variable of creative problem solving characteristics, which is used to predict students' perceptions of problem solving, is an appropriate variable. It is possible to create the ANFIS system employed in this study utilizing a variety of fuzzy functions and other neuro/fuzzy techniques, and the systems can be compared with each other.

Keywords Neuro-fuzzy systems · ANFIS, creative problem solving features · Perception towards problem solving skills · Hierarchical regression · Middle school students

1 Introduction

Kay (2010) listed the basic twenty-first century skills that today's students should develop as critical thinking, innovation, cooperation, and communication. The creativity and problem solving skills handled in the present research are also twenty-first century abilities (Yildiz & Yildiz, 2021). A problem is a goal that has been attempted to be achieved and an idea that requires a solution (Schunk, 2004). At the point of finding a solution, the problem solving process is involved (Van Hooijdonk et al., 2020). Creativity emerges when there are original and appropriate ideas that are in the problem solving process, especially where problem solutions are not easily reached (Kaufman & Sternberg, 2007; Runco & Jaeger, 2012). Different scholars have characterized creativity in various ways (Simonton, 2012; Weisberg, 2015). The most widely used definition of creativity states that it entails the development of original, excellent, and appealing solutions to a particular issue (Corazza, 2016; Mumford & Gustafson, 2007). In this definition, creativity is considered as a kind of problem-solving ability (Mumford et al., 2012; Sternberg, 2006). Creative thinking in problem solving or creative problem solving (CPS) can be considered not only as a process that people use in daily life problems and difficulties but also as opportunities they encounter (Baran-Bulut et al., 2018). In this context, Lumsdaine and Lumsdaine (1995) consider CPS, which has different definitions in the literature, as a combination of creative thinking, critical-analytical thinking, and other high-level thinking skills. It's critical to remember that, CPS is distinguished from general problem solving because creative thinking often occurs in reaction to an ill-defined problem (Brophy, 1998). Cho (2003), who considers the CPS process as a skill in itself, states that there is a dynamic interaction between the components that make up this skill to solve the problem. Thus, problem solving skills and creativity are related (Isaksen & Treffinger, 2004; Kaufman & Sternberg, 2007). Houtz (1994) argues that there are similarities between the creativity process and the problem solving process. He explains the reason for this as the fact that creativity is mostly used in the solution processes of open-ended and not fully defined problems. When one solves a problem in a way that leads to a novel and useful outcome, creativity is exhibited (Runscio & Amabile, 1999). Some researchers state that the creativity process actually involves the entire problem solving process, from problem identification to plan execution (Titus, 2000). Children need creative thinking skills as they explore new techniques and solutions to problems (Özdemir & Dikici, 2017). Middle school, in particular, is the fastest stage of a student's imagination and cognitive development. Since knowledge and experience are crucial conditions for the development of creativity, middle school students have acquired certain knowledge and accumulated certain experiences throughout this period. Furthermore, middle school students have a high level of creativity, are energetic, great observers, have a strong memory, are intelligent, imaginative, brave in their explorations, innovative, adventurous, and thirst for truth (Gong, 2020). In addition, students' attitudes towards different thinking, creativity, active learning and exploration are a result of their CPS characteristics (Kashani-Vahid et al., 2017; Saxon et al., 2003). As the perception of problem solving (PoPS) skill is a person's belief or judgment regarding his/her performance in the problem solving process (Kaplan et al., 2016), the characteristics of CPS are important in the problem solving process (Schoevers et al., 2019), middle school may be where these qualities and skills intersect because their constituent parts are likely to be similar. Because creative problem solving (CPS) process as a skill in itself is a dynamic interaction between the components that make up this skill to solve a problem. However, the issue of whether there is a connection between students' CPS characteristics and their perceptions of problem solving (PoPS) skills has not sufficiently been examined in academic studies yet. Lin and Cho (2011) indicated that divergent thinking and domain-specific knowledge and skills were found to be direct predictors of mathematics problem solving skills, whereas motivation, convergent thinking, environment, and general knowledge and skills were found to be indirect predictors. The above information in the literature supports a possible relationship between the two variables. Based on this information, in this study, it was investigated whether there is a relationship between students' PoPS skills and CPS characteristics and whether CPS features predict their PoPS skills. At this stage, analyzes were carried out with correlation and hierarchical regression, which are classical statistical methods. On the other hand, although there is a certain level of estimation with hierarchical regression, in this study, the PoPS skills of the students were predicted with the ANFIS approach, one of the artificial intelligence methods, by going a little further than the analysis with statistical methods. At the last stage of the study, the real data of the students obtained by statistical methods and the artificial data obtained by ANFIS were compared.

It is very difficult for teachers who deal with many students in the education-teaching process to search their data and identify the weak or strong points of the students, but various artificial intelligence techniques (e.g. data mining, artificial neural networks, fuzzy logic, machine learning) make this easy and interesting without the direct involvement of teachers. Incorporating the adaptive neuro fuzzy inference system into assessment-evaluation processes in education encourages teachers and administrators to focus on innovation and can increase quality, skill, satisfaction and productivity in educational institutions (Daneshvar et al., 2021). The main objective of this system is to create a suitable system to encourage schools to enhance their performance in teaching and learning. The system is an effective tool for assessing students and giving important feedback on their areas of strength and weakness to enhance their performance. With the help of an adaptive neuro-fuzzy inference system (ANFIS), this research seeks to build a model that predicts students' PoPS skill scores as a measure of their assessments of their problem-solving abilities. The ANFIS system proposed in this research was developed based on 5 sub-factors (divergent thinking, convergent thinking, motivation, environment, and general knowledge and skills) under 1 input (CPS features) and 1 output (PoPS skills). The first purpose of the model is to guide students by determining their own perceptions of problem solving skills, which are considered among the twenty-first century skills. Secondly, it is to incorporate creative problem-solving features to explain differences in PoPS skills scores to improve students' perceptions of problem-solving skills.

This research will contribute to the increase in the number of artificial intelligence applications in the field of education, an evaluation will be made with ANFIS, and the real data will be compared with the artificial data. A limited number of research use ANFIS to make predictions, especially regarding educational features. An intelligent adaptive neuro fuzzy inference system (ANFIS) was modeled by Daneshvar et al. (2021) to evaluate the performance of instructors in e-learning systems, notably in academic institutions. This system is based on 16 sub-elements in the teacher evaluation process in addition to 4 primary factors (research orientation, teaching learning process, teaching technique, and individual skills). The ANFIS system's classification of instructor performance into four established categories includes those who require training, have good skills, are very good, and are excellent. The devised method is a helpful instrument for assessing teachers and offering pertinent feedback on their areas of strength and weakness to enhance performance. Latah (2016) used the neuro-fuzzy inference method to predict students' academic achievement in a distant learning system. The Takagi Sugeno Kang fuzzy inference system is used by the suggested system to produce the fuzzy rules. The genetic algorithm is additionally utilized as a feature selection tool. The findings of the study demonstrated that the proposed system may outperform both neuro-fuzzy and traditional neural network techniques. Mehdi and Nachouki (2022) developed the ANFIS approach to creating a prediction and explanatory model that predicts the grade point average (GPA) of students enrolled in the computer technology department at Ajman University when they graduate. Researchers found that the ANFIS method outperforms popular methods like multilinear regression in terms of predictive accuracy.

In the present research, the statistics made with correlation and hierarchical regression and the results obtained with the ANFIS approach were compared. The number of studies comparing statistical results with ANFIS is limited. For example, Vasileva-Stojanovska et al. (2015) established an ANFIS model for predicting the quality of experience in education. The results showed that network jitter, an objective component, and the student's personality traits and learning style, both subjective factors, could are both subjective factors, could both accurately predict the perceived quality of the experience. Better RMSE was achieved by the ANFIS-based quality of experience prediction model than by the linear regression prediction model. However, there are studies in the literature comparing fuzzy logic, which is a component of ANFIS, and the results obtained from statistical techniques. In studies comparing fuzzy logic and statistical techniques in the field of education, Özkan

(2018), Thakre et al. (2017), Özdemir and Tekin (2016) obtained results in favor of statistical techniques, while Meenakshi and Pankaj (2015), Tailor et al. (2014), Gangadwala and Gulati (2012) obtained results in favor of fuzzy logic approach. In studies that evaluated fuzzy logic and statistical results relationally, Arslan and Zirhlioğlu (2021), Jafarkhani (2018), and Guruprasad et al. (2016) concluded that there is a strong, favorable, and notable correlation between the outcomes of both techniques. On the other hand, statistical methods were used in a limited number of studies conducted with Turkish students on PoPS skills and CPS characteristics. Kaplan et al. (2016) determined that students have a medium level of PoPS skills. Yavuz et al. (2017) concluded that the PoPS skills of middle school students are high.

Traditionally, students' academic achievement, performance and various educational characteristics are evaluated according to the grades they get or the results of their answers to the scales, and classical statistical methods are generally used in the evaluation. However, there are some limitations in making an evaluation based on the results. Artificial intelligence techniques can be used as trustworthy alternatives to existing techniques to forecast the performance of complex systems in order to cut down on research expenses and computation time. Methods such as fuzzy logic and ANFIS in artificial intelligence have been developed to estimate the output power of resources (Chen et al., 2021). The fuzzy logic approach, which tries to eliminate these limitations, has recently been used in the field of education (Taylan & Karagözoğlu, 2009). While applying the fuzzy logic method to education, students' qualifications are determined qualitatively without using formulas in calculating student performance (Barlybayev et al., 2016). However, fuzzy systems lack learning abilities (Chowdhury & Li, 1998). Combining fuzzy rules with neural networks will provide the flexibility of the evaluation tool to adapt to new situations. Thus, an educationally robust and easy-to-use assessment tool will be obtained. In the light of this information, in this study, students' perceptions of problem solving skills, which is one of their educational characteristics, were modeled with the ANFIS approach, which is one of the neuro-fuzzy systems apart from traditional methods, through creative problem solving features. ANFIS is an adaptive network that allows neural network topology to be combined with fuzzy logic. It not only incorporates the benefits of both strategies but also eliminates some of their drawbacks when used alone (Atmaca et al., 2001). Considering this advantageous situation, in the first stage, an adaptive neural-network based fuzzy logic model was developed to determine students' perceptions of problem solving skills in the current study. As a second step, statistical methods (correlation and hierarchical regression) were used to examine whether there was a relationship between students' PoPS skills and CPS characteristics. Because CPS properties were input variables for ANFIS. The correlation of students' CPS features with their PoPS skills will show that using CPS features as an input variable in estimating PoPS skills with ANFIS is an accurate assessment. Therefore, it will provide evidence for ANFIS modeling. Afterwards, students' artificial PoPS skill scores obtained with ANFIS in the first step and real PoPS skill scores obtained from their answers to the scale were compared. Because of its hybrid architecture, which combines the fuzzy logic's reasoning powers with a neural network's learning abilities to boost predictive ability, the

ANFIS methodology has outperformed other methods in terms of prediction accuracy. The functional association between the dependent variable and its predictors is therefore less important in ANFIS modeling, which is more systematic (Jang, 1993). In this study, ANFIS was used and the results were compared with another method, hierarchical regression. Thus, it was tested whether the students' PoPS skill scores, which were estimated based on their CPS characteristics, differed from their real scores. For these purposes, answers to the following research problems were sought:

1. Is it possible to predict students' PoPS skills through CPS features with the ANFIS approach?
2. Is there a relationship between students' PoPS skills and CPS characteristics?
3. Is there a significant difference between the real PoPS scores and the artificial PoPS scores of the students generated with the ANFIS approach?

1.1 Perception of problem solving skills

The perception of problem solving skills of students is crucial in the problem solving process (Wismath et al., 2014). Bingham (1998) defined problem solving as a set of efforts to eliminate the obstacles encountered to reach a specific goal. It entails putting together and coordinating a variety of abilities, beliefs, attitudes, perceptions, information, and prior accomplishments (Yavuz et al., 2017). Individuals need to have problem-solving skills to overcome the problems they encounter in daily life (Runco & Acar, 2012). In, how individuals perceive themselves regarding their problem solving skills is an important factor affecting how they think and behave in the problem solving process (Piersel et al., 1993). The PoPS skills, which emerges as an individual difference variable (MacNair & Elliott, 1992) can be defined as a person's opinion or judgment about his/her performance in the problem solving process (Kaplan et al., 2016). PoPS skills were explained by Heppner and Petersen with three sub-dimensions: approach avoidance, confidence in problem-solving skills, and personal control (Heppner & Petersen, 1982). If an individual believes that he will find an effective solution to a problem he encounters in daily life, it can be said that this student trusts his/her own problem-solving ability (Şahin et al., 1993). If the individual tries to solve some of the problems he encounters in daily life and tries to solve these problems, it can be said that this individual tends to approach avoidance by staying away from some of the problems (Heppner & Baker, 1997). If the individual believes that he/she can control his/her emotions and behaviors during the problem solving process, it can be said that this individual exhibits personal control characteristics (Heppner & Wang, 2003). When the sub-dimensions of the PoPS skills are evaluated together, it can be stated that these dimensions can reflect the individual's PoPS skills in daily life (Kaplan et al., 2016). In another definition, Ekici and Balım (2013) discussed the PoPS skill in two sub-dimensions as "perception of problem solving skills" and "perception of willingness and determination towards problem solving". It is known that individuals who perceive high problem solving skills are psychologically healthier and more successful in problem solving than those with low problem solving skills (Heppner et al., 2004). Individuals with a high perception of problem solving skills can cope with the events without worrying about the events they encounter and are more determined about the solution (Rosenberg, 1989). On the contrary, individuals with low perception of problem solving skills are not only anxious and insecure in problem solving situations, but also fail to understand the expectations of other individuals (Dixon et al., 1991). In this study, Ekici and Balım's approach was adopted to evaluate students' PoPS skills (Ekici and Balım (2013).

1.2 Creative problem solving features

Urban (2003) provides a theory of creativity that includes three cognitive characteristics (divergent thinking and action, general knowledge and thinking bases, and specific knowledge bases and domain-specific skills) as well as three personality traits (motivation, focusing and task commitment, and openness and tolerance of ambiguity). Guilford (1950, 1956) coined the term divergent thinking, which has long been associated with creativity since it is closely tied to thinking flexibility and originality (Plucker et al., 2006). Divergent thinking (Palmiero et al., 2020), or the generation of multiple ideas, has been demonstrated to assist in problem-solving creativity (Vincent et al., 2002). Unlike divergent thinking, convergent hasn't gotten much attention when it comes to creativity. As a matter of fact, Urban (2003) did not include convergent thinking among creative thinking features. Convergent thinking has been proven to be necessary for generating effective novelty Cropley (2006) or complete CPS (Brophy, 1998, 2001). The researchers went on to say that there are two types of creative thinking: domain-general and domain-specific creative thinking. Furthermore, domain-general creative thinking influences domain-specific creative thinking directly. Furthermore, gender, a person's grade level, ethnicity, and learning impairment status can all influence creative thinking (Lin & Cho, 2011). Curiosity, perseverance, and sensitivity are all closely linked to motivation, and it can be difficult to distinguish between them. So far, it's been proven that intrinsic motivation boosts creativity, although the impact of extrinsic incentives varies depending on the environment and participants' goals (Lin & Cho, 2011). Proctor and Burnett (2004), Wickes and Ward (2006) found that being intrinsically driven, curious about a topic, taking risks, and being engaged and motivated in challenging problems were all significantly and positively connected with creative thinking. Furthermore, how people approach creative problems, their openness and flexibility, their motivation (Eisenberger & Rhoades, 2001), work environment conditions (Hunter et al., 2007; Tierney & Farmer, 2004) are all factors that influence people's performance in CPS (Eisenberger & Aselage, 2009). According to Cho's "Creative Problem Solving Ability Dynamic System Model", CPS skill consists of five components: convergent thinking, divergent thinking, environment, motivation, general knowledge, and skills (Cho, 2003). In this study, Cho's (2003) approach was adopted to evaluate students' CPS features.

1.3 Neuro-fuzzy systems

Fuzzy neural systems integrate neural networks with fuzzy logic techniques (Latah, 2016). The physical architecture of the model and the representation of information are controlled by neural networks (Mehdi & Nachouki, 2022). Artificial neural networks and fuzzy systems are soft computing techniques for simulating human (domain expert) behavior. The objective is to act in a manner that is similar to that of a problem-solving domain expert. As a result, a learning process can serve as a knowledge acquisition system when there is no domain expert, not enough time, or not enough data. On the other hand, if someone possesses knowledge that can be expressed in linguistic forms, they can create a fuzzy system (Taylan & Karagözoğlu, 2009). Numerical data can be used to train neural network-based systems, and fuzzy rules can be retrieved from neural networks (Ishibuchi et al., 1998). Similar to this, linguistic knowledge can be used to create categorization systems based on fuzzy rules. The application requirements for neural systems and fuzzy logic are also highly different. For instance, neural systems are helpful if there is sufficient process data available or measurable, but fuzzy systems are good if there is adequate expert knowledge about the process. Both methods construct nonlinear systems based on bounded continuous variables; however, while fuzzy systems are viewed as symbolic qualitative systems, neural systems are treated as numeric numbers (Mitra & Hayashi, 2000). As a result, there is a symbolic link that results from the combination of neural and fuzzy systems, whereby fuzzy systems offer a strong foundation for representing expert knowledge and neural networks offer learning capabilities. Integrating systems aims to create more capable decision-making processes (Taylan & Karagözoğlu, 2009).

Numerous neuro-fuzzy architectures exist, including the Adaptive Network-based Fuzzy Inference System (ANFIS), Dynamic/Evolving Fuzzy Neural Network (DENFIS), and Hybrid Neural Fuzzy Inference System (HyFIS) (Vieira et al., 2004). Below is information about ANFIS and the fuzzy logic approach that ANFIS contains.

1.3.1 Fuzzy logic

Fuzzy logic is a computing and reasoning system that uses classes with fuzzy borders as the computation and reasoning objects. Fuzzy logic was first introduced by Lotfi A. Zadeh (1965) in a study called "Fuzzy Sets".

Classical sets are built on sharp boundaries. For example, a set A in which students with a PoPS skills value greater than 50 are characterized as having a high PoPS skills value.

$$A = \{x|x > 50\}$$

Here, a student with a PoPS skills value of 15 and a student with a value of 35 belong to the set of students with a low PoPS skills value.

Lotfi A. Zadeh defined a fuzzy set in 1965 as a set consisting of elements specified with the membership function $\mu(\S)$ and whose membership degrees can take values between 0 and 1. Words or sentences used in everyday conversation can be viewed as linguistic variables and given linguistic values, according to Zadeh. Fuzzy variables are those that gradually change from high to low and signify a transition. The fuzzy set is the collection of such variables (Jamsandekar & Mudholkar, 2013).

In a classical set, the entity takes the value “1” when it is a member of the set, and “0” when it is not a member of the set, while fuzzy sets are the extended form of classical sets, where each entity has a membership degree. Entities can have a membership degree of any value between 0 and 1. Fuzzy sets allow elements to be included in the set with partial membership. Thus, a 94 kg person can be categorized by a certain degree of membership in both the obese and non-obese sets. In the case of an increase in weight, the degree of membership in the obese set increases, and the degree of membership in the non-obese set decreases at the same time.

Membership functions are curves that assign each element in a fuzzy set a matching membership value or degree of membership in order to define a property of the set. These functions map each point of the input with a membership value between 0 and 1 (Wang, 2015). Membership functions are optionally selected by the user and shaped by user experience (Mendel, 1995). Numerous shapes and sizes, such as triangular, Gaussian, trapezoidal, and others, are available for membership functions. They indicate the fuzziness in a fuzzy set and classify the elements in the set, whether they are discrete or continuous. It is denoted by $\mu(x)$ and can be defined as $\forall \mu(\S) \in [0,1]$.

Fuzzy inference system Using user-defined rules, a fuzzy inference system evaluates the values in the input vector and gives values to the output vector. An inference system with fuzzy logic incorporates expertise and experience and processes input–output relations defined with fuzzy rules in system design (Cavallaro, 2015). Thus, it allows decision-makers to easily include their own experiences in the decision-making process (Dragovic et al., 2015). Due to its multidisciplinary nature, it is known by many names such as fuzzy inference system, fuzzy expert system, fuzzy rule-based system, fuzzy model, fuzzy logic controller, and fuzzy system (Shleeg & Ellabib, 2013).

Four functional building components make up a fundamental fuzzy logic system: fuzzification, fuzzy rule base, fuzzy inference, and defuzzification (Jang, 1993). The structure of the fuzzy inference system is shown in Fig. 1.

Fuzzification is the first step to implementing a fuzzy inference system. Fuzzification is the process of converting input values from the system into linguistic terms. It includes two processes; generating membership functions for input and output

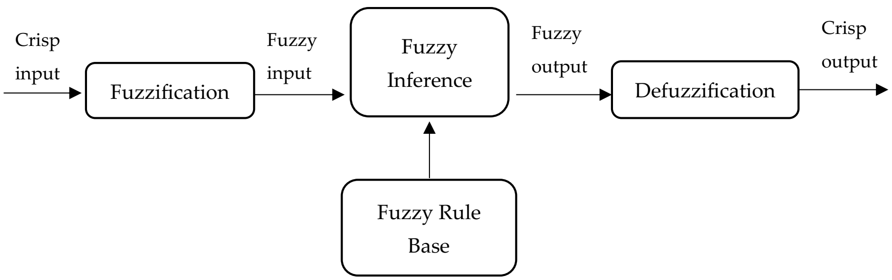

Fig. 1 Fuzzy inference system (Jang, 1993)

variables and expressing them in linguistic terms. After the membership functions are created, the fuzzy set or sets to which the input values belong and the degree of membership are determined by making use of the membership functions, and the values are assigned as linguistic terms (Bai & Wang, 2006).

The inference unit processes the linguistic terms coming from the fuzzification unit with the fuzzy rules. First, the fuzzy set and membership degree to which each input value belongs are determined. Then, these values are placed in the rule table and appropriate outputs are obtained (Çobanoğlu, 2000).

The defuzzification process is necessary to arrive at a conclusion or to make the fuzzy output available to real applications. The process of converting the linguistic term formed as a result of fuzzy inference into a numerical value is called defuzzification. The defuzzification unit enables obtaining non-fuzzy numerical values to be used in practice from fuzzy information coming from the decision-making unit (Bai & Wang, 2006; Bolat, 2006).

1.3.2 Adaptive neuro-fuzzy inference system (ANFIS)

A hybrid neuro-fuzzy system called the Adaptive Neuro Fuzzy Inference System (ANFIS) has been described by Jang and Sun (1995). ANFIS is a hybrid analytical method whose prediction mechanism combines the advantages of neural networks with fuzzy logic systems (Mehdi & Nachouki, 2022). ANFIS has certain special qualities that combine the benefits of neural networks and fuzzy logic methods for representing human behavior. When expert knowledge is available, fuzzy inference systems offer a powerful mechanism for knowledge representation even though they lack the ability to learn automatically. However, neural networks lack the ability to represent information but have a strong mechanism for learning from sample data when expert knowledge is limited. In situations where the relationship between input and output is complex, ANFIS overcomes the drawbacks of both strategies and provides a particularly potent method for system identification. This means that ANFIS may create a fuzzy rule base from a set of input/output data and adjust the parameters of the membership functions (Vasileva-Stojanovska et al., 2015). In summary, the physical architecture of the model and the representation of information are controlled by neural networks. Fuzzy inference systems, by contrast, are inspired by human thinking and improve the model's capacity to handle ambiguity inside the system (Eberhart & Kennedy, 1995; Negnevitsky, 2017). Through the instances that are given to it, ANFIS learns the characteristics of a given pattern. It then iteratively updates the system's parameters to converge toward the error criterion that is established by the system and enhances prediction (Mehdi & Nachouki, 2022).

The basis of the ANFIS method is the Takagi–Sugeno fuzzy inference system. By combining the benefits of fuzzy logic and neural network, ANFIS can successfully solve any type of complicated problem. It uses fuzzy approaches to combine numerical and linguistic knowledge. It also makes use of the artificial neural networks' data classification and pattern recognition abilities. In addition, when compared to an artificial neural network, the ANFIS creates fewer memorization errors and is more visible to the user (Walia et al., 2015).

ANFIS is a fuzzy modeling system based on rules. The establishment of fuzzy rules occurs during the training process. The training is done utilizing a set of data. The ANFIS creates a fuzzy inference system (FIS), using membership function parameters derived from training data. The Sugeno-type FIS is employed as the data set in the ANFIS model (Jang, 1993).

Two inputs x and y are used to explain the structure of ANFIS. The following is a Sugeno-type fuzzy model with two fuzzy IF–THEN rules:

$$\text{If } x \text{ is } S_1 \text{ and } y \text{ is } T_1, \text{ then } f_1 = a_1x + b_1y + c_1,$$
$$\text{If } x \text{ is } S_2 \text{ and } y \text{ is } T_2, \text{ then } f_2 = a_2x + b_2y + c_2,$$

where the fuzzy sets are represented by S_i and T_i, the output is represented by f_i, and the design parameters are represented by a_i, b_i, and c_i.

The ANFIS architecture is divided into five levels, each of which is described as follows: P_i^j represents the output of node i and layer j (Jang, 1996):

1) Every node in layer 1 is specified by the function as

$$P_i^1 = \mu_{S_i}(x), \textit{ for } i = 1, 2.$$

in which the input node i is represented by x, while the linguistic label is represented by S_i.

2) Every node in layer 2 multiplies the firing strength of a rule to get the result:

$$P_i^2 = \sigma_i = \mu_{S_i}(x) * \mu_{T_i}(y), \textit{ for } i = 1, 2.$$

3) The evaluated ring strengths are normalized in layer 3:

$$P_i^3 = \overline{\sigma_i} = \frac{\sigma_i}{\sigma_1 + \sigma_2}, \textit{ for } i = 1, 2.$$

4) Node i calculates the addition of rule i to the output in layer 4:

$$P_i^4 = \overline{\sigma_i} * f_i = \overline{\sigma_i}(a_ix + b_iy + c_i)$$

where the parameter set is a_i, b_i, c_i, and the output of layer 3 is σ_i.

5) The overall output of the ANFIS is computed by a single node at layer 5:

$$P_i^5 = \sum_i \overline{\sigma_i} * f_i = \frac{\sum_i \sigma_i * f_i}{\sum_i \sigma_i}$$

The PoPS skills of the students in our study were examined using ANFIS, that can gain knowledge and create a fuzzy rule base from a given set of input output data. A model was created to predict the PoPS skills of future students taking part in similar educational environments.

2 Methodology

2.1 Research design

The study's procedural methodology was a quantitative, descriptive, and exploratory approach. The research was carried out based on the general survey model, which is a type of quantitative research. According to the general survey model, in a multi-element universe, research is done on the entire universe, a group of samples, or samples that will be taken from it in order to form an overall opinion on the universe (Büyüköztürk, 2012). In survey research, researchers are more interested in how opinions and characteristics are distributed across the sample's participants than in how they were arrived at (Fraenkel & Wallen, 2006). According to Del Rincon et al. (2003), survey-based analyses are often employed in the field of education, maybe because of the method's obvious simplicity and openness. Descriptive research, on the other hand, aims to describe and explain what events, objects, entities, groups or various fields are. Thus, it gives the opportunity to better understand and group the investigated situations, and the relationships between the events are determined (Kaptan, 1998). In addition, the correlational survey model, which is one of the general survey models, was used in the study since the students' PoPS skills and CPS characteristics were evaluated relationally with statistical methods.

2.2 Participants

During the 2019–2020 academic year, 360 students aged 10 to 14 years old from public and private middle schools in Turkey took part in the study. Students' average age was 11.81. In this study, a convenience sampling method was used. The convenience sampling approach is used to involve people who meet certain functional requirements such as geographic proximity, easy accessibility, and voluntary engagement in studies (Johnson & Christensen, 2014). In parallel with this information, as this study was conducted in Istanbul (Turkey's largest city), the selection of students was made according to conditions such as transportation, time, cost etc. Table 1 displays the participant's demographic data.

Table 1 Participants' demographic details

Demographic characteristics		n	%
Gender	Girls	144	40
	Boys	216	60
Grade	Fifth grade	82	23
	Sixth grade	98	27
	Seventh grade	120	33
	Eighth grade	60	17
School type	Public	180	50
	Private	180	50

To comprehend the backgrounds of the middle school students taking part in the research more fully, the following information can be given about the middle school system in Turkey: Middle school lasts four years and is compulsory. Turkish, mathematics, social studies, science, T.C. courses such as religious culture and moral knowledge, History of Revolution and Kemalism, foreign language, music, visual arts, physical education and sports, information technologies and software, technology and design are taught. Central common exams are of great importance in the transition process from middle school to high school. Those who pass the national entrance exam continue to these schools while some prestigious schools may require a specified GPA for admission (Koç Aytekin & Işık Tertemiz, 2018). Problem solving skills are among the specific and general objectives of the curriculum announced by the Ministry of National Education (MoNE, 2018). Therefore, problem solving, which is a twenty-first century skill, is especially emphasized in all other courses, especially in mathematics.

2.3 Data collection tools

Two different scales named as Perception Scale for Problem Solving Skills and Creative Problem Solving Properties Inventory were used to collect data. Brief information for each scale was given below.

2.3.1 Perception scale for problem solving skills

This 5-point Likert (1 = strongly agree to 5 = strongly disagree) scale was developed by Ekici and Balım (2013) to determine students' perceptions of problem solving skills. The scale has 22 items, 15 positive and 7 negative. In addition, at the beginning of the scale, there is a part where the name of the school, grade, gender, and age of the students are asked. For the scale's construct exploratory, validity and confirmatory factor analyses were carried out during its development. Additionally, the item-total correlations of the scale's items and the cronbach alpha value of the scale were determined to assess the reliability of the scale. In line with the analyzes made, it was found that the scale was composed of two components, the variance explained by the first factor of the scale was 30.239%, and the variance explained by the second factor was 9.976%. As a result of the confirmatory factor analysis performed to test the accuracy of the factor structure of the scale, $X^2 = 483.09$, $p = 0.000 < 0.001$, df = 208; X2/df = 2.32; RMSEA = 0.039; NFI = 0.97; CFI = 0.98; NNFI = 0.98; AGFI = 0.94; GFI = 0.95. It can be said that the two-factor structure determined in line with the results obtained was confirmed by confirmatory factor analysis. The scale's Cronbach alpha reliability coefficient was determined to be.88 as a consequence of the analyses carried out during scale development. Cronbach alpha reliability for this study was calculated as 0.86. Since Cronbach's alpha values above 0.70 is accepted as a sufficient value for a reliable measurement tool (Gaur & Gaur, 2009), it can be said that the Perception Scale for Problem Solving Skills used in the study is a reliable tool. The highest score that can be obtained from this scale is 110. The scale's score gives the perception of problem solving skills levels of students.

PoPS scores were evaluated as low between 0–36, medium between 37–73, and high between 74–110.

2.3.2 Creative problem solving properties inventory

Using five subscales of the Creative Problem Solving Properties Inventory essential attributes of students' CPS skills were investigated. The scale was developed by Lin (2010) and adapted into Turkish by Baran-Bulut et al. (2018) to reveal the CPS features of middle school students. The 40-item questionnaire tool has five different factors. Those factors are named as divergent thinking (1–10 items), convergent thinking (items 11–18), motivation (items 19–24), environment (items 25–35), and general knowledge and skills (items 36–40). Each item in the scale is scored between 0 and 5. Linguistic equivalence research was the main focus of the inventory's validity and reliability research in Turkey. Then, Confirmatory Factor Analysis (CFA) and reliability coefficient Cronbach α were performed respectively for validity and reliability, and it was determined that the scale had a five-factor structure as in the original scale. As a consequence of the confirmatory factor analysis carried out to check the precision of the scale's factor structure, RMSEA = 0.046 [0.043,0.048], $\chi 2$ = 2028 (sd = 730), TLI = 0.924, CFI = 0.929. Considering the fit indices of the model, a significant model fit was obtained for each factor. Cronbach alpha reliability values are given in Table 2 according to the sub-dimensions of the scale. The psychometric properties of the Creative Problem Solving Properties Inventory were found to be suitable in validity and reliability tests. As a result, it was decided that this questionnaire be used to determine the CPS features of Turkish middle school students.

Examining Table 2, it was determined that the Cronbach's Alpha coefficients belonging to the scale were between 0.73 and 0.88. Similarly, the Cronbach's Alpha coefficients in the study were found to be between 0.71 and 0.86. From this, it can be said that the internal consistency of the data obtained from the study is high (Gaur & Gaur, 2009). The evaluation in this scale was not based on the total score of the scale, but on the total scores obtained from the sub-dimensions of the scale. Students' interpretations of points for their creative problem solving features are as follows: Divergent thinking feature 0–16 = low, 17–33 = moderate, 34–50 = high; convergent thinking feature 0–13 = low, 14–27 = moderate, 28–40 = high; motivational trait 0–10 = low, 11–20 = medium, 21–30 = high; environmental

Table 2 Reliability Values of Creative Problem Solving Features Inventory

Factors	Item	Cronbach's alpha	Cronbach's Alpha in the study
Divergent thinking	10	0.79	0.77
Convergent thinking	8	0.78	0.79
Motivation	6	0.73	0.71
Environment	11	0.88	0.86
GKS	5	0.77	0.78

characteristic 0–18 = low, 19–37 = moderate, 38–55 = high; GCS characteristic 0–8 = low, 9–17 = medium, 18–25 = high.

The lowest and highest scores that can be obtained from the scale were taken into account in determining the low-medium–high levels for both scales. These score values were determined as the lower limit and the upper limit, and the difference between them was divided by 3 and three equally spaced levels were formed.

In the first research problem, in which students' PoPS skills were modeled with the ANFIS approach and estimated through CPS features, data obtained from both the "Perception Scale for Problem Solving Skills" and "Creative Problem Solving Properties Inventory" data collection tools were used, since CPS features were the input variable and PoPS skills were the output variable. Since both variables were used in the second research problem, in which students' PoPS skills and CPS characteristics were examined in relation to each other, the data obtained from both scales were used. In the third research problem, in which the difference between the real PoPS scores of the students and the artificial PoPS scores obtained with the ANFIS approach was tested, the data obtained from the "Perception Scale for Problem Solving Skills" were used as the PoPS scores of the students were compared. It should be noted that CPS scores are also used in the calculation of students' artificial PoPS scores.

2.4 Data analysis

At the stage of answering the first research problem, in which students' PoPS skills were predicted with the ANFIS approach through CPS features, the fuzzy system is developed on MATLAB R2021b Fuzzy Logic Toolbox. Input variables of the models to be created are divergent thinking, convergent thinking, motivation, environment, and GKS. The output variable is perception of problem solving skills. A rule base is created by defining set intervals, membership degrees and membership functions for input and output values. To determine the outperforming ANFIS model, the hybrid optimization method is used to train the fuzzy inference system (FIS). At the end of these processes, students' artificial PoPS scores were generated. The obtained scores are given as an Appendix together with the real scores.

In the second research problem in which the relationship between students' PoPS skills and CPS characteristics was examined, correlation and hierarchical regression analyzes were performed. In correlation analysis, the correlation coefficient is used to examine the amount and direction of the relationship between two variables. If the variables show continuous and normal distribution, the Pearson correlation coefficient is used, and if the variables do not exhibit continuous but normal distribution, the Spearman-Brown correlation coefficient is used (Büyüköztürk, 2016). In this study, since the data has a continuous feature, it was first examined whether they showed a normal distribution. Since Shapiro-Wilks test results are used when the number of data is less than 50, and Kolmogorov–Smirnov test results are used when it is large (Büyüköztürk et al., 2010), Kolmogorov–Smirnov test (N = 360) was used in the analysis of normality. Table 3 presents Kolmogorov–Smirnov normality test results for all assessed variables.

Table 3 Kolmogorov–Smirnov normality test results

	Kolmogorov–Smirnov		
	Statistic	df	Sig
Divergent thinking	0.089	180	0.001
Convergent thinking	0.095	180	0.000
Motivation	0.072	180	0.025
Environment	0.083	180	0.004
GKS	0.073	180	0.021
PoPS skills	0.081	180	0.006

The results showed that students' CPS features and PoPS skills did not show a normal distribution. The Spearman-Brown correlation was used to analyze the relationship between CPS features and PoPS skills scores of middle school students. A hierarchical regression analysis was used to see if CPS features may predict PoPS skills. Gender, school type, and grade level served as predictive variables in Step 1, whereas CPS features and three factors served as predictive variables in Step 2. To reduce the risk of Type 1 errors, all parameters were included as predictive variables rather than assessing how each CPS feature differed in predictive PoPS skills separately in Step 2. SPSS 20.0 program was used in all of these calculations.

In the third research problem in which the difference between the real PoPS scores of the students and the artificial PoPS scores generated with the ANFIS approach was tested, descriptive statistical values of the scores were calculated and Wilcoxon Signed Order Test was used for related measurements (Büyüköztürk, 2016). Wilcoxon Signed Order Test is applied as an alternative to the parametric paired samples t-test in cases where the data is far from normal (Akgül & Çevik, 2003). In addition, Spearman Brown correlation analysis was performed to determine the relationship between the real and artificial data. This research problem was analyzed using the SPSS 20.0 program, too. The significance level for the study was accepted as "0.05" in statistical analyzes of the first and second research problems.

3 Results

3.1 The first research question results

In the first research problem in which students' PoPS skills were predicted with the ANFIS approach through CPS features, the fuzzy system is developed on MATLAB R2021b Fuzzy Logic Toolbox. Input variables of the models to be created are divergent thinking, convergent thinking, motivation, environment, and GKS. The output variable is perception of problem solving skills. The data for the results of this research problem were obtained from the "Perception Scale for Problem Solving Skills" and the "Creative Problem Solving Characteristics Inventory".

In the literature part of the research, information is given with the application of ANFIS. In line with these steps and using the MATLAB R2021b Fuzzy Logic

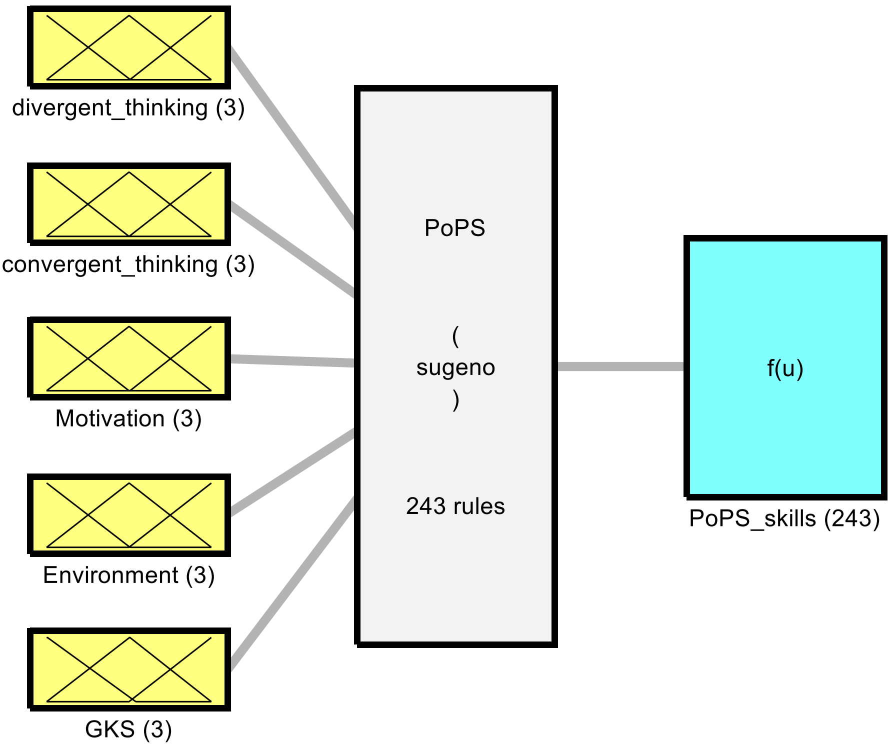

Fig. 2 The structure of the developed adaptive neuro fuzzy rule-based model

Table 4 Fuzzy sets of input and output variables

Fuzzy sets of input variables					Fuzzy sets of output variable
Divergent thinking	Convergent thinking	Motivation	Environment	GKS	PoPS skills
low	low	low	low	low	low
medium	medium	medium	medium	medium	medium
high	high	high	high	high	high

Toolbox, the following results of the model were obtained. The artificial PoPS scores of all the students generated at this stage are given in the Appendix.

Figure 2 shows the structure of the developed adaptive neuro fuzzy rule-based model. The fuzzy sets for input variables and output variables are defined in the fuzzy logic model, as shown in Table 4. After that, all variables' membership functions are defined. Three membership functions are formed for each input variable. Figure 3 illustrates the proposed model's membership functions. The ranges of these functions are determined by the studies in question. Grid partitioning is used in the ANFIS model to generate FIS. Hybrid optimization method is used for training

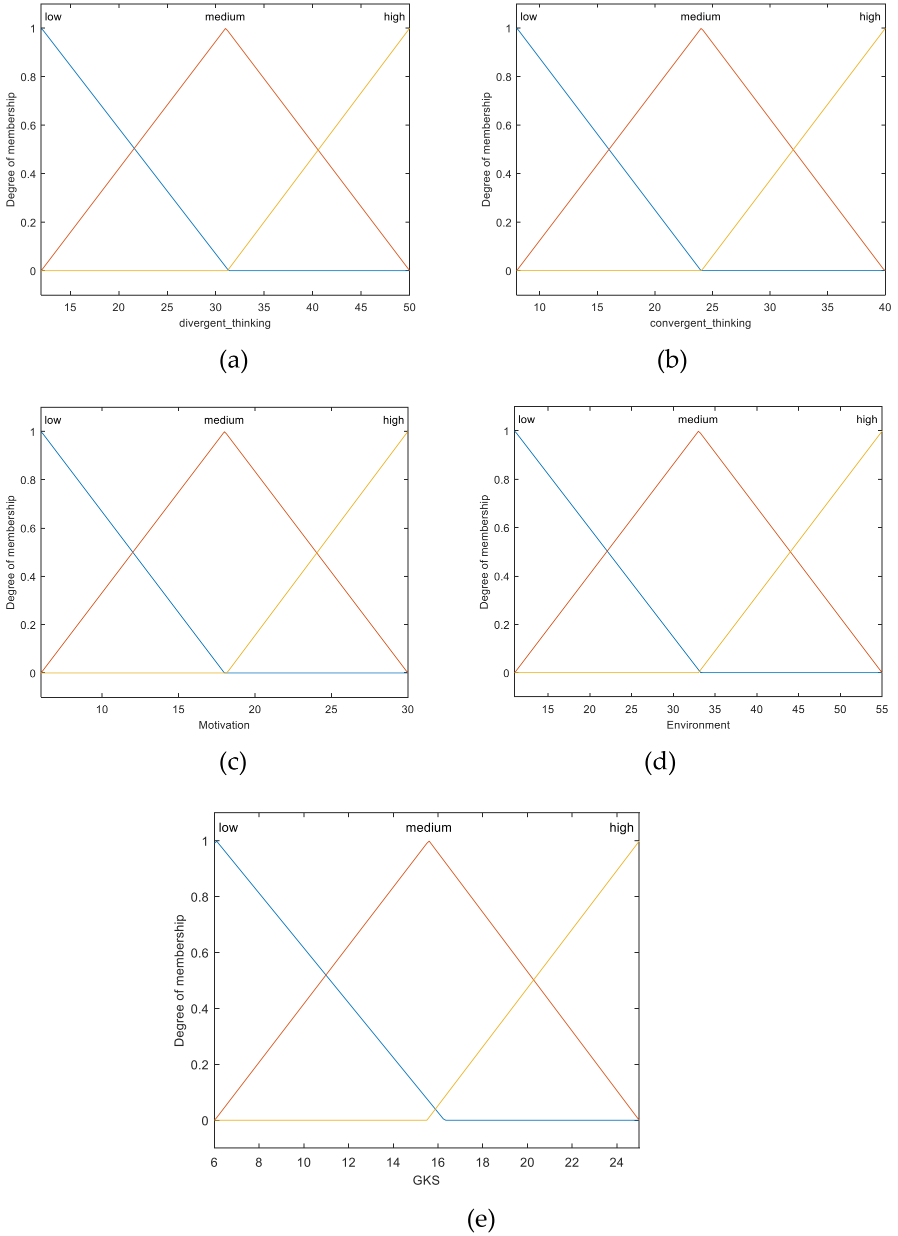

Fig. 3 Membership functions proposed for the input variables (**a**) divergent thinking, (**b**) convergent thinking, (**c**) motivation, (**d**) environment, (**e**) GKS

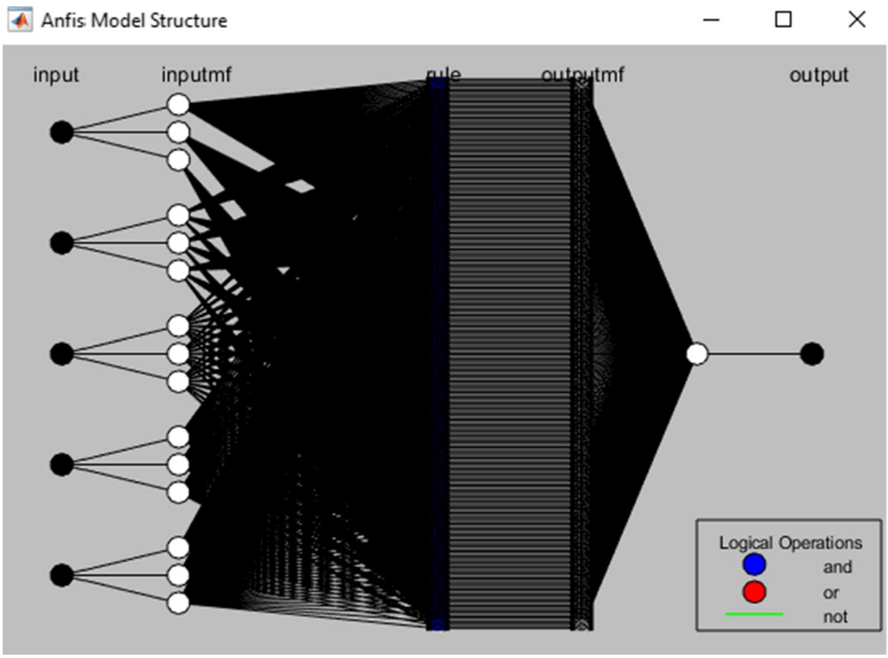

Fig. 4 The structure of the developed ANFIS model

FIS. 100 epochs are established for prediction results. The structure of the proposed ANFIS model is shown in Fig. 4.

3.2 The second research question results

The second sub-problem of the study was expressed as "*Is there a relationship between students' PoPS skills and CPS characteristics?*". Correlation and hierarchical regression analyzes were performed for this research problem. The Spearman-Brown correlation was used to analyze the relationship between CPS features and PoPS skills scores of middle school students. In this section, the data obtained from both scales used in the research were used. The correlational statistics between measures of two scales were shown in Table 5 below.

There were significant correlations between students' CPS features and PoPS skills. As presented in the table above, correlation coefficients between PoPS skills score and CPS features subscores ranged from 0.127 to 0.229. Correlation coefficients between PoPS skills and divergent thinking ($r = 0.127$, $p < 0.05$), PoPS skills and convergent thinking ($r = 0.144$, $p < 0.01$), PoPS skills and motivation ($r = 0.158$, $p < 0.01$), PoPS skills and environment ($r = 0.229$, $p < 0.01$) and PoPS skills and GKS ($r = 0.154$, $p < 0.01$) were found to be significant. Values determined by Büyüköztürk (2016) were used in the interpretation of the correlation coefficient: If the correlation coefficient is in the range of 0.00–0.30, there is a low correlation, in the range

Table 5 Correlational analysis between CPS features and PoPS skills

Variables	PoPS skills	Divergent thinking	Convergent thinking	Motivation	Environment	GKS
PoPS skills	-	0.127*	0.144**	0.158**	0.229**	0.154**
Divergent thinking		-	0.672**	0.652**	0.446**	0.450**
Convergent thinking			-	0.674**	0.569**	0.453**
Motivation					0.497**	0.404**
Environment						0.454**
GKS						-

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

of 0.30–0.70 there is a moderate relationship, and in the range of 0.70–1.00 there is a high level of correlation. When each component was considered, the correlation between PoPS skills and the environment component was the strongest. Thus, correlation statistics supported that there were small but positive significant relationships between PoPS skills and all CPS features.

Hierarchical regression analysis was performed to provide stronger evidence for the obtained results. Thus, it was aimed to determine whether CPS features significantly predicted the PoPS skills of middle school students. Table 6 shows the results on the link between demographic characteristics (gender, school type, and grade level), CPS features, and PoPS skills.

In terms of demographic variables, students' grade levels ($\beta = 0.271$, $t = 5.131$, $p < 0.05$), gender ($\beta = -0.187$, $t = -4.212$, $p < 0.05$) and school type ($\beta = -0.352$, $t = -6.612$, $p < 0.05$) can positively predict their PoPS skills. When it comes to five CPS features, the research results show that environment factor ($\beta = -0.150$, $t = -2.743$, $p < 0.05$) can positively predict PoPS skills among Turkish middle school students.

Table 6 Hierarchical regression analysis results (dependent variable = PoPS skills)

Model	β	t	R^2	ΔR^2
Step 1			0.326	0.321*
Grade	0.271	5.131*		
Gender	-0.187	-4.212*		
School type	-0.352	-6.612*		
Step 2			0.360	0.345*
Grade	0.262	4.954*		
Gender	-0.193	-4.371*		
School type	-0.350	-6.424*		
Divergent thinking	0.024	0.380		
Convergent thinking	0.008	0.118		
Motivation	-0.105	-1.651		
Environment	-0.150	-2.743*		
GKS	0.054	1.043		

Table 7 Examples of real and artificial scores

Student	Real score	Artificial score	Student	Real score	Artificial score
S1	78	69	**S11**	72	68
S2	96	91	**S12**	68	70
S3	72	72	**S13**	70	67
S4	73	71	**S14**	67	71
S5	70	64	**S15**	71	78
S6	67	67	**S16**	78	75
S7	90	93	**S17**	80	69
S8	44	44	**S18**	69	62
S9	72	72	**S19**	62	80
S10	68	68	**S20**	80	85

Table 8 Descriptive statistics results of the both scores

PoPS skills	Min	Max	Mean	SD
Real Scores	22	104	58.62	19.80
Artificial Scores	10	100	59.55	16.55

3.3 The third research question results

In the third research problem, the differentiation between the real PoPS scores of the students and the artificial PoPS scores generated with the ANFIS approach was examined. Wilcoxon Signed Order Test was used for the differentiation between two scores and the Spearman-Brown correlation was used for the relationship. The real scores generated from the answers given by the students to the "Perception Scale for Problem Solving Skills" and the artificial scores generated with the ANFIS approach are presented in the Table 7. Table 7 includes 20 examples. In addition, the scores of 360 students were given in Appendix.

The descriptive statistics results of the both scores are given in Table 8.

The mean of the real scores was 58.62, with a range of 22–104. According to Table 8, it can be said that Turkish middle school students' perceptions of problem solving skills were medium level (22–51 = low, 52–81 = medium, 82–110 = high). The mean of the artificial scores generated with the ANFIS approach was 59.55, with a range of 10–100. Similarly, according to the artificial scores obtained with the ANFIS approach, the PoPS skills of the students participating in the research are moderate (10–40 = low, 41–70 = medium, 71–100 = high). According to Table 8, the mean of the artificial scores is higher than the mean of the real scores. The standard deviation value of the real scores is higher than the standard deviation value of the artificial scores. Accordingly, it can be said that the artificial scores are distributed close to the average according to the real scores.

In order to determine the test to be used in the comparison of the real and artificial PoPS scores of the students, it was first examined whether the real

Table 9 Kolmogorov–Smirnov normality test results

PoPS skills	Kolmogorov–Smirnov		
	Statistic	df	Sig
Real scores	0.081	360	0.000
Artificial scores	0.070	360	0.000

Table 10 Wilcoxon Signed Order Test results

Artificial scores-Real scores	n	Mean Rank	Sum of Ranks	Z	p
Negative Ranks	125	108.76	13,594.50	-1.431	0.152
Positive Ranks	121	138.73	16,786.50		
Ties	114	-	-		

and artificial scores showed a normal distribution. Kolmogorov–Smirnov test ($n = 360$) was used in the analysis of normality. Table 9 presents Kolmogorov–Smirnov normality test results for all assessed variables.

Results indicated that the real and artificial scores were not in normal distribution. Therefore, the analysis was made with the Wilcoxon Signed Order Test. Table 10 presents the Wilcoxon Signed Order Test results.*Based on negative ranks

Differences between test results were in favor of artificial scores when sum of ranks were considered. However, this difference was not statistically significant [$Z = -1.431$; $p = 0.152$; $p > 0.05$]. Therefore, the real scores and the artificial ANFIS scores are close to each other, and the ANFIS model predicts results close to students' real PoPS skills scores.

The correlation between the artificial and real scores was calculated with the Spearman-Brown correlation coefficient. The reason for using this correlation coefficient is that the data do not show a normal distribution as shown in Table 9. The obtained results are presented in Table 11.

Table 11 Correlational analysis between real and artificial scores

			Artificial scores	Real scores
Spearman's rho	Artificial scores	Correlation Coefficient	1.000	0.776*
		Sig. (2-tailed)		0.000
		N	360	360
	Real scores	Correlation Coefficient	0.776*	1.000
		Sig. (2-tailed)	0.000	
		N	360	360

According to the results presented in Table 11, there is a highly significant positive correlation between the artificial and real scores ($r = 0.776$, $p = 0.000 < 0.05$). According to Büyüköztürk (2012), if the correlation coefficient is between 0.00–0.30, there is a low correlation, between 0.30–0.70 there is a moderate correlation, and between 0.70–1.00 there is a high level of correlation. Therefore, there is a high level of correlation between students' real and artificial PoPS skills scores.

4 Discussion and conclusion

This study used an adaptive neuro-fuzzy inference system (ANFIS) model to predict Turkish middle school students' PoPS skills and the hybrid optimization method was used for training fuzzy inference system. This stage, in which students' PoPS skills are predicted with the ANFIS approach, is related to the first research problem. Any academic program where problem solving abilities are particularly significant can use the designed tool. The approach can help identify students who require academic advising so that the right steps can be made to maintain a successful and successful middle school experience and prepare students for twenty-first century skills. The data of the study were collected from the answers given by the students to the Inventory of Creative Problem Solving Characteristics and Perception Scale for Problem Solving Skills. In other words, the data used are real data collected in the field. They are not ready-made data in any information system or database. It is thought that this situation has an important contribution to the validity of the research. After the data were collected, the input and output values of the model were determined. The ANFIS system proposed in this research was developed based on 5 sub-factors (divergent thinking, convergent thinking, motivation, environment, and general knowledge and skills) under 1 input (CPS features) and 1 output (PoPS skills). In the research, it was explained with the support of the literature (e.g. Mumford et al., 2012; Sternberg, 2006; Isaksen & Treffinger, 2004; Kaufman & Sternberg, 2007) that the students' perceptions of problem solving and their creative thinking features were related, the inputs of the research were determined as students' creative problem-solving characteristics and the output was their perceptions of problem-solving skills. With the ANFIS approach, students' PoPS skills scores were calculated using CPS features. The proposed method is an effective tool for evaluating students' performance and giving them meaningful feedback on their strengths and faults. An internal evaluation technique used by educational institutions to assure academic performance involves measuring educational activities (Daneshvar et al., 2021). In this study, PoPS skills from students' educational characteristics were evaluated using an adaptive neuro fuzzy inference system approach. This approach has been used to assess the data connected to the model's component information because of the difficulty and complexity of qualitative indicators, along with the impreciseness of the information obtained from experts by using linguistic variables (Vasileva-Stojanovska et al., 2015). The results of the students' input and output variables were expressed in three linguistic terms (low-medium–high). For example, PoPS scores were evaluated as low between 0–36, medium between

37–73, and high between 74–110." This is the flexibility of fuzzy linguistic variants. Normally these expressions are also used in our daily life to rate various features (Taylan & Karagözoğlu, 2009). It is thought that the use of neuro-scientific approaches in education can be an excellent method in order to evaluate the various educational characteristics of the students, to record and keep some of their characteristics in the computer system and to provide guidance to guide them for their future life. This research is an example for this.

Regarding the second research problem in which students' PoPS skills and CPS characteristics are correlated, it was concluded from the statistical analysis techniques that CPS characteristics and PoPS abilities of middle school students demonstrated a significant positive correlation. This situation may suggest that there is an inextricable and internal relationship between problem solving characteristics and perception of problem solving skills starting from the middle school level. Although there is no research stating that there is a direct relationship between students' CPS characteristics and their PoPS skills, there are studies that make associations by stating that creativity is finding unique and effective solutions to a problem (Corazza, 2016; Mumford & Gustafson, 2007) and accepting creativity as a kind of problem-solving ability (Mumford et al., 2012; Sternberg, 2006). The result of hierarchical regression analysis also showed that students' three factors (gender, grade level, and school type) and environment factor of CPS features all positively predicted students' PoPS skills. Regarding statistical results the most striking finding of the study was that the environment, which was considered as one of the components affecting creative problem solving in this study, predicted students' perceptions of problem solving skills. The higher the students' environment scores, the higher their PoPS skills. This finding suggested that the learning environment had an important role in the development of creative problem-solving abilities. This result is in perfect agreement with Gaglione's (2021) conclusion that the learning environment in the classroom in middle school is an important factor in students' perceptions of CPS characteristics. It is seen in many studies in the literature that students' creative problem-solving skills can be improved when appropriate learning environments are provided and necessary training is provided (Kim et al., 2013; Khalid et al., 2020; Hsia et al., 2021). In these studies, it was observed that there were significant increases in students' skills such as creativity and problem solving with structured training, and in this context, it was stated that creative problem solving skill levels were positively affected by the activities. Therefore, it is necessary for teachers to create appropriate learning environments for their students to develop their PoPS skills in the middle school period.

For the third research problem, the real PoPS skills scores obtained from the answers given by the students to the "Perception Scale for Problem Solving Skills" scale and the artificial PoPS skills scores obtained with the ANFIS approach were compared. Descriptive statistics results obtained with statistical techniques showed that students' perceptions of problem solving skills were moderate according to real PoPS skills scores. This result supports the previous result that middle school students have a medium level of PoPS skills in Turkey (Kaplan et al., 2016). Different from the research result, Yavuz et al. (2017) concluded that the PoPS skills of middle school students are high. According to artificial scores obtained through ANFIS, the students' PoPS skills were at medium level. Therefore, the scores obtained by the students' own answers to the data collection tool and the scores predicted by ANFIS based on the CPS characteristics were close to each other. This result was also supported by other statistical test results obtained in the research. As a matter of fact, the results of the Wilcoxon Signed Order Test showed that there was no significant difference between the artificial and real scores. Therefore, the ANFIS model predicts results close to students' real PoPS skills scores. Among the studies comparing fuzzy logic, which is a component of ANFIS, and the results obtained from statistical techniques, there are some that show similarities or differences with the results obtained in this study. While Arslan and Zirhlioğlu (2021), Özkan (2018), Thakre et al. (2017), Özdemir and Tekin (2016) obtained results in favor of the statistical method, Meenakshi and Pankaj (2015), Tailor et al. (2014), Gangadwala and Gulati (2012) fuzzy logic yielded favorable results. The study indicated a strong and positive connection between the two methods, with a correlation value of.776 used to express the relationship between data acquired using fuzzy logic and statistical methods. Similarly, Arslan and Zirhlioğlu (2021), Jafarkhani (2018), Guruprasad et al. (2016) concluded that the outcomes of the two methods are extremely significant and positively correlated.

One of the study's most significant findings is that both methods do not have superiority over each other in predicting PoPS skills of students depending on their CPS characteristics. It was also showed that which of the students' CSP features was significantly effective in predicting their PoPS skills in the statistical method, and it was concluded that the environment variable was the most important variable. However, with the ANFIS approach, such a conclusion could not be reached for each CPS feature. In this respect, it can be said that the statistical method has an advantage. In one of the limited number of studies comparing statistical results with ANFIS, unlike the one obtained in this study, Vasileva-Stojanovska et al. (2015) stated that better results were obtained with the ANFIS-based estimation model compared to the linear regression estimation model.

5 Limitations and recommendations for future research

The current study has a number of limitations. For begin, the sample only contained Turkish middle school students, thus any generalization to other sociocultural situations or educational levels should be done with caution. Students' CPS characteristics and PoPS skills in various age groups and societies should be evaluated in future studies. Second, because we employed a cross-sectional research methodology to compare middle school students' PoPS skills by evaluating them with the statistical techniques and the neuro-fuzzy model designed, we can't make any causal inferences from our results. Longitudinal data could be used in future studies to draw more accurate inferences. Third, a questionnaire consisting of closed-ended questions was used to assess students' PoPS skills. Still, the results of the questionnaire may be biased due to the limited time and the possibility of ambiguous understanding of the meaning of the statements in the items among some students (especially in the smaller grades). In future research, other methods (open-ended questions, observation, interviews etc.) can be used to assess students' PoPS skills; and again, we examined the CPS characteristics of the students with a questionnaire consisting of items that they would rate by giving numbers from 1 to 5. Other methodologies (e.g., self-reported measures, teacher-reported measures, parent-reported measures) could be used in future studies to measure students' CPS features. Furthermore, researchers can construct neuro-fuzzy models that include different input variables connected to middle school education (teacher competency, teacher attitudes toward creativity, and so on) as well as characteristics associated to educational activities in the future (types of activities, quality of activities, etc.). In this study, students' CPS characteristics were used as a predictor. In further research, using other neuro-fuzzy systems, the most effective features can be determined in order of importance. At this stage, data mining techniques can also be used. In line with the data obtained as a result of the relevant literature review and this research, it is seen that successful and valid results have been obtained from the studies conducted with the neuro-fuzzy systems. It can be recommended to conduct more academic research on neuro-fuzzy systems, especially in the field of educational sciences. It can be suggested that the system obtained in the research can also be used when evaluating students at other levels of education (primary school, high school and university). Finally, in the future, a more comprehensive research can be carried out by supporting qualitative data with quantitative data.

Appendix

Student	Real scores	Artifical scores
S1	78	69
S2	96	91
S3	72	72
S4	73	71
S5	70	64
S6	67	67
S7	90	93
S8	44	44
S9	72	72
S10	68	68
S11	70	70
S12	67	67
S13	71	71
S14	78	78
S15	80	75
S16	69	69
S17	62	62
S18	80	80
S19	85	85

Student	Real scores	Artifical scores
S20	77	59
S21	76	76
S22	74	73
S23	72	73
S24	76	66
S25	91	83
S26	95	85
S27	93	57
S28	72	72
S29	76	73
S30	64	64
S31	82	87
S32	98	87
S33	89	85
S34	95	65
S35	100	100
S36	89	84
S37	83	80
S38	92	72
S39	104	85
S40	82	82
S41	64	49
S42	89	81
S43	48	41
S44	80	78
S45	94	93
S46	90	90
S47	97	95
S48	93	93
S49	91	76
S50	98	85
S51	81	99
S52	53	52
S53	88	85
S54	96	78
S55	70	69
S56	73	82
S57	52	52
S58	51	51
S59	71	71
S60	72	71
S61	60	50
S62	61	61

Student	Real scores	Artifical scores
S63	54	63
S64	50	44
S65	48	47
S66	57	54
S67	57	58
S68	56	55
S69	50	50
S70	72	72
S71	58	63
S72	47	47
S73	26	58
S74	51	63
S75	43	43
S76	32	55
S77	68	71
S78	52	53
S79	45	45
S80	31	43
S81	51	43
S82	60	86
S83	51	54
S84	30	30
S85	75	68
S86	37	52
S87	51	56
S88	56	40
S89	42	42
S90	41	41
S91	47	53
S92	44	44
S93	32	61
S94	22	53
S95	74	74
S96	39	38
S97	37	55
S98	50	57
S99	58	60
S100	48	50
S101	44	44
S102	62	62
S103	48	53
S104	47	47
S105	45	45

Student	Real scores	Artifical scores
S106	27	26
S107	35	35
S108	43	42
S109	42	43
S110	53	54
S111	53	51
S112	61	52
S113	41	74
S114	52	61
S115	40	46
S116	40	60
S117	50	49
S118	57	60
S119	66	65
S120	44	43
S121	57	78
S122	26	37
S123	58	61
S124	37	87
S125	37	37
S126	47	48
S127	57	47
S128	59	59
S129	31	58
S130	41	43
S131	56	45
S132	45	50
S133	76	49
S134	62	61
S135	38	38
S136	60	60
S137	62	62
S138	42	63
S139	24	45
S140	57	57
S141	43	47
S142	41	64
S143	33	39
S144	37	37
S145	38	34
S146	32	34
S147	46	45
S148	37	47

Student	Real scores	Artifical scores
S149	28	27
S150	38	40
S151	22	59
S152	43	54
S153	32	32
S154	52	52
S155	28	41
S156	104	10
S157	48	57
S158	38	50
S159	51	45
S160	59	59
S161	62	53
S162	50	51
S163	41	51
S164	54	54
S165	73	62
S166	49	48
S167	36	46
S168	42	69
S169	54	53
S170	47	46
S171	26	26
S172	45	45
S173	73	73
S174	64	63
S175	92	92
S176	62	62
S177	54	58
S178	57	58
S179	66	66
S180	48	53
S181	78	69
S182	96	90
S183	72	72
S184	73	70
S185	70	64
S186	67	67
S187	90	93
S188	44	44
S189	72	71
S190	68	68
S191	70	70

Student	Real scores	Artifical scores
S192	67	67
S193	71	71
S194	78	78
S195	80	75
S196	69	69
S197	62	62
S198	80	80
S199	85	85
S200	77	59
S201	76	76
S202	74	74
S203	72	73
S204	76	66
S205	91	83
S206	95	85
S207	93	57
S208	72	72
S209	76	73
S210	64	64
S211	82	87
S212	98	87
S213	89	85
S214	95	65
S215	100	100
S216	89	84
S217	83	80
S218	92	72
S219	104	85
S220	82	82
S221	64	49
S222	89	81
S223	48	42
S224	80	78
S225	94	93
S226	90	90
S227	97	96
S228	93	93
S229	91	76
S230	98	85
S231	81	99
S232	53	52
S233	88	86
S234	96	78

Student	Real scores	Artifical scores
S235	70	69
S236	73	82
S237	52	52
S238	51	51
S239	71	71
S240	72	71
S241	60	50
S242	61	61
S243	54	63
S244	50	44
S245	48	47
S246	57	54
S247	57	57
S248	56	55
S249	50	50
S250	72	72
S251	58	63
S252	47	47
S253	26	58
S254	51	63
S255	43	43
S256	32	56
S257	68	71
S258	52	53
S259	45	45
S260	31	43
S261	51	43
S262	60	86
S263	51	54
S264	30	30
S265	75	68
S266	37	52
S267	51	56
S268	56	40
S269	42	42
S270	41	41
S271	47	53
S272	44	43
S273	32	61
S274	22	53
S275	74	74
S276	39	38
S277	37	55

Student	Real scores	Artifical scores
S278	50	57
S279	58	60
S280	48	50
S281	44	44
S282	62	62
S283	48	53
S284	47	47
S285	45	45
S286	27	26
S287	35	35
S288	43	42
S289	42	43
S290	53	54
S291	53	51
S292	61	52
S293	41	74
S294	52	61
S295	40	46
S296	40	59
S297	50	48
S298	57	57
S299	66	65
S300	44	43
S301	57	78
S302	26	37
S303	58	61
S304	37	87
S305	37	37
S306	47	48
S307	57	47
S308	59	59
S309	31	58
S310	41	43
S311	56	45
S312	45	49
S313	76	49
S314	62	61
S315	38	38
S316	60	60
S317	62	62
S318	42	63
S319	24	45
S320	57	60

Student	Real scores	Artifical scores
S321	43	48
S322	41	65
S323	33	39
S324	37	37
S325	38	34
S326	32	34
S327	46	46
S328	37	47
S329	28	27
S330	38	41
S331	22	59
S332	43	54
S333	32	32
S334	52	52
S335	28	41
S336	104	10
S337	48	58
S338	38	50
S339	51	45
S340	59	59
S341	62	53
S342	50	51
S343	41	51
S344	54	54
S345	73	62
S346	49	48
S347	36	46
S348	42	70
S349	54	53
S350	47	47
S351	26	26
S352	45	45
S353	73	73
S354	64	63
S355	92	92
S356	62	62
S357	54	58
S358	57	58
S359	66	66
S360	48	53

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Data availability Data is available upon request from the corresponding author.

Declarations

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