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Using fuzzy inference to measure and quantify engineering students' problem-solving skills

Vera Stein [1], László Hanka [2]*

[1] Óbuda University Bánki Donát Faculty of Mechanical and Safety Engineering, Hungary,
https://orcid.org/0000-0002-8868-1677
[2] Óbuda University Bánki Donát Faculty of Mechanical and Safety Engineering, Hungary,
Ludovika University of Public Service, Faculty of Military Sciences and Officer Training, Hungary,
https://orcid.org/0009-0001-2758-3889

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Abstract
The university is the final link in the chain of the conventional education structure, capable of adequately conditioning potential employees for their future work. Therefore, when evaluating training courses, it is important not to neglect the analysis of their output indicators. In addition to acquiring professional knowledge, the goal should be to train graduates to be proactive, problem-solving, and capable of teamwork.
This study investigates a methodology for fuzzy rule-based estimation of students' skills.
A significant percentage of papers on the subject of problem-solving ability analysis do not provide quantitative assessments. But even articles dealing with quantification remain at the level of mathematical thinking and statistical analysis, occasionally calling on technology for assistance. However, engineering sciences are rarely used in this context. This research fills that gap with its engineering-based approach.
This article analyses the different options for defuzzification and the effects of the shape of the membership functions. The paper presents the implemented fuzzy system and analyses the data using mathematical statistics methods. The goal is a proposal for a performance evaluation system for higher education in engineering.
The shape of the membership functions does make some difference to the evaluation of student skills, but these are not significant. It can be concluded, therefore, that this does not justify the use of a more serious mathematical apparatus, the use of bell curves with high computational demands in soft computing.

1 Introduction

Higher education—be it non-profit or for-profit—can definitely be described as a market player that serves the labour market. It is therefore clear that it has a responsibility regarding the employability of the students it sends out into the job market [18]. The university is the final link in the chain of the conventional education structure, capable of adequately conditioning potential employees for their future work. This statement can be isolated from national borders or social structures.

* Corresponding author.
E-mail address: stein.vera@bgk.uni-obuda.hu

In addition to the transfer of lexical knowledge, trends are increasingly pointing towards practice-oriented training, regardless of the field of training. Therefore, when evaluating training courses, it is important not to neglect the analysis of their output indicators. In addition to acquiring professional knowledge, the goal should be to train graduates to be proactive, problem-solving, and capable of teamwork. Researchers of this topic [4] have identified critical thinking and the development of complex problem-solving skills as key guidelines. Other researchers chose these two factors as indicators of study performance in their questionnaire surveys [8].

This research involves several groups of students attending mechanical engineering, mechatronics, and safety engineering courses at a Hungarian university. The main objective is to examine the influence of a system-based approach on students' problem-solving abilities. However, it is essential that students' skills can be evaluated as objectively as possible.

Engineering research studies understandably pay little attention to the pedagogical aspects of training, while a significant proportion of pedagogical studies show shortcomings in the objective, quantifiable measurement of student performance. By making coherent use of both approaches however, more complex results can be achieved.

A comprehensive analysis of online learning aimed to review thousands of academic papers written in recent years. After thorough selection, a total of 18 English-language articles published between 2019 and 2024 were analysed in detail, evaluating student performance and commitment. The student groups participating in the study included students enrolled in medical, nursing, pharmaceutical, psychology, management courses, and engineering students. The researchers concluded that only 22% of scientific publications contained numerical representations of student performance. The overwhelming majority of studies were based on questionnaires, which contained self-reported information by students. In their recommendation, they suggest developing standardized assessment tools in the interest of a more objective evaluation, so that subjective opinions and student self-assessment have less of a distorting effect on research results [1].

The authors of this study also believe that quantifying student skills has serious potential when examining areas of education.

In education, it has already been recognized that science, technology, engineering, and mathematics form an integral whole (STEM approach). Their fusion is important from an educational, economic, social, and even political point of view [3]. The development of the STEM approach has been a long journey, with roots dating back to the 1950s in the United States.

The abbreviation was first used in the 1990s by the US National Science Foundation (NSF), initially as SMET and later in the form now known as STEM. If the STEM concept plays an important role in education, it is impossible to ignore the application of this approach in the evaluation of education.

A significant number of papers on the subject of problem-solving ability analysis fail to provide quantitative assessments. But even articles dealing with quantification remain at the level of mathematical thinking and statistical analysis, occasionally calling on technology for assistance. However, engineering sciences are rarely used in this context. This research fills that gap with its engineering-based approach.

One of the fundamental principles of STEM is problem solving, which is a process that involves identifying the problem, developing possible solutions, and implementing the optimal solution [10]. In countries such as Hungary, where problem-based learning (PBL) is not a primary practice in engineering education or other areas of higher education, statistical methods based on grades and the analysis of questionnaire surveys cannot provide relevant results for measuring students' problem-solving skills. But it should be noted that problem-based learning (PBL) does not only have advantages; a good number of challenges have been documented in this topic [9].

In this paper, the focus of the study is to measure the skills of engineering students. An indicator to characterize the students' project approach is defined using the variables formed by the skills. The aim is to propose a performance evaluation system for higher education in engineering to measure students' project orientation and problem-solving skills, which can be identified from real-life situations using parameters that are not specific to a single discipline but can be derived from different types of indirect questioning.

When measuring with tests, the autonomy of thinking may be compromised, as the answers are also based on the logic of the questions. This method is therefore not optimal for the current

research, which leaves the traditional, essay-style elaboration of the problem within the specific target group.

Another obstacle to objective assessment may be that the person being assessed is aware that their performance will be evaluated. Stressful situations can cause individuals to underperform or overperform, depending on the person, so it is advisable to choose an assessment method that allows students' problem-solving skills to be evaluated on the basis of everyday tasks. In the study, students were given a project assignment that they could complete within a deadline, but in a stress-free environment and using any tools they wanted. This is perhaps most similar to situations that arise in everyday work.

Another interesting aspect of performance evaluation is determining the correct level of solution against which to compare the result. Should the optimal solution or the average level of solutions be the basis of reference?

In a Hungarian research study [16], university lecturers and industry leaders were asked about this topic. There was a difference in approach between the academic and industrial opinions. There was no apparent difference in terms of values, but due to differing objectives—knowledge transfer and skills development in the former case, and profit-oriented work in the latter—the reference level was not defined at the same level. From an industrial perspective, in contrast to the academic approach, it is not enough to simply compare students' performance with each other; instead, the basic principle should be a more rigorous comparison with the optimal solution.

Regardless of the area of science which a given problem requiring a solution originates from, the pattern is identical. After identifying the problem, the necessary initial parameters must be determined, which can then be used to solve the task. These parameters can be detected digitally. In this method, a value of 1 is assigned to each factor identified during the student's task solution and a value of 0 to the unidentified initial factors. Similarly, the stages of the problem-solving principle and thought process can also be assigned numerical values of 1 and 0. By summarizing and weighting these, the relative indicators necessary for measuring of skills can be calculated.

Variables of Relevancy and Accuracy can be created to define a complex competence, called Student Skills [15].

The goal was to create a model that would make it possible to measure abilities—which are sometimes very difficult to study in educational research—based on the limited information available in everyday teaching or employer practices.

Students who participated voluntarily in the study worked on a technical task based on an indirect question. The students were required to provide the source data necessary to find a solution to a specific problem.

Any objective measure of competence should be based primarily on professional proficiency. The least rigorous approach to evaluate the students' competence within and outside of education is not to measure the performance of individuals in terms of their skill to solve a given problem perfectly, but to define it in relation to the group of relevant students. The total quantity of the initial parameters identified during the development of the task are then compared with the reference value. The resulting relative measure will be referred to as Relevancy. The value of the relevancy can be in the range [0,100], the meaning of the value is percentage.

Information on the individual's motivation when working on the project should also be included. This is most evident in the detail of the presentation and the amount of additional research work that has been included. It is believed that motivation should be visible in professional performance, so this will also be determined from the information that can be generated from the problem-solving. In this measure, the aim is to assess student performance from an ever more favourable perspective. This relative measure is given in relation to the average motivation of the group in the study and will be referred to as Accuracy. When calculating this indicator, we compare the number of formulas presented in the deduction with the group average. If the solution does not include an illustration or contains an incorrect one, it will be weighted at a minimum of 80%. If the solution also demonstrates additional research, it will be weighted at an additional 10%. The accuracy values are in the range [0, 342], and meaning of accuracy values, similarly to relevancy values, is percentage.

The question then arises as to what method would be acceptable for aggregating these two measures, which would show the degree of students' competence in projects in light of the

information that can be retrieved from the tasks they have completed independently. This competence is called Student Skills.

A much more interesting aspect than general mathematical and statistical methods is the parameter soft computing-based evaluation. In education where grading on a five- or ten-point scale is commonly used, experience shows that the same student performance can result in significantly different scores when graded by different lecturers. It is precisely because of this subjective assessment that it has become necessary to use a mathematical, or rather, engineering method that softens and gives nuance to the approach of the problems [15]. Thus, the independence of relevancy and accuracy can be realized if the task-solving skill is defined as a defuzzification measure.

The effects of the membership functions shape and the different defuzzification methods on individual performance evaluations should be analysed.

The study shows a quantification method using fuzzy rule-based estimation for the problem-solving skills of engineering students and shows the effect of using different membership functions on the results.

The outline of the paper is as follows: Section 2 reviews the literature. In Section 3, the applied fuzzy system is presented in detail. Section 4 gives the analysis of the data. Finally, the Conclusions section summarizes the main research findings.

2 Literature review

As defined by Pokorádi [14], fuzzy logic is a ”mathematical tool to model the real world's behaviour, especially in a contradictory reality and when the modeler has to cope with missing data."

A study by Laufer and Takács [20] investigates the sensitivity of different defuzzification methods to changes in membership function shapes.

In the fuzzy rule-based approach, following Laufer [19], the result can be significantly determined by the types of operators chosen in the modelling, the shapes of the membership functions, and, as Portik [17] noted, the defuzzification method used in the evaluation.

This idea is later supported by Werner's [22] paper, which shows that changing some settings makes only a negligible difference to the output, but that other fuzzy features (e.g., the exact shape of membership functions, inference rule base) have a significant effect on the output.

Ashraf M. Aziz [2] discusses the problem of constructing optimal membership functions in his article, comparing triangular and trapezoidal membership functions.

In the discussion of Hasuike [6], it is important to set a reasonable membership function for real-world decision parameters in a preferably objective way. In interval estimation, the intervals must be defined in such a way that the decision-maker can determine whether an element is completely included or not included in the current dataset, which, in many cases, is an exceedingly difficult task for the modeler.

Omizegba [11] already referred to it as a scientifically known fact that the selection and shape of membership functions can influence the performance of fuzzy systems. However, despite this, it is often the case that they are determined subjectively for an engineering view, engineering practice, or computational comfort, which may not be optimal for modelling.

In Hanka's [5] paper, a shape or scale parameter and a mean value - for which the curve is symmetric - determine the shape of the membership functions. By changing the value of the parameter, it is possible to reduce the interactions of the linguistic variables by making the curve increasingly concentrated around the mean value or the other way around. In this way, the interaction of the linguistic variables can be made more dominant. It makes use of this property of the membership function it investigates to increase the accuracy of the mathematical model fitting to the time series data. It therefore gives the idea, in this case, of what effect this could have in determining the skill we are analysing.

In contrast to real-time systems, where the evaluation time depends on the availability of the result, in this case, there is enough time for evaluation. However, the idea of the patient-specific tuning of the input membership functions mentioned in Laufer's [21] work is not far from the authors’ approach. In this study, however, it is more appropriate to fine-tune the input membership functions to the experience gained during the study of the learning process.

In modern pedagogical research, the shape of a function curve describing the change in the probability of solving a given type of task as a function of learning-practice time is crucial. Following the results of Pálvölgyi [13], this is a sigmoid-shaped curve (*Figure 1*).

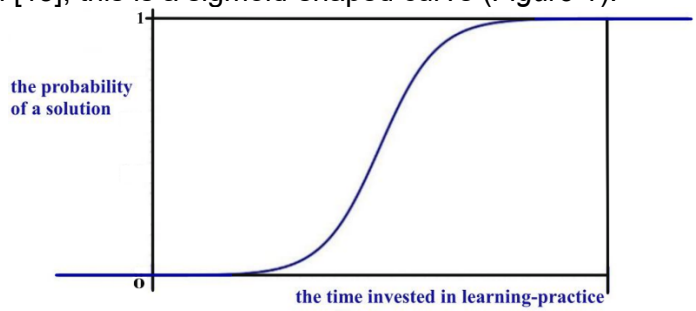


Figure 1. Learning curve following Pálvölgyi

More than a decade before Pálvölgyi's work, Ozen [12] had already analysed the effect of the parameters of sigmoid membership functions (centre and width) on human decision-making. Finally, it can be concluded that the rating of task-solving skills is also the result of such human rating. Though in different ways, yet both studies raise similar ideas.

From these, it is therefore worth looking at how the use of right-to-left sigmoidally varying functions, practically bell curves, for membership functions affects the outcome of the fuzzy model.

Jin Zhao [7] in his paper evaluated different types of membership functions in the fuzzy control of driving an induction motor. Although the process to be modelled is completely different from the one being studied, the lesson that can be learned from comparing different types of membership functions - triangular, trapezoidal, Gaussian, bell, sigmoidal, and polynomial - also certainly demonstrates that this type of research is justified.

3 The subject of the study

For modelling the problem presented in the first paragraph, in this study a fuzzy inference system has been chosen as a mathematical tool. This paragraph details the applied fuzzy system.

In the first step two input variables are defined: “relevancy” and “accuracy.” For both input variables four ranges and linguistic variables are defined as follows.

For relevancy, as input 1, ranges are

[0, 42], [18,65], [42, 90], [65, 100]

and linguistic variables are

weak, average, above average, strong, respectively.

The explanation for choosing ranges by these values is that according to research results, the minimum student performance was 18% and the maximum was 90%. Between these observed extremal values the remaining interval was partitioned into equal-lenght subintervals, and fuzzy sets have been defined by these values as centers.

For accuracy, as input 2, the ranges are

[0, 100], [0,220], [100, 342], [220, 342]

and corresponding linguistic variables are also

weak, average, above average, strong, respectively.

The idea for choosing ranges by these values is similar to the previous but a bit different at the same time. The research result proved, that accidentally the basic requirement for students and the average student’s performance coincide this is considered as 100%. Many students provided much higher level of performance, some of them achieved 342%, so this performance, as achievable, was considered maximum. Between these values the interval was partitioned into equal-lenght subintervals, and fuzzy sets have been defined by these values as centers, including zero and 342.

The following step is selecting an appropriate type of membership function. One of the most important goals of this study is to examine the effect of the shape of membership functions on the result of the inference. Therefore, in the model several membership functions have been applied and the inferred data have been examined. Two basically different types of membership functions are

triangular and bell-shaped curves. For example, considering relevancy, two applied membership function systems can be seen in *Figure 2*.

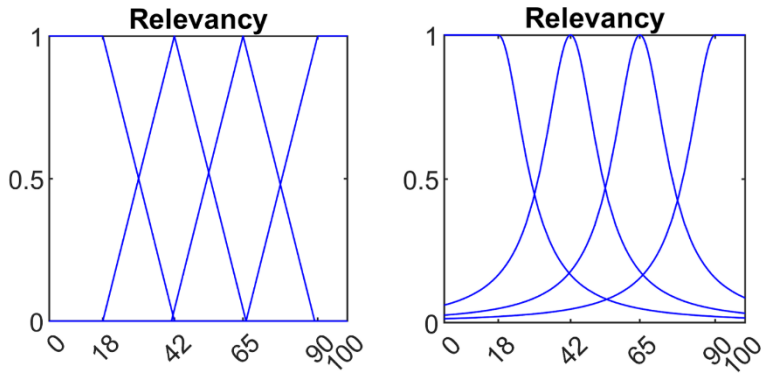


Figure 2. Membership function system for relevancy: Triangular and bell-shaped functions (created by the authors)

Mathematical formulas for triangular functions are self evident, but there are several possibilities for specifying a “bell shaped” curve, in this study the corresponding formula is the following:

$$\mu(x) = \frac{1}{1 + c(x-m)^2} \tag{1}$$

In this formula m is the center of the curve, in other words, the curve is symmetric to location m, and c is a scale parameter. For various scale parameters, the shape of the curve can be modified. If the value of c is increasing, the graph of the membership function becomes increasingly concentrated around the center m. The advantage of this formula is that mathematically it is rather simple yet at the same time it can be adjusted easily by the scale parameter. The effect of the scale parameter for the inference is one of the objectives of this study.

The way for choosing an appropriate scale parameter c is as follows: Scale parameter determines the width of membership functions. Width determines on the one hand the overlap of membership functions, which affects how many rules contribute to the inference result and how strongly they contribute. This affects the distribution of firing strengths across the rule base. On the other hand it affects the smoothness of the inference surface. Narrow sets can produce more localized changes, wider overlapping sets yield smoother transitions. Therefore c values affect the system's ability to represent fine-scale variations, interpolate between samples, and provide possibility for generalization. Considering all of these properties, using several sets of c values in calculations, the chosen c values provided the mathematical model, that meets the requirements of the proposed fuzzy model for the problem under imnvestigation.

The following step is introducing the output variable. For output “student skills” was defined. For this output also four ranges and corresponding linguistic variables were defined, that are as follows:

[0, 62], [50, 76], [62, 90], [76, 100]
not acceptable, acceptable, good, perfect respectively.

The choice of these values for fuzzy sets is straightforward, because 50% is the limit for pass, below this value the student fails. And similarly, 90% is the lower limit of the best evaluation, above this value the rating of the student is excellent. The remaining range between these limits was partitioned into equal length subintervals.

For output, the question is the same: which type of membership function provides a better result. The same types, triangular and bell-shaped functions have been chosen for modelling the output.

Summarizing previous definitions, in *Figure 3* triangular membership function systems, and in Figure 4 bell-shaped membership function systems are displayed for two inputs and for the output as well.

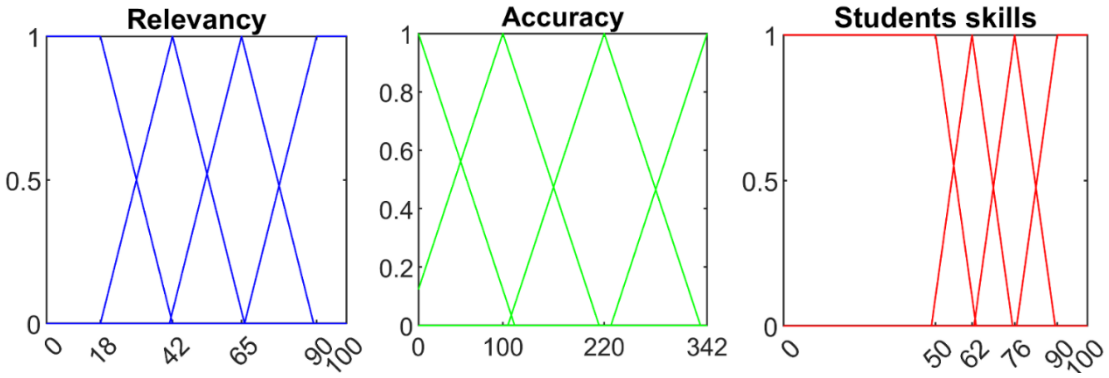


Figure 3. Triangular membership function systems for two inputs and for the output (created by the authors)

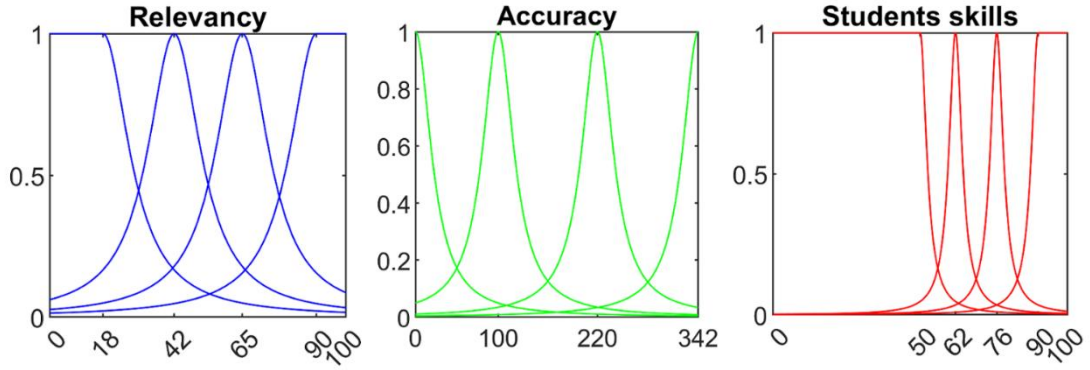


Figure 4. Bell-shaped membership function systems for two inputs and for the output (created by the authors)

For making an inference, the rule base of the system must be specified. Since in this model four linguistic variables have been defined for both inputs, in the rulebase there are 16 rules. For simplicity's sake, these 16 rules are given by the following matrix (*Table 1*):

Table 1. The rule-based matrix

		relevancy			
		weak	average	above average	strong
accuracy	weak	N	N	A	G
	average	N	A	G	P
	above average	N	G	P	P
	strong	A	P	P	P

Where letters N, A, G and P stand for Not acceptable, Acceptable, Good and Perfect, respectively. The rule base was developed based on a synthesis of the views of academic and industry experts surveyed in another phase of this research.

Inferences have been calculated according to the commonly applied Mamdani method. For inferences an appropriate defuzzification method is also required.

Table 2 summarises the evaluation of the defuzzification methods compared in this research. In the comparison, the ratings are transformed from the percentages of student skill in solving the tasks into grades, which are used to evaluate the methods.

Table 2. Summary of the defuzzification methods

Defuzzification method	Attributes
CoA (“Centroid”)	•rigorous valuation, but realistic •the performance of the midfield is degraded •less student-friendly than the MoM
LoM	•educationally unrealistic, because the lowest performance is not below 50% •most acceptable rating
MoM	•rigorous valuation, but realistic •gives the best rating with minimum failure
SoM	•the most rigorous evaluation method •in extremely poor or extremely good results

A comparison of the shape of the membership functions is therefore made for the CoA and MoM defuzzification, which are the most appropriate from the point of view of both the educators and the students.

According to the rulebase specified above, calculations were performed by Matlab. When using Matlab in a fuzzy model, one possibility is using the toolbox. In this study the toolbox has not been applied, authors created their own code for calculations. This code provides on the one hand, inference surfaces, on the other hand numerical data for several input data pairs.

In *Figures 5* and *6* inference surfaces are displayed for triangular membership function systems, and for CoA and MoM defuzzification method, respectively. In *Figures 6* and *7* inference surfaces are displayed for bell-shaped membership function systems, and for the CoA and MoM defuzzification method, respectively.

Figures 5, 6, 7 and *8* are perfect to visualize inferences, but a rigorous examination requires accurate data for several input data pairs. The benefit of the code created by the authors is that it provides the output data easily for several inputs.

A statistical analysis of the data series using triangular and bell-shaped membership functions can answer the question of how the shape of the membership functions causes differences in Student Skills rates and whether these differences justify the use of more computationally demanding bell-shaped membership functions. The data series is illustrated by the inference surfaces (*Figures 5, 6, 7, and 8*).

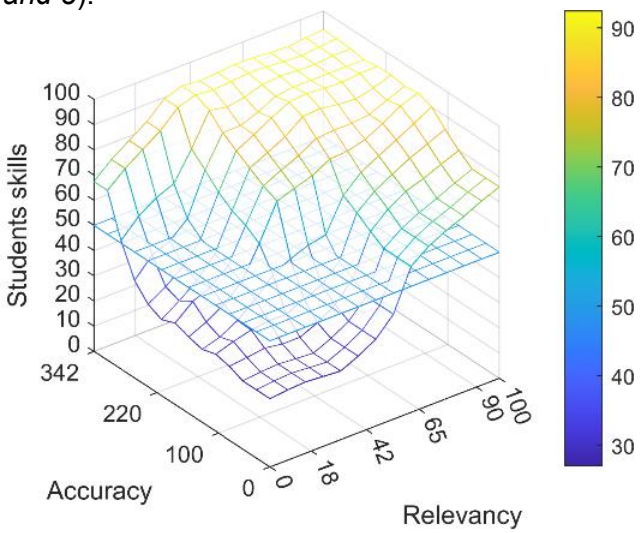


Figure 5. Student Skills with triangular-shaped membership functions for CoA (created by the authors)

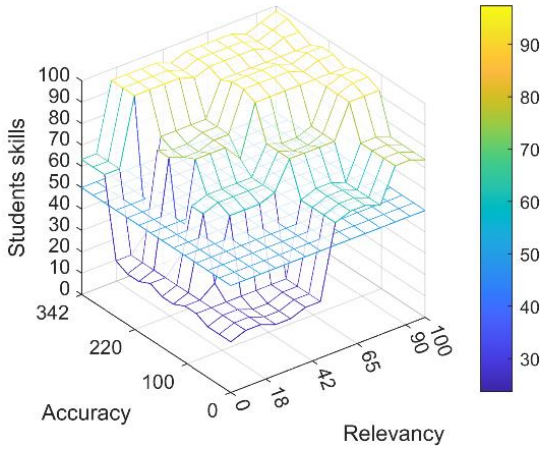


Figure 6. Student Skills with triangular-shaped membership functions for MoM (created by the authors)

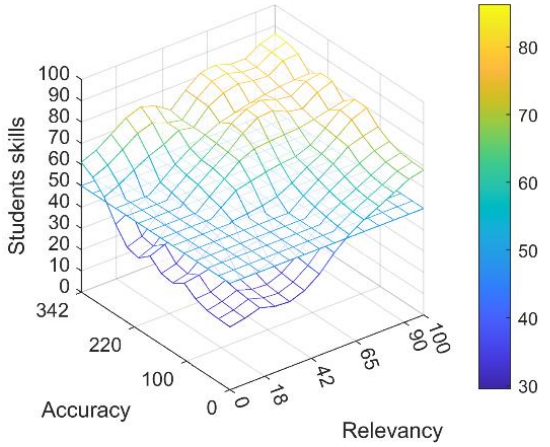


Figure 7. Student Skills with bell-shaped membership functions for CoA (created by the authors)

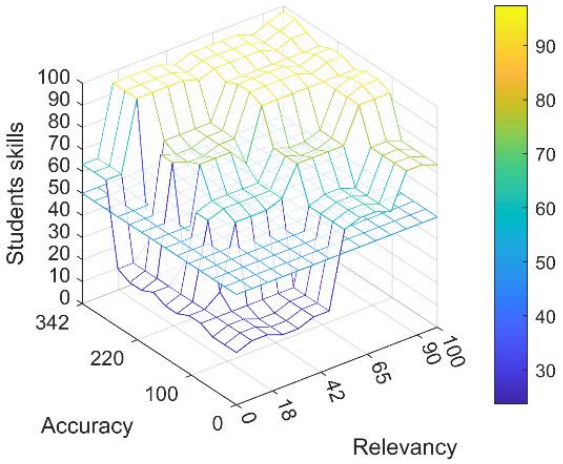


Figure 8. Student Skills with bell-shaped membership functions for MOM (created by the authors)

In this study not only the “type” of membership function (triangular vs. bell-shaped) has been examined but also the “shape” of these functions. The “shape” of the function means how it is concentrated around the mean value. The effect of the shape on the output value was investigated. To illustrate the procedure, three different bell-shaped membership functions are displayed in *Figure 9* for “input 1”. In formula (*1*) the value of constant c is 0.04, 0.008 and 0.002 respectively. For the “input 2” and for the “output” the same modifications were applied.

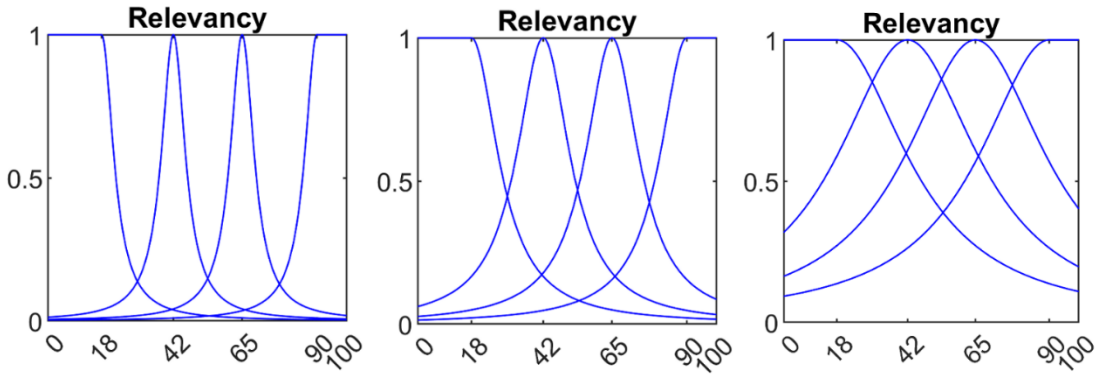


Figure 9. Membership functions for "input 1" with different shapes (created by the authors)

The effect of the shape of the membership function using the centroid defuzzification method can be seen in *Figure 10*.

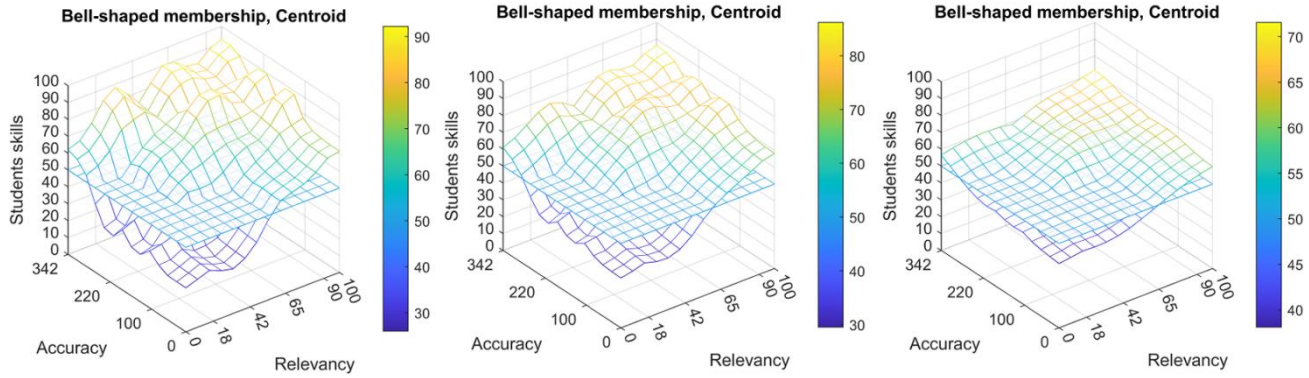


Figure 10. Inference surfaces for different shape membership functions (From left to right c = 0.04, 0.008 and 0.002) (created by the authors)

The effect can be easily visualized. If the membership function is strongly concentrated around the mean value – c value is "big" –, the inference surface has strong oscillations, which does not fit the modelled problem well. If the membership function is widely spread around the mean value – c value is "small" –, the inference surface is too plane, nearly horizontal, which does not fit the modelled problem well, either. This is why for modelling the students' skill problem, a "medium" quantity was chosen for constant c. A similar conclusion is true for triangular membership functions.

The most striking finding when examining the data sets is that the values obtained from the two different MoM defuzzifications are identical for the characterization of skill in solving the problem. Thus, if no other consideration will justify it, the more computationally expensive method can be abandoned, and the use of triangular functions in soft computing is sufficient.

For this study, the data for 148 students have been collected and examined. For the illustration an extract of this database and inference data is given in *Table 3*.

Table 3. Inference data for a specified group of students

(created by the authors)

			Student skills			
			Triangular membership		**Bell-shaped membership**	
Code of students	**Relevancy**	**Accuracy**	**Centroid**	**MOM**	**Centroid**	**MOM**
H117	0.058823529	0.409779661	28.09883	26.31579	33.10131	26.31579

H118	0.294117647	1.016949153	34.29595	26.31579	39.94773	26.31579
H119	0.411764706	2.531073446	79.60374	76.31579	64.28618	76.31579
H120	0.235294118	0.881355932	30.22024	26.31579	34.40757	26.31579
H121	0.647058824	2.033898305	89.52116	94.73684	76.21961	94.73684
H122	0.235294118	0.451977401	31.15495	26.31579	35.62006	26.31579
H123	0.176470588	0.564971751	28.16611	26.31579	34.67725	26.31579
H124	0.235294118	1.107344633	30.66734	26.31579	35.0797	26.31579
H125	0.058823529	0.531073446	28.25387	26.31579	33.94827	26.31579
H126	0.294117647	0.994350282	34.29595	26.31579	39.85527	26.31579
H127	0.294117647	1.163841808	35.44418	26.31579	40.43609	26.31579
H128	0.294117647	0.768361582	34.29595	26.31579	39.09967	26.31579
H129	0.411764706	1.468926554	63.34518	60.52632	54.63406	60.52632
H131	0.294117647	1.107344633	34.82648	26.31579	40.25346	26.31579
H132	0.235294118	0.734463277	30.23178	26.31579	34.08675	26.31579
H133	0.294117647	0.768361582	34.29595	26.31579	39.09967	26.31579
H134	0.352941176	0.666666667	37.75652	63.15789	42.94508	63.15789
H135	0.117647059	0.903954802	27.31653	23.68421	32.00219	23.68421
H136	0.294117647	1.242937853	36.46127	26.31579	40.78945	26.31579
H137	0.294117647	1.163841808	35.44418	26.31579	40.43609	26.31579
H138	0.117647059	0.497175141	28.33363	26.31579	34.71943	26.31579
H139	0.352941176	1.401129944	45.93965	60.52632	48.46304	60.52632
H140	0.411764706	1.654519774	64.52979	76.31579	55.10878	76.31579
H141	0.117647059	0.474576271	28.26932	26.31579	34.40459	26.31579
H142	0.294117647	0.858757062	34.29595	26.31579	39.3687	26.31579
H143	0.235294118	0.790960452	30.22024	26.31579	34.17811	26.31579

In the following section the analysis of results will be presented for the whole database.

4 Data analysis

In order to analyse the calculations' results using mathematical statistics methods, it is necessary to test whether the relevancy and accuracy indicators generated are really normally distributed variables. Given the diversity of student performance and the relatively large size of the sample studied, this hypothesis is valid, but it can only be accepted with a high degree of accuracy after rigorous mathematical analysis. The same hypothesis applies to the student skills indicator resulting from defuzzification.

This analysis has been applied to the whole population as well as to sub-populations. All students, as well as the first and second-year groups of mechatronics and mechanical engineering training courses, were also analysed separately.

As an example, the histogram of the full dataset and the relevance values of the first year of mechatronics training are shown in *Figure 10*.

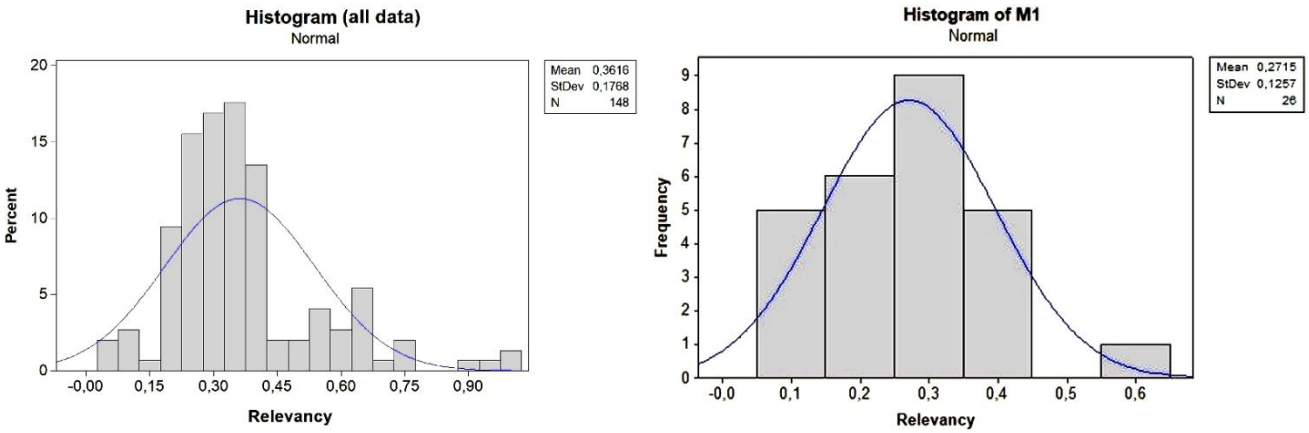


Figure 10. Histograms (from left to right of all data and of the mechatronics training) (created by the authors)

Applying a χ^2-test to the goodness-of-fit analysis, it can be verified that both the relevancy and accuracy attributes trained on the whole student population and its subset follow a normal distribution, as do the student skills indicators based on them using soft computing – for both defuzzification methods used.

Since it can be verified that the distribution of the probability variables is normal, further calculations should be based on an independence test to verify that the relevancy and accuracy indicators represent unique information and not just quantities with the same content. The χ^2-test verifies that the indicators are independent of each other. The statistical analysis was calculated using the Minitab software based on the data sets.

5 Conclusions

The paper described a fuzzy rule-based quantifying method for the estimation of problem-solving skills of engineering students. When the differences between the data obtained using bell curves and triangular CoA defuzzification methods are plotted, they have a mean of 0.9, an expected value of 4, and a standard deviation of 7. So, the bell curve evaluation tends to give 4% better student results, but it is a small difference, and the standard deviation is quite disconcerting. The difference is not even meaningful, and this surface bias does not clearly show which curve shape would be more favourable for the evaluation.

In the next section, for the membership function of a given shape, the difference between the Student Skills indicator values obtained from CoA and MoM defuzzification is tested. For this purpose, the difference in percentage measures is calculated, and the relevance of the difference can be judged using this data set.

When using triangular membership functions, the expected value of the CoA and MoM defuzzification methods for the differences between the values of the sub-populations by year groups and by training is 0, as for the full population, so they do not differ significantly. Therefore, the MoM method is more preferable for the students in this relation.

For bell-shaped membership functions, the expected value of the deviations between the skill rating values obtained in the CoA and MoM defuzzification for the subset of groups and training is between 0 and 1, which is still very small, at most 1% of the deviation. The conclusion here is the same as when using triangular membership functions.

The shape of the membership functions does make some difference to the evaluation of student skills, but these are not significant, only a few percent difference. It can be concluded, therefore, that this does not justify the use of a more serious mathematical apparatus, the use of bell curves with high computational demands in soft computing.

The use of the triangular membership functions is therefore chosen, and results in the use of the MoM method, which is considered the more appropriate of the two defuzzification methods by the lecturers.

For a subgroup of second-year mechatronics students, further analysis can be conducted later, because in their case the grades obtained in the systems engineering course are also available. Since the subject of this study is exactly the effectiveness of the acquisition of this subject on the students' problem-solving ability, it is useful to compare the results with the more subjective lecturer's perception. This method has made it possible to measure and quantify students' problem-solving skills.

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