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Problems of Teaching Future Teachers of Humanities the Basics of Fuzzy Logic and Ways to Overcome Them

Abstract

The rapid development of computer technology has led to the use of fuzzy set theory in the medical, financial, economic, commercial and other fields as one of the basic components of artificial intelligence. This is due to its universal mechanism designed to analyze research in the field of humanities research. The mathematical apparatus of fuzzy set theory allows them to be performed with unformalized data, and the development and improvement of information and communication technologies make it possible to automate this process. Unformalized, abstract, "blurred" statistics, which are difficult to analyze, are also common in pedagogy. But in pedagogical practice, fuzzy logic has not been widely used. The article proves the importance and expediency of teaching students, future teachers of computer science, skills in the application of fuzzy set theory. The ability to use the mechanisms of fuzzy logic in applied programs will allow future teachers in their further pedagogical activities to conduct multi-criteria analysis of various characteristics of their students, analysis of pedagogical methods, comprehensive assessment of competencies and more.
The article presents the experience of teaching fuzzy set theory, the logic of teaching and its sequence, as well as the results of such training at a pedagogical university. The necessity of the step-by-step study of fuzzy set theory is proved - from acquaintance with its basic concepts, giving examples of its application in expert systems, neural networks and artificial intelligence systems to independent construction of fuzzy knowledge representation model, development of linguistic variables and use of spreadsheet or specialized programs. The results of the experimental introduction of the topic "Fuzzy model of knowledge representation" in a training course of computer disciplines are shown. Examination of learning outcomes reveals a positive attitude of the students toward mastering the skills of using fuzzy set theory and willingness to apply it in their further pedagogical activities.

Keywords: Fuzzy Logic, Fuzzy Sets, Linguistic Variables, Humanities Research, Teacher Education.

Introduction

Formulation of the problem. One of the features of human mental activity is that humans think in abstract categories. Such thinking is characterized by vague terms, non-quantitative and inaccurate conclusions. And, if at first glance it seems that this is a shortcoming of human thinking, then after a deeper analysis, it turns out that such thinking has certain advantages. Due to such vagueness and blur, humans are able to decipher incomprehensible handwriting, to identify certain patterns presented implicitly and

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incompletely, to recognize images, to provide exhaustive description of fragmentary data.

It is not correct to consider classical binary mathematical logic as a model of ideal thinking at the present stage of science development. Methods of classical "clear" logic are often ineffective, especially for the humanities research, and this forces us to look for new tools of description for unformalized, qualitative characteristics. As a result, scientists are increasingly recognizing the expediency of thinking based not on a direct search of a set of alternatives, but on a qualitative assessment, the so-called "fuzzy logic."

We can say that fuzzy logic can provide effective means of reflecting inaccuracies and uncertainties of our real world.

Incorrect, unformalized tasks exist in all subject areas. The range of applications of fuzzy logic models is too wide – from the management of any technical, financial, logistical processes to the assessment of their qualitative characteristics. Such tasks are also very common in pedagogy. In particular, when determining the quality of knowledge, the level of competence, when choosing the best student to receive an award, etc., it is almost impossible to get accurate results, it is only possible to approach to them as close as possible. This requires methods of representing fuzzy knowledge and mechanisms for drawing conclusions based on it.

However, despite widespread introduction of fuzzy set theory in various fields of human activity (the medical, financial, economic one, etc.), it has not been widely used in pedagogical practice. Although in pedagogy, in the multi-criteria analysis of certain characteristics, most of which have a "blurred" nature, such as "insufficient funding," "low quality textbooks," "more or less favorable conditions," "the best student," the need for tools which provide not only clear answers "yes-no," but also various intermediate values that embody the probability of occurrence of an event is particularly clear.

Unfortunately, the theory of fuzzy problematics ("soft calculations") in most pedagogical publications either is presented too abbreviated, which generates a superficial attitude toward it and underestimation of its potential, or, conversely, contains an abstract theory of its aspects, which is difficult to perceive and, therefore, is not used.

Analysis of Recent Research and Publications

The founder of the mathematical discipline, which is based on the theory of fuzzy sets is Lotfi Zadeh (1975). His main idea was that the way of thinking characteristic of man cannot be described within the framework of traditional mathematical formalisms. L. Zadeh took the first step toward converging the accuracy of classical mathematics with the mass blurring of the real world. L. Zadeh set as a pragmatic goal the creation of such a mathematical apparatus that would be able to model human reasoning and explain human decision-making techniques. For this new field of science, he coined the name "fuzzy logic."

Gradually, with the progressive development of science and technology, the mathematical apparatus that translates ambiguous statements into the language of clear formalized mathematics began to become widely used and became the subject of numerous studies.

Today, fuzzy set theory is widely used in expert systems, neural networks and artificial intelligence systems, and the world has a sufficient number of scientific papers on this topic. The theoretical foundations of fuzzy set theory are laid in the works of B. Cosco (1986; 1991), the author of the FAT theorem (Fuzzy Approximation Theorem). According to this theorem, any classical mathematics can be approximated by means of fuzzy logic. L. Zadeh's idea, confirmed by B. Cosco's theorem, gained wide recognition after an expert system developed on the basis of fuzzy rules was the only one in the world to predict the stock market crisis of 1988 (U.S. Bureau., 2021).

Fuzzy set theory has been widely applied in the automotive, transport, financial, medical and other fields. This theory allows to structure human reasoning that is endowed with insufficiently clear boundaries, subjective abstract assessments. Such reasoning is typical of humanities research, in particular, in the field of pedagogy, where the study of qualitative characteristics (competence, social activity, motivation, etc.) prevails over the study of quantitative ones (average score, quality of knowledge). Possibilities of "soft calculations" in humanities research have been studied by M. Vershinin and L. Vershinina (2007). They proved that classical quantitative analysis has its limits beyond which quality and depth can be lost. A rational scale for measuring the properties of humanities objects can be obtained by applying fuzzy logic.

The problematics, models and prospects of teaching "soft" mathematical models are studied by V. Arnold (2004). S. Tarkanovskyi (2010) considers the design of intelligent educational systems on the basis of fuzzy set theory. He has developed an automated environment for building individual trajectories for medical services. The possibility of using the apparatus of fuzzy set theory in the design of distance learning technologies has been demonstrated in scientific works of A. Smirnov (2016).

The study of fuzzy logic is in the programs of specialized and economic specialties of higher educational institutions. A. Leonenkov highlights a wide range of possibilities for developing fuzzy models in conducting various studies. He also carefully describes the features of fuzzy modeling in MATLAB and fuzzyTECH software environments (Leonenkov, 2003). O. Reva (2004; 2005; 2006) attaches great importance to the theory of fuzzy sets in his pedagogical research. The author, together with other researchers, developed models of "facilitated assessment scale," in particular, to measure undisciplined behavior of students.

According to E. Chernyavska and V. Novak, F. Herrera and others, the theory of fuzzy sets has a wide field of application for solving many pedagogical problems. They are convinced that the tools of fuzzy set theory provide a teacher with ample opportunities for conducting and automating research (Chernyavskaya, 2011; Novak, Perfil'yeva, Mochkorzh, 2006; Herrera, Herrera-Viedma, 2000). However, whereas future teachers of technical specialization (mathematics, physics, computer science) deeply study the theory of fuzzy sets and the mechanisms for their use, in training students of humanities specialties, attention to the study of fuzzy logic is almost not paid.

The above determines the relevance of considering the methodology of teaching the basics of fuzzy logic to students of pedagogical higher education institutions, in particular, future teachers of humanities.

The purpose of the article is to substantiate the importance of teaching students, future teachers of humanities, the basics of fuzzy logic, identifying problems that hinder successful teaching and highlighting effective and affordable pedagogical methods of overcoming these problems.

Research Methods

As the main methods of experimental research, the following ones were used:

- Study of experience and systematization of domestic and foreign approaches to the study of the apparatus of fuzzy set theory.
- Analysis of the peculiarities of the organization of the process of studying fuzzy sets for future teachers.
- Conducting pedagogical measurements (questionnaires, observations, analysis of learning outcomes).
- Synthesis of experience in teaching the basics of fuzzy logic at pedagogical universities.
- Pedagogical experiment, finding effective ways to teach the theory of fuzzy sets to future teachers of humanities.

Sumy State Pedagogical University became the experimental base of the research. The pedagogical experiment lasted two years (2018-2020) and consisted of the stating stage and the forming one. At the stating stage, the prospects and relevance of teaching students "soft calculations" were substantiated and, by conducting student assessment and surveys, difficulties that hinder the process of mastering by students of pedagogical universities the theory of fuzzy sets were identified; at the forming stage, pedagogical methods that improve the teaching process were tested. The experiment involved data processing at the forming and stating stages, comparison and verification of the obtained results using methods of mathematical statistics. The experiment took place in the process of studying the discipline "Selected IT issues" for third-year students. The total number of respondents was 105 people; 85 pedagogical university students and 25 computer science teachers were experts. An important condition for conducting the experiment was the inclusion of students studying in the humanities.

Reaserch Results

The topic "Basics of fuzzy logic" is included in the variable component of the discipline "Selective IT issues," which is provided for by the program for students of pedagogical universities. Due to the limited number of hours (6 hours) devoted to this topic, students fragmentarily study the mathematical apparatus and master the skills of fuzzy modeling. According to the topic plan, after a lecture, which provides an overview of theoretical material, they perform laboratory work, working according to the algorithms given in the instructions using the programs MatLab or FuzzyLogicToolbox. These programs have a set of built-in functions designed to create functions of membership of fuzzy sets, to combine them and to visualize the results.

The experience of teaching the discipline and, in particular, this topic, showed that students are quite successful in performing laboratory work on the topic "Design and development of a fuzzy inference system in an interactive mode." This is due to the formed digital competence, acquired skills of algorithmic thinking. But already the next laboratory work "Solving typical problems" is performed mostly reproductively, and independent design and development of own tasks, in particular, an expert system based on fuzzy sets, causes significant difficulties. Students do not sufficiently understand the essence of fuzzy sets and the potential of applied application of fuzzy logic theory. Adhering to the algorithm described in the instruction, they do not think about the fact that the principles of fuzzy methods, operations on fuzzy sets and the logic of formalization of various criteria can also be applied in performing any applied pedagogical task.

The results of student surveys after studying this topic confirmed these observations. The survey provided for detailed answers to the following questions: "Do you think that the topic "Basics of fuzzy logic" is important for future teachers?", "Assess the level of your knowledge of fuzzy set theory on a 5-point scale," "Which parts of the aforementioned topic caused the greatest difficulties?", "Do you think it is appropriate to further study the theory of fuzzy sets?".

The results of the analysis of the answers to the questionnaire questions are presented in the diagrams.

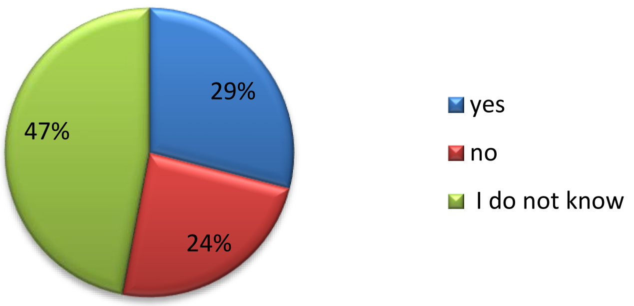

Fig. 1.

Students' judgments about the importance of the topic "Basics of fuzzy logic" for future teachers"

The results of the survey indicate a lack of awareness of the importance of fuzzy set theory in teaching. This is confirmed by the fact that only 24% of the respondents said a resounding "No," and almost half of them (47%), after studying the theory and conducting laboratory work, could not make a decision and therefore answered "I do not know."

The results of the respondents' assessment of their own level of knowledge on a 5-point scale are presented in Figure 2.

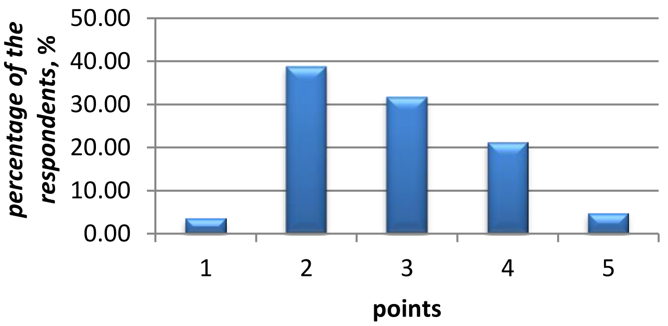

Fig. 2.

Distribution of answers to the question "Assess the level of acquired knowledge of fuzzy set theory on a 5-point scale"

The learning outcomes explain the distribution of answers to the above question. 38.82% of the respondents rated their knowledge at 2 points, and 31.76% - at 3 points. We conclude that the topic was quite difficult and incomprehensible to the students.

Answers to the open-ended question "Which of the following topics caused the most difficulties?" provide an explanation for the low scores on learning outcomes. The most common answers were: a very complex mathematical apparatus; routine heavy calculations; I do not understand how to apply it; an incomprehensible program for automation of calculations.

As a result, when asked about the need for future teachers to further study fuzzy set theory, the answers were distributed as shown in the diagram.

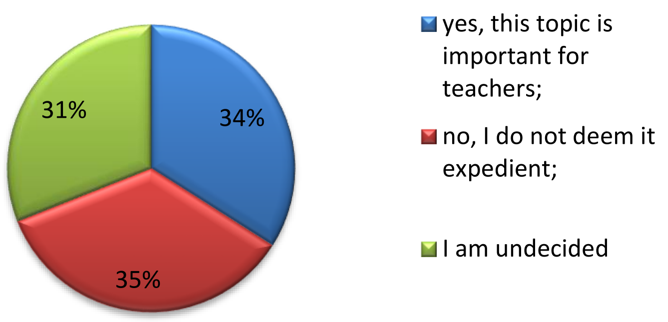

Fig. 3.

Distribution of answers to questions about the expediency of further studying the theory of fuzzy sets

Analyzing the respondents' answers and assessing the students' knowledge on this topic revealed that the students have a low level of interest in and a low level of knowledge of the theory of fuzzy sets (Fig. 4). We believe that this is the reason for the lack of motivation and desire to further study and apply fuzzy logic in pedagogical research.

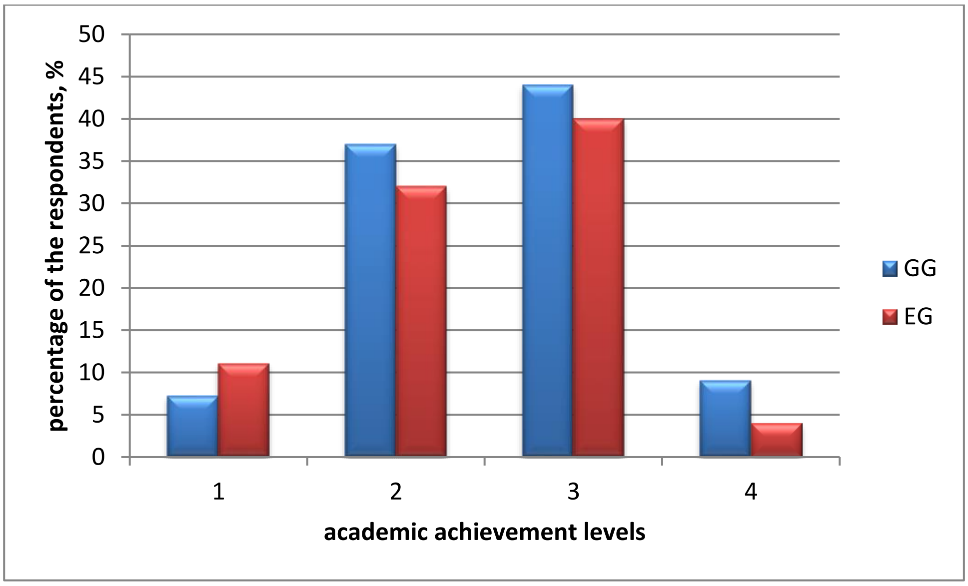

Fig. 4.

The level of student academic achievement at the beginning of the experiment

Thus, acquaintance with the experience of teachers teaching computer science, study of methodological literature, personal observations, student questionnaires and student assessment showed: the topic of the basics of fuzzy logic, at first glance, is simple, but in the process of studying, students encounter the following difficulties:

1. *Unawareness of the need to master fuzzy logic.* Without motivation in learning, it is impossible to encourage students to carry out any educational activities, and therefore, without argumentation and proving the relevance of the theory of fuzzy sets, the study of the topic becomes problematic.
2. *Mechanical memorization.* Students try to memorize formulas mechanically, but do not understand their essence. As a result, the connection between fuzzy sets and the logic of their application is not understood.
3. *Problems with calculations.* Not all students, especially in the humanities, have a thorough mathematical background, so it is difficult for them to master the features of "soft calculations." As a result, students block learning material and do not even try to understand it.

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4. *Insufficient time to study the topic.* A significant amount of information is provided in a short time. Theoretical material, not supported by sufficient practice, leads to confusion in the use of concepts and knowledge, the application of operations on this knowledge and the formation of fuzzy conclusions.

We assume that this situation is determined by the pedagogical approaches and techniques used in the study of the topic "Fundamentals of fuzzy logic." Since for conducting pedagogical research on the basis of qualitative characteristics the role of fuzzy logic, its significant potential and wide range of applications are obvious, an idea of improving pedagogical methods for mastering the topic "Fundamentals of fuzzy logic" by students of pedagogical universities arose.

To overcome the identified problems, we conducted the second stage of the experiment, which involved students of humanities (an experimental group). The second stage was based on changing approaches to studying the basics of fuzzy logic.

Let us outline the aspects that led to a positive result in the levels of academic achievement of the students in the experimental group.

First, during the training, special attention was paid to the motivational and psychological components.

Understanding social significance, needs, future orientation and cognitive interests, emotions and aspirations allowed to identify the following motivational levers for teaching future teachers the basics of fuzzy logic:

- Multidisciplinary nature of research (a huge number of humanities research, in which linguistic fuzzy variables are used, is conducted in pedagogy).
- Developing context of training (it is useful for future teachers to know and be able to master an apparatus for modeling the human thought process).
- Improvement of information competence (the ability to use the apparatus of fuzzy logic will allow to effectively use information technology and software, work with information in its various forms and representations in future professional activities).
- Prospectivity and relevance of the topic, applied potential for the teacher.

It was important to prove to the students the viability of using the basics of fuzzy logic. Thus, fuzzy adaptive planning and real-time management systems are becoming increasingly common in educational marketing and management.

It was noted that the use of fuzzy sets is almost inextricably linked with data mining. In particular, fuzzy neural networks, which form conclusions based on the apparatus of "soft computing," are considered universal approximators today, and linguistic information can be successfully used in decision-making when solving multicriteria problems (Herrera, Herrera-Viedma, 2000).

Fuzzy queries in databases and fuzzy associative rules are considered to be promising areas in modern information processing systems. Fuzzy queries are queries formed in natural language, taking into account the vagueness, blur of the query. Fuzzy associative rules are tools for extracting from the databases patterns formed in the form of linguistic statements (Nasseri et al., 2012).

Secondly, when studying the theory of fuzzy sets, special attention was paid to a comprehensible presentation of the lecture material, its visualization.

The main ideas of fuzzy logic were covered through an analogy with classical logic, ideas of artificial intelligence, through models of knowledge representation, the essence and methods of formalizing fuzzy or incomplete data, the essence and logic of developing expert systems. Quite complex theoretical material was enriched with examples of the use of "soft calculations" in the pedagogical and other fields of science.

Mastering the terminology, in particular, the concept of fuzzy sets, linguistic variable, membership function, usefulness term, it was advisable to draw an analogy with classical set theory, to demonstrate examples of models of applying fuzzy set theory in various fields of human activity. It was important to convey that the essence of "fuzzy sets" is in intuitive understanding the common properties of the elements of a set, but to a greater or lesser extent, and this is what determines their belonging to the set with different degrees of belonging.

A fuzzy set is characterized by a membership function denoted as MFc(x). A fuzzy set C is a set of pairs of the form C = {MFc (x)/x}, MFc(x) [0,1]. MFc(x) = 0 determines the absence of membership, MFc(x) = 1 determines the complete membership of a set.

For example, the formalization of the fuzzy definition of "coffee temperature" is as follows.

$$\mathrm{C} = \left\{\frac{0}{0};\ \frac{0}{10};\frac{0}{20};\frac{0{,}1}{30};\frac{0{,}2}{40};\frac{0{,}5}{50};\frac{0{,}7}{60};\frac{0{,}9}{70};\frac{1}{80};\frac{1}{90};\frac{1}{100}\right\}$$

where

x is a temperature scale in degrees Celsius (area of reasoning).

The set characterizes people's opinions about coffee by its temperature. For all people, coffee at a temperature of 100^0C is considered hot, and a coffee temperature of 70^0C is considered hot for some, but not for others. This is how the vagueness of the problem of a certain set is manifested.

For fuzzy sets, as well as for classical ones, the basic logical operations are defined, the most common of which are intersection, union, difference, symmetric difference, addition, algebraic addition, multiplication by a number. The difference is in the introduction of the operators of minimum for the intersection of sets and maximum for the union of two fuzzy sets (Chernyavskaya, 2011).

Let set A be defined by the function $MF_A(x)$, set B – by $MF_B(x)$, and set C – by the function $MF_C(x)$. The set C is the result of the operations of intersection, union, inversion (1).

$$C = A \cap B: MF_C(x) = \min(MF_A(x), MF_B(x));$$
$$C = A \cup B: MF_C(x) = \max(MF_A(x), MF_B(x));$$
$$C = A: MF_C(x) = 1 - MF_A(x) \quad (1)$$

The laws of commutativity, associativity, distributivity, and set composition methods are used for intersection and union of two fuzzy sets.

To describe fuzzy sets, the concepts of fuzzy and linguistic variables are introduced.

A fuzzy set is described by a set (N,X,A), where N is the name of a variable, X is a universal set, and A is a fuzzy set in the domain of the universal set X.

A linguistic variable is at a higher level, so its values may be fuzzy variables. Each linguistic variable contains in its composition: the name; sets of its values (basic term set T); a universal set X; a syntactic rule G, which generates new terms when using natural or formal language; a semantic rule P, which places in correspondence with each value of the linguistic variable a fuzzy subset of the set X.

For our example, the term "hot coffee" is the name of a linguistic variable. The basic term set for it will consist of three fuzzy variables: "Cold," "Moderate," "Hot," and the scope of reasoning is in the range [0,100].

The mathematical apparatus is supplemented by the construction of a membership function for each linguistic term from the basic term set. The most common are triangular, trapezoidal and Gaussian membership functions.

The mechanism of logical inference consists mainly of four stages: fuzzification or introduction of fuzziness, fuzzy inference, formation of a base of rules for fuzzy inference and de-fuzzification (reduction to precision).

It was important to show future teachers how fuzzy set theory can be applied.

To this end, the following task is solved: on the basis of binary fuzzy sets, to build a model that advises a student in choosing his/her future profession.

Suppose that a fuzzy set X is a set of specialties. X = {"manager," "programmer," "driver," "journalist," "teacher"}.

A fuzzy set Y is a set of professional characteristics. Y = {"flexibility of thinking," "speed of decision making," "attention concentration," "visual memory," "speed of reaction," "sociability," "physical activity," "coordination of movements," "emotional stability," "responsibility"}.

A fuzzy set Z is a set of high school students. Z = {"Petrenko," "Ivanenko," "Sydorenko", "Vasylenko", "Hryschenko"}

The values of the membership functions for the created sets are presented in Tables 1 and 2.

Table 1.

Fuzzy Set of Career Guidance

Profession	**Set of professional characteristics Y**									
	Flexibility of thinking	**Speed of decision**	**Attention concentration**	**Visual memory**	**Speed of reaction**	**Sociability**	**Physical activity**	**Coordination of movements**	**Emotional stability**	**Responsibility**
Manager	0.9	0.9	0.8	0.4	0.5	0.3	0.6	0.2	0.9	0.8
Programmer	0.8	0.5	0.9	0.3	0.1	0.2	0.2	0.2	0.5	0.5
Driver	0.3	0.9	0.6	0.5	0.9	0.8	0.9	0.8	0.6	0.3
Journalist	0.5	0.4	0.5	0.5	0.2	0.2	0.3	0.3	0.9	0.8

The expert grades determine the degree of belonging to these student characteristics.

Table 2.

Fuzzy Set of Candidates

Professional characteristics	**Students' surnames**				
	Petrenko	**Ivanenko**	**Sydorenko**	**Vasylenko**	**Hryschenko**
Flexibility of thinking	0.9	0.8	0.7	0.9	1
Speed of decision making	0.6	0.4	0.8	0.5	0.6
Attention concentration	0.5	0.2	0.3	0.8	0.7
Speed of reaction	1	0.6	0.5	0.7	0.4
Sociability	0.4	0.5	1	0.7	0.8
Physical activity	0.5	0.8	0.9	0.5	0.4
Coordination of movements	0.5	0.6	0.7	0.6	0.5
Emotional stability	0.8	1	0.2	0.5	0.6
Responsibility	0.3	0.5	0.9	0.6	0.8

The considered sets satisfy the formal requirements necessary to perform a fuzzy composition according to formula 2.

$$\mu_{Q\cdot R}\left(< x_i, x_j >\right) = \max\{\min\{\mu_Q\left(< x_i, x_j >\right), \mu_Q\left(< x_j, x_k >\right)\}\} \quad (2)$$

The result of the operation of fuzzy composition is presented in a tabular form (Table 3).

Table 3.

Fuzzy Composition of Two Sets

Profession	**Students' surnames**				
	Petrenko	**Ivanenko**	**Sydorenko**	**Vasylenko**	**Hryschenko**
Manager	0.9	0.9	0.8	0.9	0.9
Programmer	0.8	0.8	0.7	0.8	0.8
Driver	0.9	0.8	0.9	0.7	0.8
Journalist	0.8	0.9	0.8	0.6	0.8
Teacher	0.7	0.7	0.8	0.8	0.7

The values of the membership function are obtained using formulas 1. First, the minimum values of all pairs of elements of the first row of Table 3 and the first column of Table 4 - min {0,9, 0,9} = 0,9, min {0,9, 0,8} = 0.8 and so on - are found. After finding all 10 minimum elements of the membership function, we find among them the maximum element, which is the desired value $\mu_{Q\cdot R}\left(< x_i, x_j >\right)$=max{0.9, 0.8, 0.5, 0.4, 0.5, 0.3, 0.5, 0.2, 0.8, 0.3}=0.9. The other values of the function are found similarly.

Table 3 shows that, as the best profession, for student Petrenko, the professions "manager" and "driver" are recommended; for Ivanenko - "manager" and "journalist"; for Sydorenko - "driver"; for Vasylenko and Hryschenko - "manager."

It is advisable to develop tables and arguments "on paper," but to include software in the calculations, in particular, MS-Excel spreadsheet processor. Performing this task first in a copybook and then in a spreadsheet of the spreadsheet processor, students begin to understand the basics and essence of methods of work with fuzzy sets, learn to form the rules of inference, track errors.

The next step showed how software, such as Matlab, facilitates performing such tasks. The figure shows the program window, which visualizes the two input fuzzy sets and the result of their processing (Fig. 5). The process automation provided by the program after performing such tasks "manually" no longer allowed the students to treat them superficially and reproductively. Observations of performing the tasks showed: with the realization of the potential of software, there was a creative attitude, the desire of the students for independent research work.

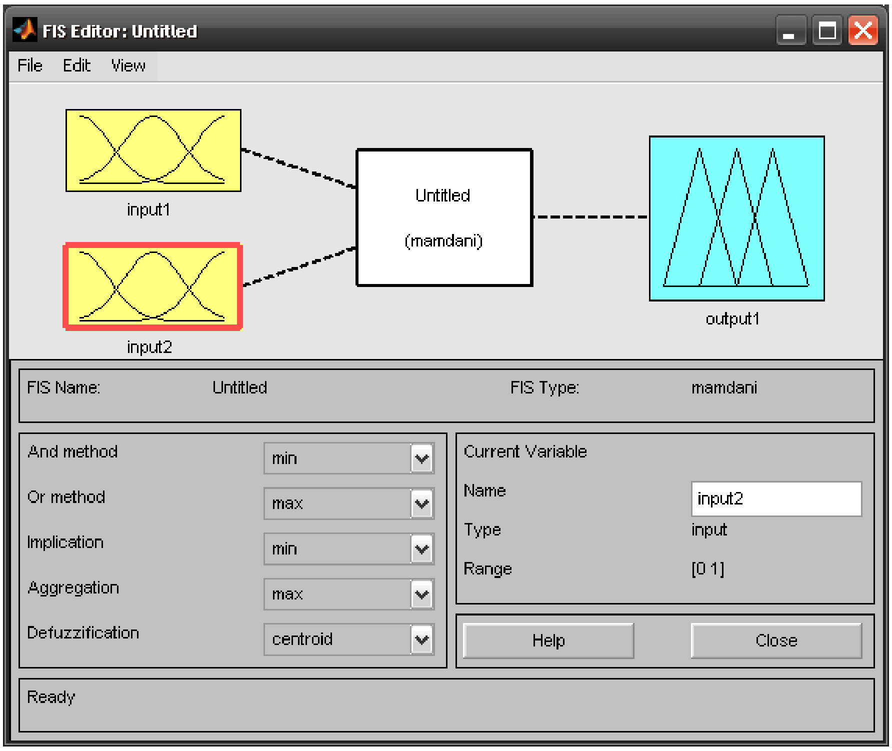

Fig. 5.

Matlab Program Window

The students were asked to perform similar tasks independently according to a similar algorithm. At the beginning, they learned to construct membership functions for terms used for linguistic evaluation of a variable (for example, the linguistic variable "student behavior"). The method of statistical processing of opinions of a group of 5 experts was used for the constructed function. The results of processing the opinions of the experts and their visualization were performed using a spreadsheet processor.

In the following tasks, the students independently modeled tasks such as "assessment of professional competencies," "choice of the group leader," "quality of teaching a discipline" or developed any model of their choice. The skills worked on formulated the sequence of performing a task and included: problem statement, formalization of fuzzy data, establishment of inference rules, development of skills of working with spreadsheets, use of a special software environment, visualization. Independent performance of such tasks allowed the students to feel the significant potential of the applied role of fuzzy sets.

The problem of lack of time to study this topic was solved during independent work or project activities, which were evaluated by additional points.

The learning outcomes of the students of the experimental and control groups were studied based on the results of tests on the topic "Basics of fuzzy logic" at four levels:

Low (1 - corresponds to the assessment of academic achievement in the range from 1 to 4).

Medium (2 - corresponds to the assessment of academic achievement in the range from 5 to 7).

Sufficient (3 - corresponds to the assessment of academic achievement in the range from 8 to 10).

High (4 - corresponds to the assessment of academic achievement in the range from 11 to 12).

At the beginning of the experiment, using Pearson's criterion χ^2 and Student's criterion, it was found that the level of the students' knowledge of the basics of fuzzy logic was statistically the same. At the end of the experiment, the average scores of the academic achievements of the control and experimental groups were studied, which showed a statistical difference at the level of significance of 0.05. In the experimental group, the average score was higher by 23.8%, which proves the effectiveness of the implemented teaching methods (Table 4).

Table 4.

Evaluation of the Average Scores of the Control and Experimental Groups (According to Student's Criterion for Significance Level of 0.05)

Group	**Number of respondents**	**Average score at the beginning of the experiment**	**Average score at the end of the experiment**	**Remark**
CG	45	6.42	6.7	T_{stat}=0.45 < 1.96 = Tcr (at the beginning of the experiment).
EG	40	6.33	8.3	T_{stat} = |-2.4| > 1.96 = Tcr at the end of the experiment

Comparisons of the learning outcomes of the control and experimental groups are presented in Figure 6.

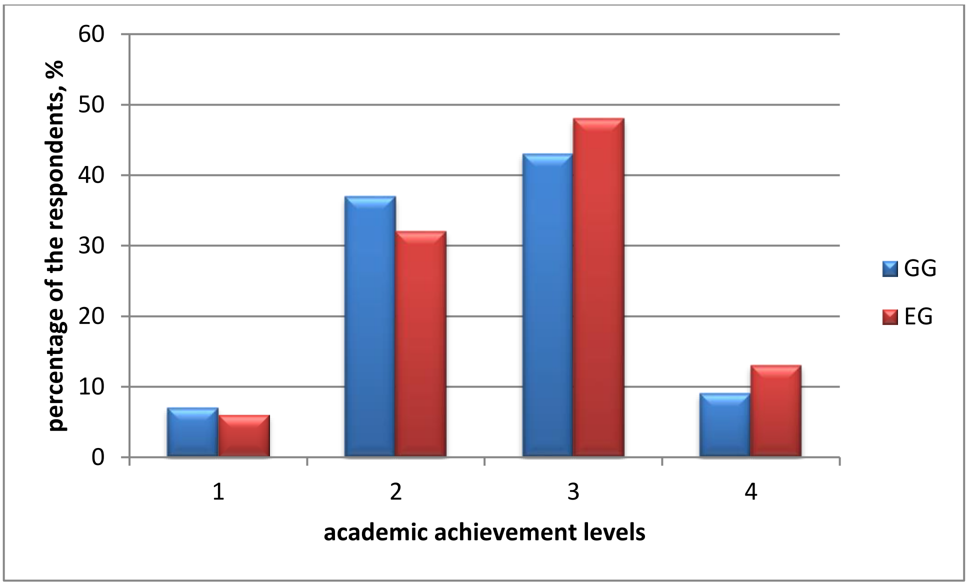

Fig. 6.

The level of the students' academic achievement at the end of the experiment

As a result of performing the tasks, the students demonstrated a sufficient level of knowledge in the field of fuzzy logic (75% of them performed the tasks with grades "5" and "4"), 69% developed their own projects and implemented them. 84% of the students showed a willingness to use the material studied to solve applied problems.

After conducting the experiment, a re-survey was also conducted; the results of processing the questions and answers show: an increase in the percentage of students satisfied with studying the basics of fuzzy logic (up to 78%), an increase in the number of students who expressed a desire to deepen the knowledge obtained and to continue to study "soft calculations," 24% of the students overcame uncertainty in the use of the mathematical apparatus, and they expressed confidence in their abilities.

Conclusions and Prospects for Further Research

Thus, the study of the theoretical foundations and methods of fuzzy modeling is of great practical importance for most areas of human activity, including the pedagogical one. The significant potential of the theory of fuzzy logic and a wide range of its application determines the introduction of this topic in the training of future teachers of not only technical disciplines but also the humanities.

As a result of the research, problems were identified that hinder successful training of students of pedagogical universities (Bakhov, Boichenko, 2020). The main ones, to our opinion, are the following: students' lack of awareness of the need to master fuzzy logic; mechanical memorization of formulas and operations;

problems with mathematical calculations; insufficient time to study this topic.

Introducing pedagogical methods such as: increasing the role of motivation to learn, outlining the prospects of fuzzy logic for a teacher, presenting theoretical material enriched with examples, associations and visualization, development and gradual creation of one's own fuzzy model, as well as independent research work improved the learning outcomes, which is shown by a re-survey and a reassessment of the student's knowledge at the end of the experiment (Bakulina, Lehan, Bakhov, 2019).

We consider it promising to expand the range of using, in the educational process, educational techniques of distance learning and to use game technologies in the study of fuzzy set theory, as well as to promote pedagogical research based on fuzzy logic, in particular, to use other software: Deductor program and Loginom analytical platform (Arustamov, n.d.).

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