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Visual methods of processing survey data in social disciplines based on fuzzy logic

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Abstract. All universities are responsible for assessing the quality of education. One of the required factors is the results of the students' research. The procedure involves, most often, the preparation by the staff the questionnaire, which is voluntarily answered by students; then, the university staff uses the statistical methods to analyze data and prepare reports. The proposed EQE method by the application of the fuzzy relations and the optimistic fuzzy aggregation norm may show a closer connection between the students' answers and the achieved results. Moreover, the objects obtained by the application of the EQE method can be visualized by using the t-SNE technique, cosine between vectors and distances of points in five-dimensional space.

Key words: information system; quality of education; fuzzy relations; optimistic fuzzy aggregation norm.

1. Introduction

Modern times are forcing constant improvement of the quality of products and services provided. It is also essential to maintain a high level of already implemented products. Many organizations, regardless of their size and type, implement quality management systems that are designed to demonstrate the ability to continuously deliver products following customer requirements and current regulations and striving to increase customer satisfaction (according to the most common standard ISO 9001, the product is also a service).

In the industry, there are appropriate measurement and control systems (e.g., vision) that continuously monitor the quality of manufactured products. The finished batch of products is also checked with this method. The last step is the rating by the recipient customers. Researchers try to help businesses by analyzing and looking for new methods based on numerical algorithms of economic problems, for example, delivering products [1] or reducing costs [2].

Higher education institutions (HEIs) are a specific industry that delivers service processes (mainly education and research). Similarly, as in entrepreneurial organizations, there are many sorts of collected data that must be analyzed and proceed. They also need process control (as, i.e., the EntPC, [3]) systems based on mathematical models to support decision-making processes.

HEIs have also to assess the achievements of academic staff. Bibliometricians develop methods for estimating the scientific achievements of researchers. They classify data considering many variables about academics, journals, or institutions which they can use to observe how different scientific fields develop within a chosen discipline [4] or how scientists' achievements evaluate. Scientists determine the scientific field, that they sometimes change a little; moreover, they can cooperate with other scientists, so generally, their achievement may belong to a few scientific fields. Hence, it is essential to find ways to control the disciplinary similarity of researchers to assess the development of university departments or groups of academics, mainly when they apply for grants. We can also use fuzzy logic methods to evaluate the scientific achievements of researchers or institutions considering the scientific fields [5].

In the case of various types of services performed by private or public entities, for example, in the area of health care or education, at multiple levels, the customer/ client/ patient satisfaction survey plays a significant role. In Poland, in the case of higher education institutions, according to the Law on Higher Education [6], each university is obliged to take care of the quality of education, survey its aspects, inform about its results, and design corrective actions. In the article, the method of the preparation and visualization of the results of the educational quality is prepared based on students' research with the 10-item questionnaire conducted in one of the universities in Poland.

The concept of using fuzzy relations as a basis of educational systems, especially in the fields of students' assessment, has been researched for many years. For example, in 1995, R. Biswas showed two methods of evaluation of students, which were based on fuzzy logic [7]. Next, in 1999, Chen and Lee [8] proposed two new

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methods for the assessment of student response scripts based on fuzzy sets and Biswas' works and could avoid complicated matching operations. Moreover, Ma and Zhou [9] researched in the area of student-centered studying and presented an integrated fuzzy logic method developed for this case of assessment. Furthermore, new types of fuzzy sets were described to assess students' achievements better. D. Molodsov [10] introduced the idea of soft fuzzy sets, which was developed by Ahmad and Kharal [11]. Next, P. Majumdar and S.K, Samanta [12] described a new technique, which was based on generalized soft fuzzy sets to determine students' grades and then prepared rankings of them.

Weon and Kim [13] proposed a new strategy, called fuzzy evaluation, to assess the studying achievements of students, which was based on fuzzy linguistic variables to represent items' meaning, complexity, and difficulty. Moreover, Bai and Chen [14] used fuzzy membership functions and fuzzy rules representing the difficulty, importance, and complexity of items to develop educational grading systems. Next, Dayan et al. [15] applied socio-economics backgrounds and the social difficulty coefficient to compare students' achievements using generalized fuzzy soft matrix theory. Furthermore, Mreła et al. used fuzzy relations to assess learning outcomes acquirement [16]. These papers were mostly based on research done for assessing the students' results of studying, but these methods may also be used to evaluate students' answers to question about the quality of education.

Nowadays, scientists apply fuzzy methods more and more often in technical processes. However, some social sciences, especially in people's opinions analysis, need the support of computer systems. Analyzing the students' opinions is one of these areas because of the large numbers of students, electronic data collection methods, and linguistic assessment presentation methods. Authors introduced the model of applying fuzzy relations and, proposed by authors, optimistic fuzzy aggregation norm to analyze the big data collected by universities forced to assess the quality of education.

The study is practice-oriented because the described case study shows how the layout of an assembly plant can be modified to form an ideal re-layout.

2. Research on the quality of education

The necessity of the formal educational evaluation is imposed on universities in Poland by the Ministry of Higher Education [6], and now all universities have prepared procedures for maintaining and checking university education quality, including the description of the conducting students' survey, who are very important internal stakeholders. These survey procedures describe the monitoring, providing information about the results, and ongoing improvement of the quality of education. They also specify the types of evaluation questionnaires addressed to individual groups and indicate the frequency of application of their specific kinds to particular groups. Moreover, they also define a detailed procedure for dealing with the provision of certain types of collected data and set the rules for the assessment of teaching activities by indicating the estimated reliability thresholds.

In some universities in Poland, like for example, Adam Mickiewicz University in Poznań, Warsaw University of Technology, Faculty of Materials Science and Engineering, or Kazimierz Wielki University in Bydgoszcz [17-19], the survey reports present the average grades of students calculated based on their answers to some number of questions which are connected to the quality of education. The conclusions of the presented reports give readers information about the quality of education, but the results are not directly related to areas of quality of education.

The EQE method, proposed in the article, based on the students' survey results and fuzzy relations, associates students' grades with areas of educational quality defined in the quality of education procedures. The goal of the research is to determine the method which would describe the level of the quality of education in defined areas of educational quality. Based on these results, the results of different universities or different faculties in one university can be compared and visualize.

The EQE method is presented in the results of the survey of one of the universities in Poland. The university procedure states the areas of education quality, which are surveyed by the university staff. The names of these areas, translated into English by the authors, are the following: organization of classes, methods of teaching, the social climate of classes, perceivable benefits of participating in classes, and learning outcomes. The staff issued ten questions which are answered by the students. Then based on the students' responses, there are prepared reports on the quality of education.

Thus, the students issue marks by answering ten questions (Table 1). The students assess the education quality of one education module/subject (including different forms of classes) run by a specific academic teacher. In this study of education quality, there is a five-point scale, in which one is the lowest and five the highest. The assessment is voluntary, takes place after the completed course of the given module/subject, and is carried out among students of all ages. All students can thoroughly evaluate and make additional comments about the course, quality, and conditions of implementation of a given form of teaching.

After receiving the students' responses to the questions (marks $1, 2, \ldots, 5$), there are calculated the averages for each group of students. Based on these averages, the reports of education quality are prepared. These evaluation results are considered during staff meetings where the academic teachers discuss ways of improvement of the education quality level and effectiveness of the education process. The students' responses allow university authorities and academic teachers to take into account the opinions of students. Moreover, surveys are essential feedback for lecturers and have, among others, an impact on teachers' interim evaluation.

TABLE 1 Questions asked to students during the study of the quality of education translated to English by the authors

Symbol	Question
Q_1	The lecturer familiarized the students with the program of the subject during the first meeting.
Q_2	The lecturer was available during consultations/office hours.
Q_3	Classes were held on time and as planned.
Q_4	The lecturer was prepared for classes.
Q_5	The content was provided in a clear and accessible way
Q_6	The pace of classes was adapted to the possibilities of students
Q_7	The lecturer was courteous and friendly towards students.
Q_8	Classes inspired independent thinking.
Q_9	Classes enabled gaining new knowledge and skills.
Q_{10}	The assessment was consistent with the stated criteria.

The authors would like to take into consideration not only the averages of students' responses but also the connections between areas of education quality and questions. Not all questions are related to all areas to the same extent, so the method of the education quality estimation (EQE) is proposed. The foundation of this method is based on experts-academic teachers' knowledge about relations between areas of education quality and questions, which helps estimate levels of importance of each question to study the given education area. Hence, Table 2 assigns questions to specific areas of education quality considered by the university authorities responsible for the education. The authors being academic teachers, played here the role of the experts and developed values (fuzzy relation R_1) presented in Table 2.

TABLE 2. Assignment of questions to specific areas of education quality with their symbols, where Q_j (j=1,2,...,J) denote the symbols of questions

Areas of education quality	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
A_1- Organization of classes	0.8	0.7	0.1	0.8	0.8	0.8	0.3	0.1	0.1	0.1
A_2 - Methods of teaching	0.7	0.3	0.6	0.9	0.9	0.1	0.7	0.8	0.9	0.5
A_3- The social climate of classes	0.3	0.6	0.5	0.5	0.8	0.6	0.9	0.7	0.4	0.7
A_4- Perceivable benefits of participating in classes	0.6	0.2	0.1	0.7	0.9	0.7	0.4	0.5	0.9	0.3
A_5- Learning outcomes	0.6	0.5	0.2	0.6	0.7	0.4	0.3	0.7	0.9	0.9

3. Application of fuzzy logic

In the case of quality of education, it can be said that, for example, that "the education quality is high" or "the level of the social climate of classes is low". Sometimes, it is connected with the grade (number), for example, "the teachers got Grade 5 in the area of teaching methods". The problem is with exact understanding such sentences.

Fuzzy logic was invented to deal with situations which can be described in natural human language [20, 21]. Instead of saying that the element does not or belongs to the set, it can be stated that it belongs to some extent. Let X be a universe. The fuzzy set A is a set of elements from X with a membership function $\mu_A: X \to [0,1]$ that describes their belonging to set A, so $A = \{(x, \mu_A(x));\ x \in X\}$. If $R \subseteq X \times Y$ is a fuzzy set, it is called a fuzzy relation.

Let us accept the following notation:

- $S = \{S_i,\ i = 1,2,\dots,I\}$ – the set of students taking part in the survey;
- $Q = \{Q_j,\ j = 1,2,\dots,J\}$ – the set of questions that must be answered by the students (here $J = 10$);
- $A = \{A_k,\ k = 1,2,\dots,K\}$ – the set of education areas (here $K = 5$).

Based on these sets, the fuzzy relations can be developed:

- $R_1 \subseteq A \times Q$, where $R_1(A_k, Q_j)$ denotes the level of explanation that question Q_j gives to the area A_k;
- $R_2 \subseteq Q \times S$, where $R_2(Q_j, S_i)$ denotes the S_i answer to question Q_j;
- $R \subseteq A \times S$, where $R(A_k, S_i)$ denotes the level of area quality A_k given by student S_i.

The problem of estimating levels of area quality by students can be evaluated directly (what is very difficult because of the complexity of the problem and a large number of students) or by the application of a composition of fuzzy relations, so $R = R_1 \circ R_2$ where $\circ$ denotes $S-T$-composition of fuzzy relations [22], so

$$R(x,z) = S_{y \in Y}(T(R_1(x,y), R_2(y,z))) \qquad (1)$$

for each $x \in X, y \in Y$ and $z \in Z$. To present the method EQE, the triangular algebraic norms are applied [22], so

$$T(x,z) = xy \text{ and } S(x,z) = x + y - xy. \qquad (2)$$

On the bases of fuzzy relation R, the authorities know levels of students' estimations of the education quality of the discussed areas. However, to find levels of education quality in these areas, one of the aggregation methods has to be applied. The authors have chosen the optimistic fuzzy aggregation norm S, which was defined in [23].

Let $x, y \in X$. The function $S: X \times X \to [0,1]$ is called an optimistic fuzzy aggregation norm if it fulfills the following conditions:

(S1) $S(x,y) \in [0,1]$ (normalization)
(S2) $S(0,0) = 0$ (border condition)
(S3) $S(x,y) = S(y,x)$ (commutativity)

(S4) $S(x,y) > \max\{x,y\}$ if $x \neq 0 \wedge y \neq 0$ (optimism).
One of examples of an optimistic fuzzy aggregation norm is the following function:

$$S(x,y) = x + y - xy \quad (3)$$

for $x,y \in [0,1]$. The proof of the fact that S fulfills all conditions (S1) – (S4) is easy to see.

4. Application of the method EQE

The results of education quality surveys are stored on UKW servers in the form of a database in which tables contain the following data:

- response ID,
- question ID,
- lecturer ID,
- cycle class identifier for class questions,
- group number,
- record creation date,
- response value ID,
- program code for questions about the study program,
- Hash MD5 to combine responses and comments into a single survey card.

Data from the tables were exported to .csv files and pre-processed to obtain only records with answer values for the Faculty of Mathematics, Physics and Technology for the first and second semesters in the academic years 2013/2014, 2014/2015, 2015/2016, 2016/2017, 2017/2018 and the first semester of 2018/2019. Files prepared in this way (for each semester separately) and a file with content such as in Table 3 provided input information for the application calculating the level of education in the areas mentioned above.

Let A denote the quantum of quality which augmented the level of quality if the student answered the given questions. Table 3 presents parts of the input data (fuzzy relation R_2). The authors propose that $A = 0.05$.
The authors developed the IT application to the proceed calculation in the NI LabVIEW, graphical programming environment.

TABLE 3. Quanta of quality given by students answering questions $Q_1 - Q_{10}$ (relation R_2), Faculty of Mathematics, Physics and Informatics, I semester, 2016/2017

Questions	S_1	S_2	S_3	S_4	S_5	S_6	S_7	…	S_{904}
Q_1	5	2	5	5	5	5	5	…	5
Q_2	4	3	5	5	5	5	5	…	5
Q_3	4	2	5	5	5	5	5	…	5
Q_4	4	1	5	5	5	5	5	…	5
Q_5	3	1	5	5	5	3	5	…	5
Q_6	4	1	5	5	5	4	5	…	5
Q_7	4	3	5	5	5	5	5	…	5
Q_8	4	1	5	5	5	5	5	…	5
Q_9	4	1	5	5	5	5	5	…	5
Q_{10}	5	5	5	5	5	5	5	…	5

5. Steps of EQE method

1. The experts have to describe areas of quality, prepare questions and values of the relation between them (Tables 1 and 2).
2. Students answer the questions choosing one number belonging to the set $\{1,2,3,4,5\}$ (Table 3).
3. The experts propose that the value of educational quality is equal to $a = 0.05$.
4. Based on the values of the relation R_2, the new relation R_2^* is prepared with the application of an optimistic fuzzy aggregation norm (3):
   if $R_2(j,i) = 1$, then $R_2^*(j,i) = S(0,a) = 0.05$;
   if $R_2(j,i) = 2$, then $R_2^*(j,i) = S(S(0,a)) = 0.0975$;
   and finally
   if $R_2(j,i) = 5$, then $R_2^*(j,i) = S(S \ldots S(0,a)) = 0.09823$.
5. The relation R is calculated with $S-T$-composition defined in formula (1), by the application of S and T norms defined in (2). Let $i = 1,2 \ldots, I$, $k = 1,2, \ldots, K$, $j = 1,2, \ldots, J$. Then
   $$R(A_k, S_i) = S_{j=1,\ldots,J}\left(T\left(R_1(A_k, Q_j), R_2^*(Q_j, S_i)\right)\right)$$
   To find $R(A_k)$, the level of quality of education in the area A_k, k=1,2, …, K, the average is applied. Thus,
   $R(A_k) = \frac{1}{I}\sum_{i=1}^{I} R(A_k, S_i)$ for each $k = 1,2, \ldots, K$.
   Table 4 presents levels of quality education in the areas A_k, k=1,2, …,5 in the considered semesters.

TABLE 4. Levels of areas of education quality assessment by groups of students

Areas of quality of education	2013		2014		2015		…	2018
	I	II	I	II	I	II		I
A_1	0.56	0.42	0.75	0.65	0.71	0.71	…	0.70
A_2	0.66	0.52	0.83	0.76	0.80	0.80	…	0.80
A_3	0.59	0.45	0.77	0.69	0.74	0.74	…	0.73
A_4	0.55	0.42	0.73	0.64	0.69	0.70	…	0.69
A_5	0.58	0.44	0.76	0.68	0.73	0.73	…	0.72

Based on Table 4, the results of students' estimations of educational quality can be considered and compared. The committee responsible for the quality of education can prepare some assessment criteria. They can set some intervals saying that if $R(A_1) < 0.4$, then the quality of classes organization (A_1) is low in the considered semester. Of course, these intervals may be different for each area. Moreover, analyzing the time series courses of Table 4 is essential for the education quality assessment. The committee may observe whether, in some period, these values are increasing, decreasing, or fluctuating. When the new factor to education is introduced (i.e., online teaching), it is necessary to check its influence on the education quality.

6. Visualization

One of the techniques of visualization, which reduces nonlinearly many-dimensional data to two-dimensional space, is called T-distributed Stochastic Neighbor Embedding (t-SNE). This method was developed by Laurens van der Maaten and Geoffrey Hinton [24] and models each object in high-dimensional space to a two or three-dimensional space in such a way that with high probability, similar objects are presented by close points and non-similar objects are shown by distant points.

The levels of educational quality in five areas represent 5-dimensional space, which is difficult to visualize. Figure 1 presents the result of the application of the t-SNE technique to 5-dimensional data.

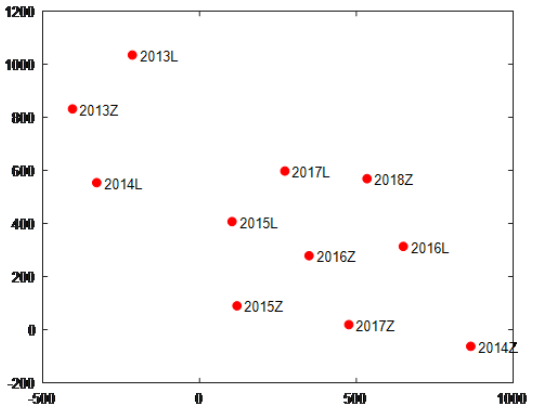

Fig. 1. The visualization of areas of educational quality by t-SNE technique
2013Z, 2014Z, …, 2018Z denote the I semester of these academic years
2013L, 2014L, …, 2017L denote the II semester of these academic years

As can be noticed that data are grouped in two different sections; the points representing the quality of education during the first semesters (2013Z, 2013L, and 2014L) create one part, and the rest of the points create the second section. While combining the information from this diagram with the data from Table 4, it can be seen that the quality of education was improved after these first three semesters.

Another possibility of preparing visualization of data is the application for students' answers to the t-SNE technique. Let us consider the diagrams presented in Fig. 2, where the values of relation R_2 are shown. The yellow points represent students who answered 5 for all questions, green – denote students with all answers equal 4, blue – denotes students with all answers equal 3, red – denotes students with all answers equal 2. The diagram on the left shows students where most students with the same answers (2,3,4,5) are colored yellow, green, blue and, red, and the rest of these students are colored magenta. The diagram on the right shows students where there is no force to put colors foreground. Based on the left diagram, it can be noticed where there are points representing students with the same answers. Moreover, the size of the section gives information on the size of the students' groups.

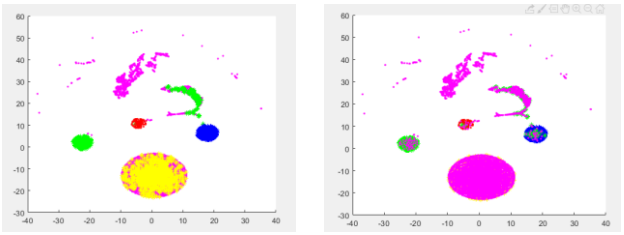

Fig. 2. Diagrams of students' quality estimation (relation R_2) prepared on the basis of t-SNE technique for students' answers for all considered semesters, where yellow – denotes students with all answers equal 5, green – denotes students with all answers equal 4, blue – denotes students with all answers equal 3, red – denotes students with all answers equal 2 and magenta denotes students with mixed (real) answers,
Left – yellow, green, blue and red points are drawn later, so they cover the magenta points,
Right – the diagram of students' answers.

The next method of presenting the results of educational quality depends on the consideration of the educational quality of the discussed semesters as points of the five-dimensional space, which coordinates are the levels of educational quality in five discussed areas. It is the application of TOPSIS technique (Technique for Order Preference by Similarity to Ideal Solution) [25]. Then, the cosine values of angles between position vectors representing the levels of educational quality in different areas and vector [1,1,1,1,1] are calculated and presented in Table 5. When the angles between position vectors of quality of education are compared, it can be observed, similarly as in the case of the application of the t-SNE technique (Fig. 2) that in semesters I and II of 2013 and semester II of 2014, the levels of the quality of education are a little lower, so the quality of education is improved in the next semesters.

TABLE 5. Cosines of angles of between vectors representing semesters of academic years 2013-2018 and the vector [1,1,1,1,1]

	2013		2014		…	2018
	I	II	I	II		I
Cosine	0.9976	0.9966	0.9988	0.9983	…	0.9987

The next method, which gives similar results, is calculating the Euclidean distances between each vector representing levels of educational quality in considered areas and reference point (1,1,1,1,1). It can be noticed that the educational quality in the students' opinions is the lowest during the first semesters of the research (I and II semesters of 2013 and II semester of 2014).

Since the students' answers were too similar (students' answers were mostly 5 to all questions), the authors prepared the hypothetical data for different semesters which were different. Using the EQE method and visualized it with t-SNE method, Fig. 3 was prepared.

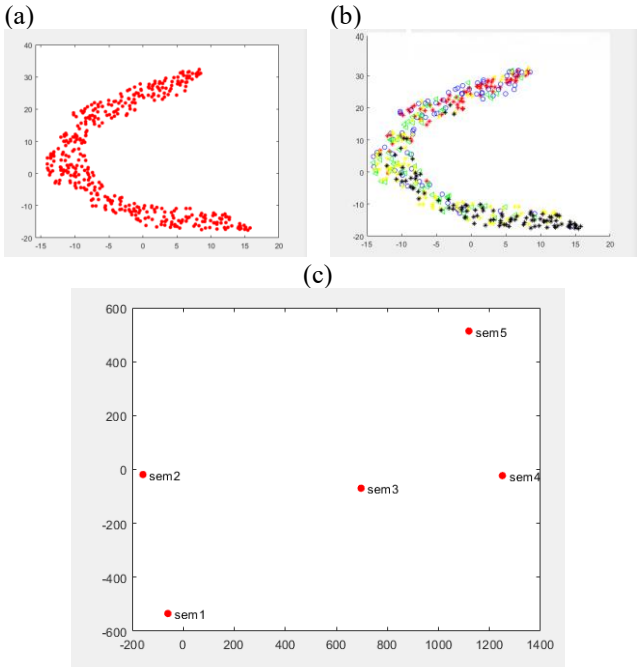

Fig. 3. Diagrams of students' quality estimations
(a) – all students' quality estimation,
(b) –quality estimations of different semester students, where red denotes I semester students, blue – II, greeen – III, yellow – IV, black – V,
(c) – visualization of students' estimations based on t-SNE technique.

It can be noticed that all students' education quality estimation are placed in Fig. 3(a). However, if these estimations are colored, then the various levels of dispersion may be observed (Fig. 3(b)). The I and II semester's students are mostly grouped in the upper part of this figure, the V semester – in the bottom part and the III and IV - are the most dispersed and placed along the whole figure. Fig. 3(c) shows that younger students (I and II) and elder students (III – V) constitute two different clusters.

Based on this visualization, the heads of university faculties can see where the academic staff should put more efforts to increase the level of education quality.

7. Conclusions

The outcomes of the EQE method are numbers belonging to interval [0,1], which show levels of students' estimations of different areas of educational quality. This method gives the university staff the assessment of areas of educational quality represented with numbers and then, based on them, diagrams. The application of the EQE method can help university staff to prepare the reports which present not only the statistical results of the students' survey but also the conclusions associated with the areas of educational quality.

When the results of the application of the EQE method are compared with the simple statistical analysis of the students' estimations, the proposed method seems to give results, which seem to be closer to the estimations of levels of educational quality in proposed areas of quality of education. In the future research of educational quality, it is important to find the measure of the "connections" to the proposed areas of quality of education.

When the statistical methods are used to organize and present data, the averages and other statistical measures are calculated, and based on these results, some conclusions on educational qualities in different areas are conducted. The university staff takes into consideration the relation between questions and areas of considered quality. Still, it seems that any numbers and functions do not represent this relation, so it is not explicitly presented. In the case of the EQE method, the relation between the questions and the areas of educational quality are explicitly stated, so it seems that when the academic staff prepares the questions and the values of fuzzy relation R_1, then these questions may be closely related to the purpose of the survey. Moreover, the EQE method may use all questions to calculate the values of relation R, so applying the explanation that the averages give more reliable results than one measurement, it can be seen that the EQE method's result should give more reliable results. However, the values of the relation R_1 should be verified by more surveys of students from different faculties and universities.

Because of that, the EQE method is proposed to estimate levels of education quality in five areas that take into consideration the connections between these areas and questions answered by students. The proposed relations can take values from the interval [0,1], so the fuzzy logic and fuzzy relations are beneficial. Hence, instead of using the statistical analysis, which treats all questions and answers on the same levels (averages), the estimations of levels of education quality areas are based on varying importance of questions.

Having calculated the levels of educational quality in five areas, the method of presentation should be chosen. The t-SNE technique seems to be more beneficial because it reduces the dimensions of objects in such a way that objects which are close in reality are also close after the transformation. The t-SNE method presents not only the clusters of objects but also the levels of dispersion of objects if the data is divided into a few groups.

Moreover, using the results as position vectors or points in five-dimensional space, the cosine of angles between these vectors and one given vector or distances between these points and one given point show differences between objects and let prepare some reports.

The results of the research on the educational quality surveys should help universities be more competitive, so they have to study the foundations of concepts lying behind the quality. Nowadays, university staff responsible for these surveys and reports based on them do the statistical analysis, mostly calculate the averages of students' answers. However, the questions which the students answered relate to the considered areas of education quality in varying degrees, so not taking into account the relations between the discussed areas and questions seems to impoverish results.

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