American University Kyiv

A Capstone Project

FUZZY LOGIC AS A TOOL FOR ASSESSING GROUP WORK OF IT STUDENTS

НЕЧІТКА ЛОГІКА ЯК ІНСТРУМЕНТ ОЦІНЮВАННЯ ГРУПОВОЇ РОБОТИ СТУДЕНТІВ ІТ НАПРЯМКУ

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ABSTRACT

This paper investigates an approach to assessing student performance in team projects based on the mathematical apparatus of fuzzy logic. The relevance of the work is driven by the need to improve student assessment processes in group projects, particularly in the field of IT education, where teamwork is a key element of professional training. The proposed model allows to take into account the multidimensionality of assessment parameters, such as technical competence, communication skills, initiative, teamwork, time management, and analytical skills. Each parameter is represented as a set of levels, which allows for an objective consideration of both the strengths and weaknesses of the student.

The modelling has confirmed that the system provides flexibility in taking into account various parameters of student performance, fair distribution of grades and individual feedback.

The proposed approach can be successfully applied in the field of education to create more fair and adaptive assessment systems, in particular in the field of IT and engineering, where teamwork is a key component of the learning process. This work can be continued in the direction of scaling the model to other areas, such as medicine, law, etc., where group work is also an important element of professional activity.

Keywords: fuzzy logic, student assessment, team assessment, mathematical model.

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INTRODUCTION

Information technology is currently one of the most important subject areas in the world and in Ukraine. Government customers, private entrepreneurs and large companies alike need specialists in this field. Today, IT companies are among the most influential in the world, and this trend continues to grow. At the government level, IT is also very relevant and continues to develop. A good example is the first-of-its-kind Diia app.

This profession is also of interest to many people of all ages because it has many advantages. Nevertheless, to become a specialist in this field, you need a high-quality education. Today, unified grading systems that do not take into account the variety of parameters that need to be considered in the final assessment of a student are gradually losing their relevance. Individual feedback that shows students their strengths and weaknesses is increasingly valued.

At the same time, a teacher does not always have the opportunity to provide each student with quality feedback and conduct a fully objective assessment of their knowledge. Technical skills are certainly basic and very important. However, at the same time, teamwork is a very important skill. Often, private or university courses cannot provide a sufficient level of training in this area, because group projects are multifaceted and complex. Conventional tests cannot fully assess the skills of an individual.

The aim of the work is to develop an mathematical model for evaluating students' work in group projects, which allows to take into account the multifactorial nature of the assessment, objectively determine the level of contribution of each team member, and increase the efficiency of the educational process in IT education.

As part of the study, the following **tasks** are planned to be completed:

- Analysis of existing methods for assessing students in group projects;
- Finding a universal solution to the problem of objective assessment of all aspects of teamwork;
- Developing a theoretical model with the prospect of automating the solution;
- Testing the model on a hypothetical group of students;
- Drawing conclusions on the work done.

CHAPTER 1. OVERVIEW OF THE SUBJECT AREA

1.1 Relevance, analysis of the subject area

Information technology is one of the most important subject areas in the world and in Ukraine today. The number of IT schools, specialities and the need for specialists is constantly growing. According to various sources and studies, the share of the IT sector in Ukraine's GDP is between 2% and 5%. The IT sector generates billions of dollars in foreign currency flows to Ukraine, which is especially important and relevant in wartime.

For this reason, government agencies have long been stimulating the IT sector through government reforms and educational programmes. For example, in 2022, the state initiative IT Generation was launched, which offered 60,000 students a free IT profession [1].

Also, the number of government orders for IT specialists remains stable and even grows every year. For example, in 2024, the number of state orders in the field of Information Technology, Bachelor's degree, was more than 10,000 places. This is the second largest state order after the field of Education/Pedagogy, where the number of state orders is only a few thousand more [2].

Thus, the educational process in Ukraine in the field of information technology is a very important and relevant area. One of the key factors in the successful education of students of any speciality is a fair assessment, which can not only objectively show the level of knowledge of the student, but also point out to the student the areas that should be worked on more actively.

Technical knowledge alone is not enough to be an IT professional. An effective employee in this field must constantly learn new technologies that make products safer, more convenient and cheaper. Teamwork is also an important aspect, as most products are created by teams. It doesn't matter whether it is a government order or a private company, the team to develop a high-quality and safe product must include several specialists. This is due to the large amount of knowledge that needs to be mastered to do the job. Also, the process of creating a particular part of the product requires a large amount of time.

That's why teams include development, cybersecurity, requirements and data analytics, designers, and so on. The ability to work in a team is becoming one of the most important skills that a future IT professional must have.

1.2 Analysis of scientific papers

There are many articles exploring approaches to assessing individual student contributions to group projects. The main challenge is the need to ensure fair assessments for each participant, taking into account both the technical and interpersonal skills acquired during the work.

The conclusions recommend the use of the Neuro-Parametric Assessment (NPA) for large groups, as this method allows for accurate assessment even with a large number of participants, although it carries a certain risk of manipulation. For small groups with a series of projects, the Project-based Interactive Methodology (PiM) approach was found to be the most effective, as it ensures high accuracy of assessment without additional burden on students and teachers. Computer modelling to assess the fairness and accuracy of these methods is very important, offering new ways to improve assessment systems in educational institutions, as it avoids bias and reduces the influence of subjective factors [3].

In modern engineering education, the development of teamwork skills is important, but assessing individual contributions to team projects is often a difficult task. To solve the problem of uneven distribution of grades and avoid "free riding", peer review is introduced, where students evaluate the contribution of each team member according to predefined criteria.

This approach allows adjusting the overall team score according to the individual contribution of each participant, which increases the fairness of assessment, motivation to work and the effectiveness of team interaction. Students also note improvements in their interaction in teams, which contributes to the formation of key professional skills [4, 5].

Recommendations for effective implementation include clearly defining the purpose of the assessment, using appropriate tools, ensuring partial anonymity, and providing regular feedback. Formative assessments help students improve their skills as they progress through the course, while summative assessments can be used for final evaluations. This contributes to the development of critical teamwork skills that are essential for successful professional activities [6].

The use of peer and self-assessment in teaching contributes to the development of metacognitive skills and increases students' self-efficacy. The results of the study show that peer assessment provides high reliability compared to expert assessments, although students tend to overestimate the work of their peers. At the same time, self-assessment demonstrates lower reliability, but has an important impact on student motivation and improvement of their ability to self-regulate. Therefore, a combined approach to assessment will be most effective, where part of the scores and feedback can be provided by peers, and the other part can be evaluated by teachers and experts. At the same time, self-assessment can greatly affect the objective results, so the use of self-assessment in the formation of the final score can distort the real results [7-9].

The study also showed that the effectiveness of peer assessment remains stable in different educational contexts, regardless of the level of education, the form of feedback (written, oral, evaluation) and the use of additional tools such as rubrics or anonymity. This confirms the feasibility of integrating peer assessment as a formative practice into the educational process [10].

In the article about peer review in the course "Software Design in C++", it is stated that an evaluation rubric was used, which included the following criteria: code design, clean code, complexity, creativity, and user interface. Each criterion was evaluated on a scale from 0 to 5, and each of them was assigned a weight when calculating the overall grade [11].

Studies aimed at assessing students' performance in group work offer a variety of assessment models that take into account both the process and the product of group work. The evaluation criteria include meeting attendance, equality of contribution, collaboration, time and task management, creative problem solving, receptivity to feedback, effort, initiative, responsibility and supportive behaviour [12, 13].

So, to solve the problem of objective assessment of IT students, a formalised automated approach would be the best approach. It should take into account both expert assessments and peer assessments. For maximum effectiveness, the educational process should also include a self-assessment process, but it would be incorrect to involve such an assessment in the formation of the final grade, as this number would be very easy to manipulate.

The assessment of such a specific area as group work should take into account both technical skills and verbal skills (communication). This is important, because today the most effective employees in IT companies are those who have good characteristics in both of these areas (also called hard skills and soft skills).

It is also suggested to include the student's analytical skills in this article. It is important not just to discuss the task with the team (verbal skills) and complete the task (technical skills). It is also necessary to correctly interpret the requirements set by the customer, and in the case of a student, by the teacher, so that there are no logical errors in the completed project. Analytical skills include: critical thinking that questions the correctness of the initial data, interpretation of results, ability to solve systemic problems, ability to make predictions, documentation and presentation of results.

1.3 Method selection and justification

Given the large number of factors that are difficult to assess, it becomes necessary to select an appropriate assessment system. It should take into account not only technical knowledge, but also the role of other skills that are important for teamwork. Of all the above approaches, I would like to highlight fuzzy logic.

The basic concept of fuzzy logic is the use of fuzzy sets, which allow objects to be classified not strictly in the categories of "belongs" or "does not belong", but using a continuum of values (degrees of membership). The degree of membership is a number from 0 to 1 that indicates how strongly an object belongs to a certain group in fuzzy logic: 0 means that the object does not belong to the group at all, and 1 means that it belongs completely. [14]. With this approach, it is possible not only to include parameters that are difficult to assess using traditional methods, but also to assign different values to each of the parameters. For example, technical knowledge is more important than a student's ability to manage their own time. Or a student's initiative, which is certainly an important characteristic, may not be more important than the student's general teamwork skills.

Many studies have been devoted to the application of various fuzzy logic approaches in education and assessment systems [15, 16]. This method also allows analysing and evaluating complex student activity, including participation in discussions, test scores, perseverance, and other parameters that are difficult to objectively describe with a single numerical value. A mathematical model using fuzzy logic takes into account the importance of each of these parameters, weighing them to generate a final grade.

In addition, fuzzy logic is used to create adaptive learning systems that adjust to the student's level of knowledge and learning style. It also helps automate recommendation processes by selecting the best learning resources and tasks. As a result, each student receives an individual approach, which helps to improve learning outcomes [15].

IT requires close teamwork and teamwork is often difficult to measure. Different team members may have a specific set of responsibilities. You can't evaluate a student solely by the number of committees or solely by how often a participant expresses his or her opinion in a discussion. The team may unconsciously divide into more "leaders", more "managers" and more "programmers". Each role is important and the mathematical model should take into account all these aspects. A correctly formed assessment will not only objectively evaluate the student's achievements after teamwork, but will also be able to provide correct feedback.

Humanitarian fields such as economics, philology, law, etc. are also close to such a fuzzy set of parameters for assessment. The study [16] describes the formalisation of the process of assessing the level of speech and communication professional competence of students of economic specialities based on the mathematical apparatus of neural networks and fuzzy logic. This approach can be a good example for solving the problems posed in our study.

CHAPTER 2. DESCRIPTION OF THE APPROACH

2.1 The basic model

The solution for a more objective assessment of students' work in an IT team based on fuzzy logic will be based on a mathematical model. It will take into account various factors, such as technical knowledge, communication skills, time management skills, etc. The formula will determine the results of each student, namely whether a particular score (grade) belongs to a certain class, such as the High Grade or Average Grade class. The general concept of the proposed approach is presented in Figure 1.

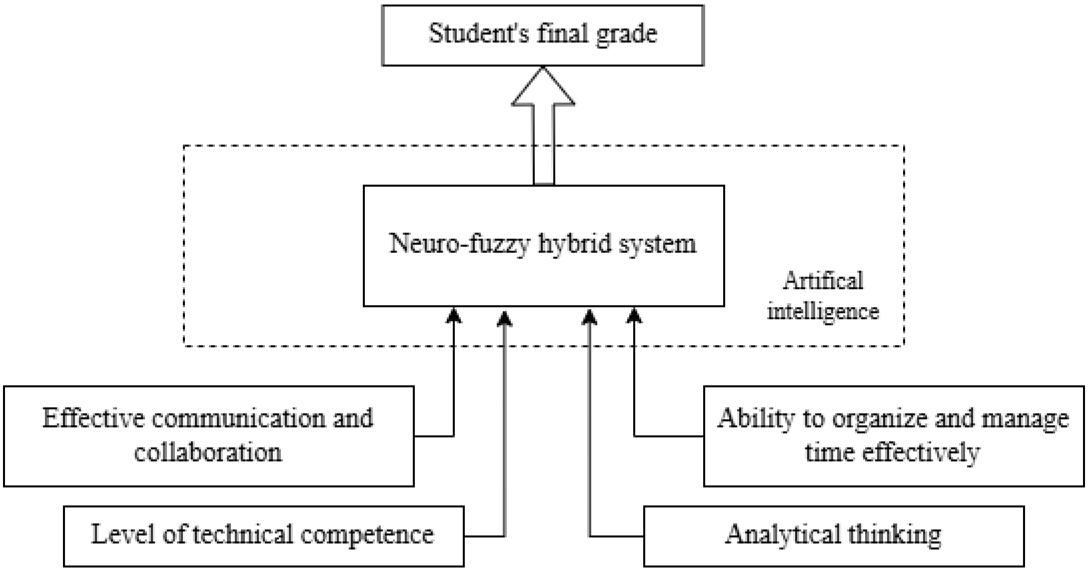

Fig. 1. Hybrid system for assessing the results of student work on a project with a team

All the parameters proposed in this model are assessments of the teacher, teaching assistant, and students who worked together with the assesses on the team project. The assessments are collected through questions that elaborate on the essence of each of the parameters.

To implement a hybrid model in accordance with the approach shown in Figure 1, the following factors need to be identified:

- Level of technical competence. This skill is very important for any direction in which a student plans to realise himself or herself in the future, because the main tool will be specialised knowledge, such as knowledge of the technology used in the project, skills in writing code, commenting on code, etc. We will analyse a more detailed set of parameters that make up this factor below.
- Efficiency of communication and cooperation. This factor is particularly important in teamwork. The ability to express thoughts verbally and in writing, to share feedback, to

collaborate, to contribute through good organisational skills or extensive technical knowledge is very important in collaborative project development.

- Ability to organise and manage time effectively. Each student must be punctual, able to correctly assess their capabilities to take on the right number of tasks, and have a tendency to take initiative, according to a study [13].
- Analytical thinking. This factor is not covered in other studies, so its role will not be as high as the other criteria. Nevertheless, the ability to correctly interpret the task, the results, the ability to think a little wider than described by the customer is also an important criterion for assessing a student's readiness to work in a team and complete real projects.

2.2 Description of model parameters

Each of the above parameters has a rather broad concept. Therefore, for a correct and objective interpretation of the results, it is necessary to detail each of them. This results in a "conclusion tree" where each parameter consists of several factors, each of which plays a role in the final score.

Figure 2 shows the general concept of the model, which provides for the formation of the final estimate based on the parameters of $= f_1, \dots. f_4$, where:

- f_1 - assessing the level of technical competence;
- f_2 - assessing the effectiveness of communication and cooperation;
- f_3 - assessment of the ability to organise and manage time effectively;
- f_4 - assessment of analytical thinking;

In turn, the parameters of f_n consist of linguistic variables x_{ni} , where *n* is the ordinal number of the parameter *f*, and *i* is the ordinal number of the parameter *x*. That is, $f_n = x_{n1}, x_{n2}, \dots x_{ni}$. Figure 2 shows the structure of the neuro-fuzzy hybrid system (NFHS).

Detailed interpretation of each linguistic variable *x*:

- for the function :f_1

  x_{11}- Knowledge of the technology used on the project;

  x_{12}- Understandable code architecture;

  x_{13}- Compliance with clean code requirements;

  x_{14}- Creativity of implementation;

  x_{15}- Use of basic programming patterns in the technology;

  x_{16}- Complexity of implementation;
- for the function :f_2

  x_{21}- Attendance at meetings;

  x_{22}- Activity at meetings;

  x_{23}- Activity in team discussions (evaluated by peers);

x_{24}- Equality of contribution (as rated by peers);

x_{25}- Collaboration (assessed by peers);

x_{26}- Ability to help colleagues (as assessed by peers);

x_{27}- Quality of feedback (as assessed by peers);

x_{28}- Perception of feedback;

- for the function :f_3

x_{31}- Completion of the task on time;

x_{32}- Efforts made, i.e. how important the student was to the group (evaluated by peers);

x_{33}- Initiative (evaluated by peers);

x_{34}- Responsibility for the duties assumed;

x_{35}- Ability to assess oneself correctly;

- for the function :f_4

x_{41}- Critical thinking, questioning the correctness of the original data;

x_{42}- Correct interpretation of results;

x_{43}- Documentation and presentation of results in oral or written form;

x_{44}- Ability to solve systemic problems;

x_{45}- Ability to make predictions.

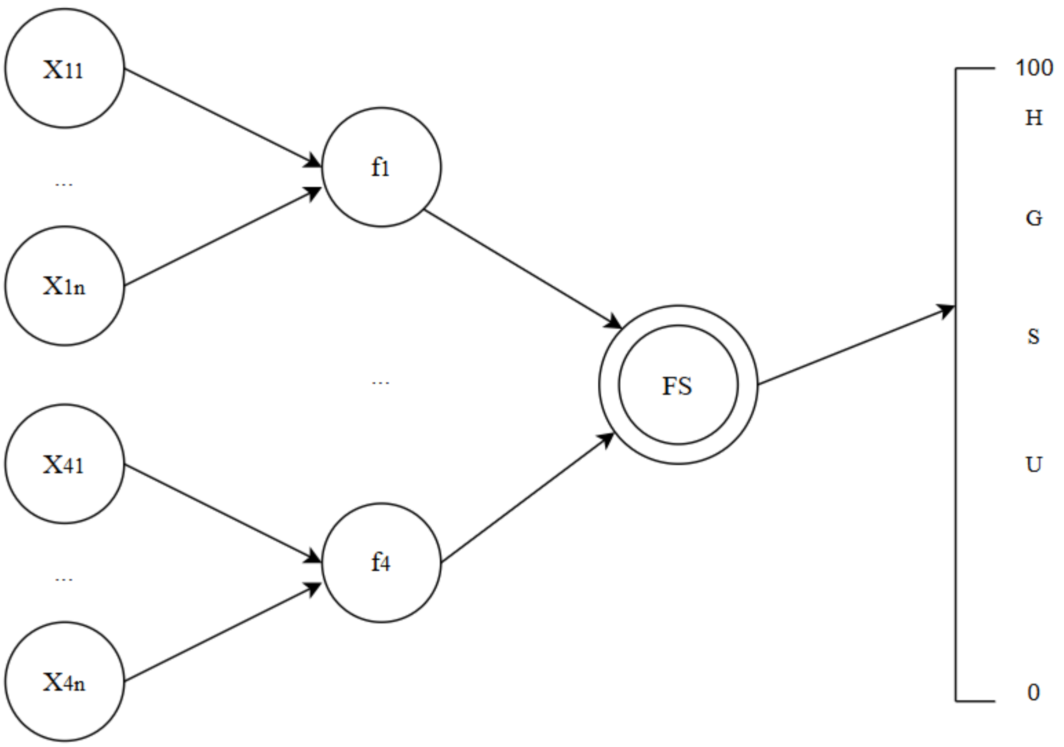

Figure 2. The structure of the NFHS assessment of the results of the students' team project

To simplify the comparison of the proposed approach with traditional estimation methods, it is proposed to determine the values of the parameters x_{ni} so that as a result, the function f_n takes on a value in the range [0-100].

Different approaches can be used to find the values of thex_{ni} parameters, such as simple questionnaires for the teacher and students working in a group with the assessee. These parameters cannot be unified due to the specifics of courses and areas in the IT field. Projects may use different technologies, or there may be a low need for correct interpretation of the final results, which reduces the importance of this parameter in the formation of the final grade.

Using the range of values of thex_{ni} parameters, you can highlight the importance of each parameter, which may be specific to a particular course. For example, consider the assessment of the qualitative parameter f_1. The maximum values of the ranges of the linguistic variables$x_{11} - x_{16}$ should result in the number 100. An example of the formation of such ranges is given in Table 1.

Table 1.

PROFESSIONAL CHARACTERISTICS OF ASSESSING THE LEVEL OF STUDENT TECHNICAL COMPETENCE

Designation	Score (range)	Designation	Score (range)
x_{11}	[0 - 30]	x_{14}	[0 - 10]
x_{12}	[0 - 10]	x_{15}	[0 - 20]
x_{13}	[0 - 20]	x_{16}	[0 - 10]

The score for each of these parameters can also be formed from several sub-parameters, which will form a total picture of the level of compliance of the student with a particular professional characteristic. The parameters of $f_1, \dots. f_4$ are determined in a similar way.

2.3 Mathematical model

The next stage in building a fuzzy model for assessing teamwork of IT students will be to build membership functions for all factors and form the result. In order to make this method easier to compare with traditional assessment methods, we will also introduce general assessment levels:

- High (H) - (90-100]
- Good (G) - (75-90]
- Satisfactory (S) - (60-74]
- Unsatisfactory (U) - [0-59].

To determine whether each parameter belongs to f_n, we will use the Gaussian function, as it is quite simple and has only 2 parameters, which adds flexibility to the model:

$$\mu(x) = ae^{-\frac{(x-b)^2}{2\sigma^2}},$$

where:

- *a is* the amplitude of the function. For our case, the amplitude of the function was chosen as *a = 1,* since for further defuzzification and correct interpretation of the results, we require a normalized function. This means that all membership functions will have the same maximum, equal to one: $\mu(x)_i^{max} = 1$.
- e - mathematical constant equal to approximately 2.71828;
- x - the variable whose function we are looking for. In our case, this is the parameter f_n, which means the final score for one of the professional indicators;
- b is the shift of the centre of the distribution, i.e. the maximum value of the function;
- σ - standard deviation, i.e. how "wide" the function is;
- μ - is the value of the membership function.

For different ranges of NFHS estimates, we select the appropriate parameters b and σ. The parameters were chosen so that the intersection of the membership functions occurs at the level of 0.5. This allows for system normalization, meaning that the weight of each level is balanced when forming the final evaluation. Additionally, the intersections occur at approximately 60, 75, and 90, corresponding to traditional student grading levels, making it easier to compare results with traditional scores. However, their values can be changed depending on the needs of the model.

H has a function value of 1.0 at the maximum score and U is shifted closer to the centre of the graph. This is due to the need to reduce the weight of U at high score levels. The disadvantage of not having a maximum value for U at zero points can be levelled out by normalisation. In the final calculations, we will normalise the relationship in such a way as to add up all the values of the membership function and determine how much weight is given to the value of a particular membership function.

Table 2

NTFS VARIABLES FOR ASSESSING STUDENT PERFORMANCE IN A TEAM

Assessment level	b	σ
High (H)	100	8.5
Good (G)	83	6
Satisfactory (S)	63	11
Unsatisfactory (U)	23	23

By changing these parameters, you can influence the intersection of membership functions. Small intersections (with smaller σ) can offset the benefits of using fuzzy logic. Too large values of σ will increase the value of the membership function of the parameter in each category. Therefore, the optimal selection of parameters is an important aspect. Figure 3 shows the membership functions with the parameters listed in Table 2.

To generate the final score, it is necessary to take into account the degree to which the value belongs to each of the functions. Also, to make it easier to manage the final model, it is necessary to introduce the concept of weight for each of the parameters. This is important because the IT industry has many areas and one factor may be generally more important than another depending on the course.

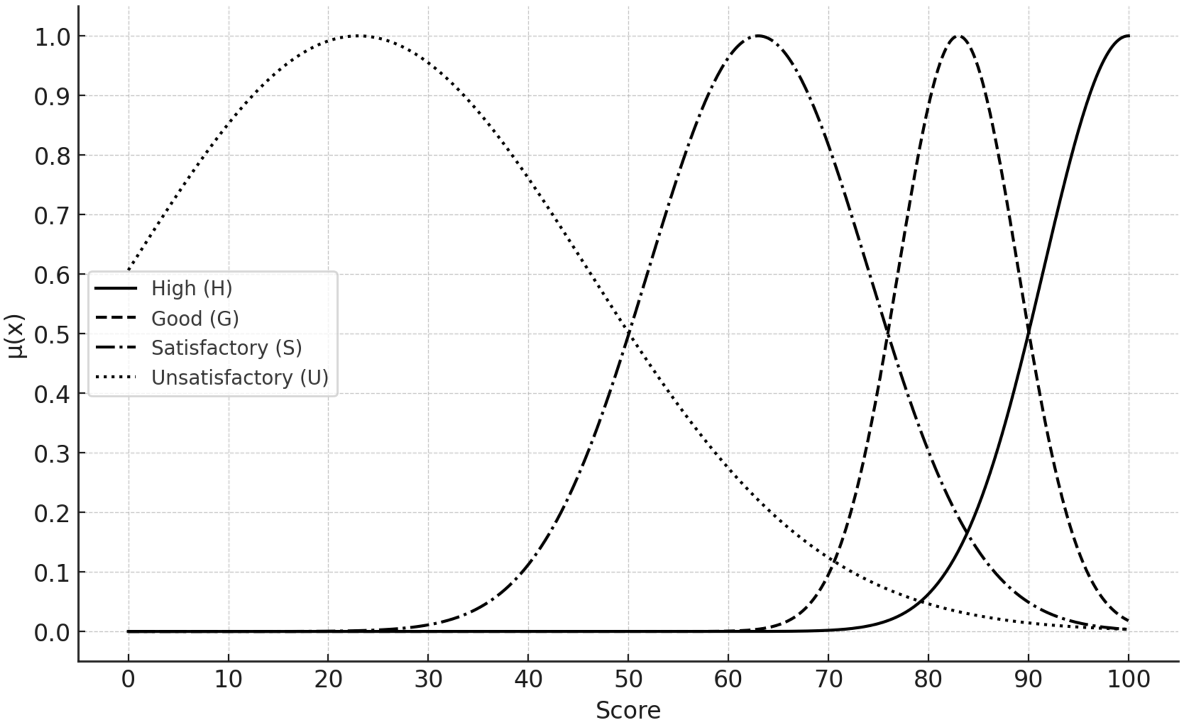

Fig. 3. Membership functions for the indicator of student's professional characteristics

To defuzzify, i.e. to transform the final scores into the values of membership functions to one final score, it is necessary to determine the dependencies of the factors on the output indicator. For this purpose, the following system of equations is proposed in this paper:

$$\mu^U = w_1 \cdot max(\mu^U(f_1) \cdot \mu^U(f_2) \cdot \mu^U(f_3) \cdot \mu^U(f_4)) + w_2 \cdot max(\mu^U(f_1) \cdot \mu^S(f_2) \cdot \mu^U(f_3) \cdot \mu^U(f_4)) +$$
$$+ w_3 \cdot max(\mu^U(f_1) \cdot \mu^U(f_2) \cdot \mu^U(f_3) \cdot \mu^S(f_4)] + w_4 \cdot max(\mu^U(f_1) \cdot \mu^U(f_2) \cdot \mu^S(f_3) \cdot \mu^U(f_4)]$$

$$\mu^S = w_5 \cdot max(\mu^S(f_1) \cdot \mu^S(f_2) \cdot \mu^S(f_3) \cdot \mu^S(f_4)] + w_6 \cdot max(\mu^S(f_1) \cdot \mu^S(f_2) \cdot \mu^U(f_3) \cdot \mu^S(f_4)) +$$
$$+ w_7 \cdot max(\mu^S(f_1) \cdot \mu^S(f_2) \cdot \mu^S(f_3) \cdot \mu^U(f_4)) + w_8 \cdot max(\mu^S(f_1) \cdot \mu^U(f_2) \cdot \mu^S(f_3) \cdot \mu^S(f_4))$$

$$\mu^G = w_9 \cdot max(\mu^G(f_1) \cdot \mu^G(f_2) \cdot \mu^G(f_3) \cdot \mu^G(f_4)) + w_{10} \cdot max((\mu^G(f_1) \cdot \mu^G(f_2) \cdot \mu^S(f_3) \cdot \mu^G(f_4) +$$
$$+ w_{11} \cdot max(\mu^G(f_1) \cdot \mu^S(f_2) \cdot \mu^G(f_3) \cdot \mu^G(f_4)) + w_{12} \cdot max(\mu^G(f_1) \cdot \mu^G(f_2) \cdot \mu^G(f_3) \cdot \mu^S(f_4))$$

$$\mu^{H} = w_{13} \cdot max(\mu^{H}(f_1) \cdot \mu^{H}(f_2) \cdot \mu^{H}(f_3) \cdot \mu^{H}(f_4)) + w_{14} \cdot max(\mu^{H}(f_1) \cdot \mu^{H}(f_2) \cdot \mu^{H}(f_3) \cdot \mu^{G}(f_4)) +$$
$$+ w_{15} \cdot max(\mu^{H}(f_1) \cdot \mu^{H}(f_2) \cdot \mu^{G}(f_3) \cdot \mu^{H}(f_4)) + w_{16} \cdot max(\mu^{H}(f_1) \cdot \mu^{G}(f_2) \cdot \mu^{H}(f_3) \cdot \mu^{H}(f_4))$$

Defuzzification is the last stage in the development of a neuro-fuzzy hybrid system. In fact, it is the process of converting the resulting fuzzy variable into an exact value that can be understood by a human. Let's denote the final score as *FS*. To perform the defuzzification, we use the classical centroid formula, in which the centre of the value is determined for each range and multiplied by the value of the membership function [14]:

$$FS = \frac{\sum_{i=1}^{n} [\frac{FS_{min} + FS_{max}}{2}] \cdot \mu_i}{\sum_{i=1}^{n} \mu_i},$$

where n is the number of terms of the *FS* variable (in our case, $n = 4$); $[FS_{min}, FS_{max}]$ is the range of the measurement scale for each assessment level; i is the membership of the function value.

After the defuzzification procedure, we get the student's final grade, which takes into account the advanced parameters and the weight of each of them.

CHAPTER 3. THE EXPERIMENT

A hypothetical experiment was conducted to demonstrate the effectiveness of using fuzzy logic in assessing the results of students' work in team projects. The experiment involved a group of six students working on a single project in a modularised environment of a working company. The project had requirements that required a high level of technical competence, teamwork and analytical skills.

The purpose of the hypothetical experiment is to make calculations and check whether the model correctly calculates students who should obviously get a high or low grade, as well as what results the model gives at different values of *the f-function.*

Let's demonstrate how the model works on one student. After that, the table will present the results of similar calculations for a group of students. First, let's define the values of X, which are obtained by interviewing the teacher or students' colleagues as described in Section 2.2. The data are presented in Table 3.

EXPERIMENTAL VALUES OF LINGUISTIC VARIABLES X FOR A HYPOTHETICAL STUDENT

Table 3

Designation	Score range	Score fact	Designation	Score range	Score fact
x_{11}	[0 - 30]	26	x_{14}	[0 - 20]	18
x_{12}	[0 - 10]	8	x_{15}	[0 - 10]	6
x_{13}	[0 - 20]	13	x_{16}	[0 - 10]	6
x_{21}	[0 - 25]	19	x_{25}	[0 - 13]	13
x_{22}	[0 - 15]	14	x_{26}	[0 - 7]	7
x_{23}	[0 - 7]	7	x_{27}	[0 - 18]	16
x_{24}	[0 - 8]	7	x_{28}	[0 - 7]	5
x_{31}	[0 - 34]	26	x_{34}	[0 - 16]	15
x_{32}	[0 - 25]	25	x_{35}	[0 - 10]	10
x_{33}	[0 - 15]	11			
x_{41}	[0 - 20]	16	x_{44}	[0 - 20]	18
x_{42}	[0 - 20]	20	x_{45}	[0 - 20]	16
x_{43}	[0 - 20]	20			

Since the sum of the maximum values of the linguistic parameters is 100, we can simply add these parameters and get the initial values of the function f_i:

- $f_1 = x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} = 77$
- $f_2 = x_{21} + x_{22} + x_{23} + x_{24} + x_{25} + x_{26} + x_{27} + x_{28} = 88$
- $f_3 = x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} = 87$
- $f_4 = x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} = 90$

The next step is to determine the values of the degrees of membership of $\mu_i(f_i)$ by the Gaussian function described in section 2.3. The final values of the function f for this student's assessment are given in Table 4. Here is an example of how to calculate one such value. The following values are calculated in the same way:

$$\mu_U(f_1) = 1 \cdot e^{-\frac{(77-23)^2}{2 \cdot 23^2}} \approx 0.0635; \ \mu_S(f_1) = 1 \cdot e^{-\frac{(77-63)^2}{2 \cdot 11^2}} \approx 0.4448;$$

$$\mu_G(f_1) = 1 \cdot e^{-\frac{(77-83)^2}{2 \cdot 6^2}} \approx 0.6065; \ \mu_H(f_1) = 1 \cdot e^{-\frac{(77-100)^2}{2 \cdot 8.5^2}} \approx 0.0257.$$

Table 4

EXPERIMENTAL VALUES OF $\mu_{U,S,G,H}(f_i)$ FOR A HYPOTHETICAL STUDENT

	High (H)	Good (G)	Satisfactory (S)	Unsatisfactory (U)
f_1	0.0257	0.6065	0.4449	0.0257
f_2	0.3691	0.7066	0.0755	0.0184
f_3	0.3105	0.8007	0.0925	0.0208
f_4	0.5005	0.5063	0.0491	0.0143

The next step is to apply the rules described in Section 2.3 to the membership functions already defined. For the sake of simplicity, we will set the weights of each rule element w to 0.25, which means that each rule is equivalent in the final membership function evaluation. An example of code that implements all the logic described above and also takes into account the rules is given in Appendix 1. The code is written in Python. It can be run with any available tools.

$$\mu_U \approx 0.0738;\ \mu_S \approx 0.4449;\ \mu_G \approx 0.7772;\ \mu_H \approx 0.6286;$$

The last step is to apply the defuzzification formula, which is also presented at the end of section 2.3.

$$FS = \frac{\sum_{i=1}^{n} [\frac{FS_{min}+FS_{max}}{2}]\cdot\mu_i}{\sum_{i=1}^{n} \mu_i} = \frac{24.5\cdot\mu_U + 62\cdot\mu_S + 82{,}5\cdot\mu_G + 95\cdot\mu_H}{\mu_U + \mu_S + \mu_G + \mu_H} =$$

$$79.6195.$$

Thus, the student's final grade is 79 points for the traditional grading system. Taking into account the student's initial scores in all areas, we can conclude that the model does not have perfectly matched parameters, and does not take into account the weights of each individual professional parameter f_i. In order to better investigate under which parameters the model produces what results, Table 5 below shows other hypothetical students.

Table 5

EXPERIMENTAL VALUES OF $\mu_{U,S,G,H}(f_i)$ FOR A HYPOTHETICAL STUDENT

Student	f_1	f_2	f_3	f_4	FS (Final Score)
1	77	88	87	90	79.6195
2	100	100	100	100	92.71
3	75	75	75	75	63.50
4	60	60	60	60	53.97
5	20	20	20	20	40.57
6	50	94	96	92	65.60

Based on the data from students 2, 3 and 4, it is clear that the model tends to underestimate the results, even with fairly high average scores. This suggests that the model parameters should be adjusted so that the predicted values are as close as possible to the actual values. In all three cases, the scores are significantly underestimated.

At the same time, in the case of student 5, the scores are, on the contrary, overestimated, which may indicate that the model rules are not properly formed. Nevertheless, the example of student 6 demonstrates that such a model is capable of generating a balanced assessment for a student who has both strong and weak indicators in different areas. For example, in Student 6, it is clear that the technical component of his professional activity is a weakness. However, this does not mean that a student should not be allowed to sit for an exam, for example, solely because of a low level of knowledge in a technical area.

This highlights the potential of the model to generate flexible and reasonable assessments, even in cases with significant fluctuations in individual performance.

CONCLUSION

This paper analyses the existing methods of assessing IT students in groups. It has been found that traditional approaches do not take into account the full multidimensionality of factors that affect the effectiveness of a student's work in a team.

The use of fuzzy logic as an effective tool for automating the assessment process is proposed. This approach allows taking into account various aspects of teamwork, including technical, communication, organisational and analytical skills.

A mathematical model based on membership functions was created to automate the assessment. The functions take into account several evaluation parameters and allow for flexible changes in the weight of the rules by which these parameters are taken into account in the calculation, depending on the specifics of the project.

The experiment showed that the model at this stage of development has certain shortcomings. Nevertheless, after the correct selection of parameters, it can serve as a tool for objective assessment of students, especially in cases where there is no clear answer about the strengths and weaknesses of the student. The model is also useful in situations where it is difficult to determine what should be emphasised, for example, in the case of IT students - technical knowledge or other professional skills.

The developed approach can be implemented in the educational process to create adaptive assessment systems that contribute to more effective learning, development of key skills and individual approach to students.

I see the expediency of continuing research to improve the model by integrating neural networks to automatically adjust the parameters of membership functions. This will allow the system to be adapted to the specifics of different educational programmes and types of group projects.

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APPENDIX I

```
import numpy as np

def gaussian_membership(x_values, b_values, sigma_values, a=1):
    """
    Calculate the Gaussian membership values for a set of inputs.

    Parameters:
    - x_values: List or array of input values (e.g., F parameters).
    - b_values: List of mean (center) values for each assessment level.
    - sigma_values: List of standard deviation values for each assessment level.
    - a: Amplitude of the Gaussian function (default is 1).

    Returns:
    - A dictionary where keys are indices of b/sigma pairs, and values are lists
of membership values for each x.
    """
    membership_values = {}

    for i, (b, sigma) in enumerate(zip(b_values, sigma_values)):
        membership_values[i] = [a * np.exp(-((x - b) ** 2) / (2 * sigma ** 2))
for x in x_values]

    return membership_values

def calculate_final_memberships(membership_results):
    """
    Calculate the final membership values based on revised rules.

    Parameters:
    - membership_results: Dictionary of membership values for each level.

    Returns:
    - Final membership values for each level (U, S, G, H).
    """
    def aggregate_rules_max_weighted(rules, weight):
        return sum(weight * max(rule) for rule in rules)

    # Extract membership values for each F parameter
    mu_U = membership_results[3]  # Unsatisfactory
    mu_S = membership_results[2]  # Satisfactory
    mu_G = membership_results[1]  # Good
    mu_H = membership_results[0]  # High

    # Rules for each level with consideration of lower levels
    rules_U = [
        [mu_U[0], mu_U[1], mu_U[2], mu_U[3]],
        [mu_U[0], mu_U[1], mu_U[2], mu_S[3]],
        [mu_U[0], mu_U[1], mu_S[2], mu_U[3]],
        [mu_U[0], mu_S[1], mu_U[2], mu_U[3]]
    ]

    rules_S = [
        [mu_S[0], mu_S[1], mu_S[2], mu_S[3]],
        [mu_S[0], mu_S[1], mu_U[2], mu_S[3]],
        [mu_S[0], mu_S[1], mu_S[2], mu_U[3]],
        [mu_S[0], mu_U[1], mu_S[2], mu_S[3]]
    ]

    rules_G = [
        [mu_G[0], mu_G[1], mu_G[2], mu_G[3]],
        [mu_G[0], mu_G[1], mu_G[2], mu_S[3]],
```

```
        [mu_G[0], mu_G[1], mu_S[2], mu_G[3]],
        [mu_G[0], mu_S[1], mu_G[2], mu_G[3]]
    ]

    rules_H = [
        [mu_H[0], mu_H[1], mu_H[2], mu_H[3]],
        [mu_H[0], mu_H[1], mu_H[2], mu_G[3]],
        [mu_H[0], mu_H[1], mu_G[2], mu_H[3]],
        [mu_H[0], mu_G[1], mu_H[2], mu_H[3]]
    ]

    # Calculate aggregate values for all levels using max and weight
    weight = 0.25
    final_U = aggregate_rules_max_weighted(rules_U, weight)
    final_S = aggregate_rules_max_weighted(rules_S, weight)
    final_G = aggregate_rules_max_weighted(rules_G, weight)
    final_H = aggregate_rules_max_weighted(rules_H, weight)

    return {
        "Unsatisfactory": final_U,
        "Satisfactory": final_S,
        "Good": final_G,
        "High": final_H
    }

def calculate_final_score(final_memberships):
    """
    Calculate the final score (FS) using the given formula.

    Parameters:
    - final_memberships: Dictionary of final membership values for each level.

    Returns:
    - The calculated final score (FS).
    """
    # Define score ranges for each level
    score_ranges = {
        "High": (90, 100),
        "Good": (75, 90),
        "Satisfactory": (50, 74),
        "Unsatisfactory": (0, 49)
    }

    # Normalize memberships
    total_membership = sum(final_memberships.values())
    normalized_memberships = {
        level: (membership / total_membership if total_membership != 0 else 0)
        for level, membership in final_memberships.items()
    }

    numerator = 0

    for level, membership in normalized_memberships.items():
        FS_min, FS_max = score_ranges[level]
        numerator += ((FS_min + FS_max) / 2) * membership

    return numerator

# Example input values
students_F = [
    [77, 88, 87, 90],  # Student 1
    [100, 100, 100, 100],  # Student 2
    [75, 75, 75, 75],   # Student 3
```

```
    [60, 60, 60, 60],   # Student 4
    [20, 20, 20, 20],   # Student 5
    [50, 94, 96, 92],   # Student 6
    [88, 50, 48, 95],   # Student 7
    [70, 90, 20, 60]    # Student 8
]

# Parameters for Gaussian function (from the table)
b_values  =  [100,  83,  68,  30]    #  Centers  for  High,  Good,  Satisfactory,
Unsatisfactory
sigma_values = [8.5, 6, 6.8, 25.5]  # Standard deviations for each level

a = 1  # Amplitude (default)

# Process each student
for i, F in enumerate(students_F, start=1):
    # Calculate membership values
    membership_results = gaussian_membership(F, b_values, sigma_values, a)

    # Calculate final memberships
    final_memberships = calculate_final_memberships(membership_results)

    # Calculate final score
    final_score = calculate_final_score(final_memberships)

    # Display the results for the student
    print(f"Student {i}:")
    for level, value in final_memberships.items():
        print(f"  {level}: {value:.4f}")
    print(f"  Final Score (FS): {final_score:.2f}\n")
```