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A QUANTITATIVE METHOD SUPPORTING THE MANAGEMENT OF THE TEACHING PROCESS

A new method has been presented for testing the effectiveness of the teaching process based on a matrix questionnaire survey. This approach allows us to apply to the questionnaire data various quantitative and statistical methods such as: the classification and grouping of objects, factor analysis, as well as the game theory. This method of testing recognizes teaching as a continuous process, i.e. models it to the extent that it occurs in reality.

Keywords: *teaching process, management, quantitative method, multidimensional analysis*

1. Education as a factor preventing social exclusion

The conditions for the functioning of citizens are constantly changing, due to new challenges emerging and the evolution of the environment. For some time, the conceptual category of social exclusion has been used in science. This phenomenon is subject to direct examination in the context of sociology and social psychology. It thus has multiple aspects and therefore may also be analyzed from the educational point of view.

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To prevent the exclusion of a citizen from the community in which he lives, he must be ensured the opportunity to acquire the skills needed, among other things, for the exercise of his profession. The system of education, on one hand, has to provide access to general knowledge, needed in the longer term, as well as to teach the skills needed in the near term. In order to ensure a proper level of education, thanks to which social exclusion may be reduced by as much as possible, among other things, surveys of participants' opinion regarding this process should be carried out [5], [10], [11], [12]*.

Social exclusion means not only lack of opportunities to participate in (daily) social life [9] but also regardless of the knowledge one has acquired, one may be unable to promote oneself, or carry out tasks efficiently. Therefore, this problem can be subjected to multidimensional analysis, among others, by examining:

- structure of the knowledge gained,
- ability to use this knowledge in professional practice,
- desire to obtain new qualifications during ones professional life.

These are some of many important factors preventing social exclusion.

2. Teaching of subjects in terms of choices made and social communication

As a result of the transformation carried out in recent years in Poland and the world as a whole, the requirements for university graduates have altered. Not just in Poland but also increasingly in various regions of the world, in particular within the framework of the European Union, professional work requires continuous examination, enabling assessment of students' level of preparation for their professional life. Therefore, it seems interesting to know the opinion of the students themselves in terms of the special and general knowledge gained during their academic studies. This in turn enables more accurate assessment of their degree of preparation to carry out future tasks at different stages of their professional career, and thus to assess the potential *usefulness* of the knowledge gained by them in practice. Methods of multidimensional statistical analysis enable the quantification of the knowledge acquired by students in terms of its usefulness. Therefore, the aim of the studies undertaken was to develop a methodology enabling assessment of the importance of the subjects taught on the evolution of personality traits affecting the students' conduct in their future professional career. Traditional methods for assessing the knowledge acquired at the

*The study of the learning process was carried out in the Faculty of Informatics and Management of the Wroclaw University of Technology under the direction of T. Stalewski, among other things, on the opinion of students and graduates about the role of the subjects taught on future professional performance.

time of the study (inclusion and the final evaluation of the study completion), do not always enable an appropriate evaluation of students' level of preparation for professional life, especially at the beginning of their career. Therefore, in the view of the authors, it is also interesting to know the opinion, in this respect, of the participants in the teaching process themselves [7].

3. Test method for teaching process

In tests of the effectiveness of teaching (the efficiency of the teaching process) carried out, among other things, surveys containing miscellaneous questions with various scales of answers are used, often with a predominance of questions with "Yes/No" answers [1], [6], [7]. The analysis and interpretation of data collected in this way raise serious difficulties, particularly in relation to multidimensional statistical analysis. The authors propose a method that treats the answers to the questions as a form of matrix. The rows of this matrix make up the sequence of vectors $\mathbf{X}_1, \dots, \mathbf{X}_n$ representing the tested objects. They may represent, depending on the test, a set of statistical observations on each of the n tested objects. The columns of this matrix make up a sequence of vectors $\mathbf{Y}_1, \dots, \mathbf{Y}_m$, each representing the observations of one of the m traits investigated. In this way, the matrix $\mathbf{M}_{n \times m}$ is obtained and can be subjected to mathematical analysis, in which the main emphasis will be placed on statistical analysis. Each row mathematically constitutes a point in m -dimensional Cartesian space. The number of rows is the number n of m -dimensional points. Owing to this, it is possible to examine the distance between each pair of these points and the mathematical or statistical relations between them.

This approach is universal, thus its mathematical analysis can be described in the form of the following diagram illustrating an algorithm for its implementation: This so called survey matrix is a significant addition to the traditional questionnaire (Fig. 1) and allows the investigator to use a continuous scale describing the response. This leads to the possibility of using tools for multidimensional comparative analysis (MCA). The essential nature of these tools includes two main dimensions:

- taxonomic – ordering and grouping test objects [2],
- factor analysis – providing a new set of traits (characteristics) for the tested objects of any nature (from a continuous scale, i.e. mathematically objects are points in a certain space, while the number of the traits is the dimension of this space), as linear combinations of the observed traits. These new traits are called factors and are orthogonal to each other, i.e. create a new (Cartesian) spatial system. This allows us to clarify or interpret the structure of the connections between the observed traits of the objects.

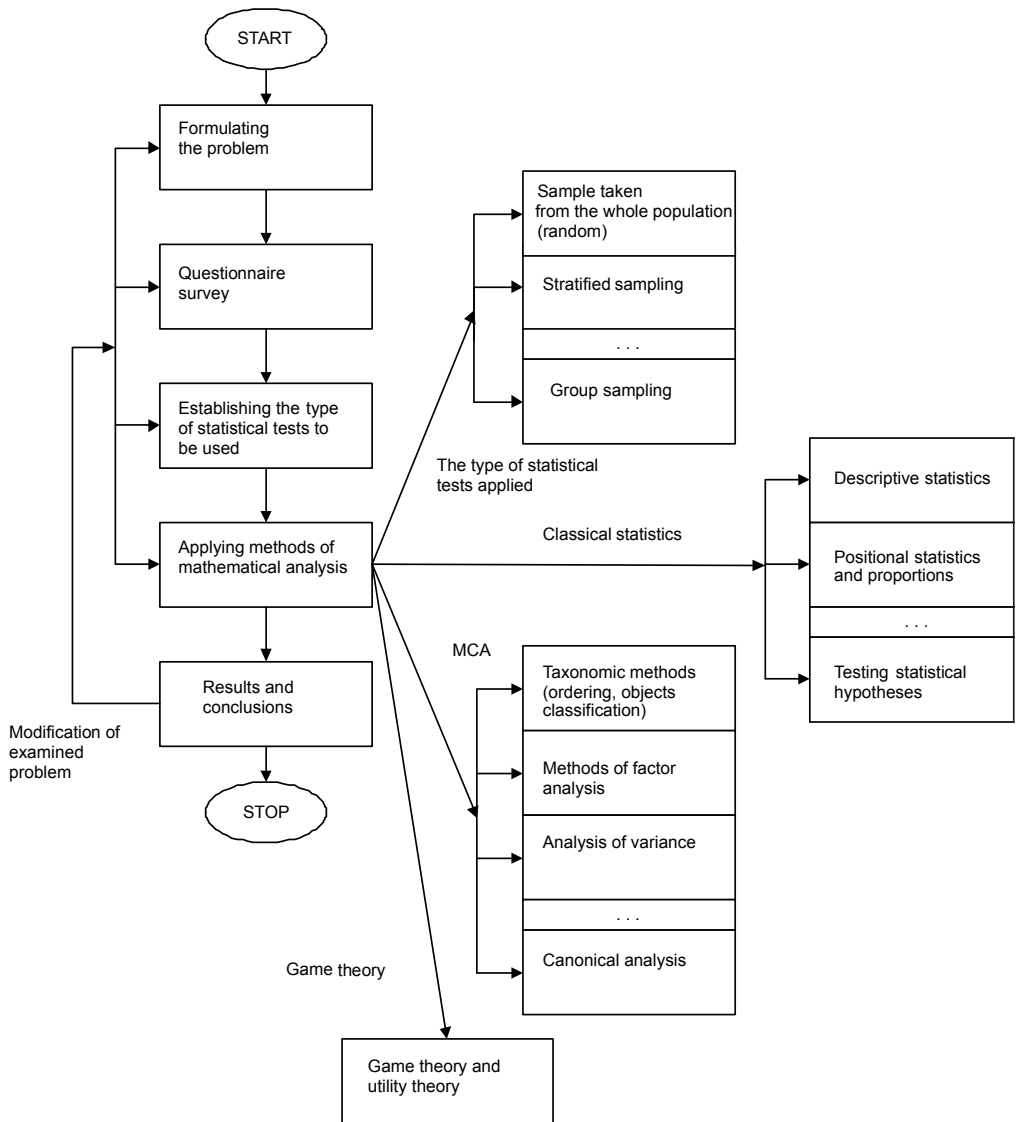


Fig. 1. Flow chart for a quantitative method of testing the teaching process. Source: author's work

Benefits arising from the use of MCA in testing the teaching process are:

- frequent necessity of reducing the huge amount of information about the tested objects to only a few basic categories which are the only ones subjected to detailed statistical analysis,
- obtaining homogeneous groups of objects in terms of the traits possessed, which consequently makes it much easier to find (name) their basic properties,

- allowing the investigator to focus on the most fundamental aspects of the examined teaching process, occurrences, terms, traits, etc.,
- defining and explaining the structure of the relations between the traits of the objects tested.

The method proposed was used for a survey carried out at the Land Forces Military Academy in Wrocław and at Wrocław University of Technology, which allowed us to assess the significance of the subjects taught on the development of the essential qualities of the personality of future officers and their impact on the evolution of professional careers. As already mentioned, the answers to the survey are treated as a matrix. The rows correspond to individual subjects, and the columns correspond to the traits of the cadets' characters, which are expected to be affected by the teaching process. We attempted to determine the effect of teaching on the chosen traits of personality for each of the subjects taught. The data from the survey were analysed using factor analysis (in the form of principal component analysis), taxonomic analysis, classification of objects, multifactorial analysis of variance and canonical analysis [1–3], [6], [8], [9], [14].

The method of principal components allows us to designate factors conditioning the examined phenomenon, in our case the education of students and this enables us to describe some common factors that affect the existence of the relations between the objects tested. The essence of this method relies principally on the fact that the variation in the variables observed can be well described by a much smaller number of hidden, independent non-observable variables, referred to as factors. In statistical surveys, the assumption of the normality of the variables observed is usually required. Using the method of factors, this presumption is not so important. Normality is required only when the asymptotic properties of the principal component coefficients are tested, as well as in the case of the construction of tests and confidence intervals for these coefficients [3]. Another advantage of this method is that it can be applied to the analysis of non-random variables. Classification of objects is to some extent a continuation of factor analysis, since the number of factors substantially determines the number of classes of objects, derived according to the method of classification adopted.

Application of analysis of variance allows us to examine interactive relations between the groups of taught subjects derived and personality traits.

Canonical analysis, in turn, gives the opportunity to examine the relations between groups and, among others, individual objects. This is a generalization of linear multiple regression, i.e. it concerns the testing of two sets of variables. Any possible links are presented in the form of relations between the two types of new variables, in this analysis called the canonical variables. The first set of canonical variables is defined by linear functions of the first set of the tested variables, and other canonical variables are linear functions of the second set of original variables.

Analysis of correspondence is also a method of factor analysis and allows us to extract relations between variables (traits) and objects (subjects) primarily in a graphi-

cal form. This method is the only one which allows us to place the traits and objects into one arrangement of factors. This enables determining structural relations between variables and objects as a layout of orthogonal factors. In this way, the method considerably increases the ease of interpretation. In addition, it makes the analysis of both quantitative and qualitative data possible and does not increase the sample size required [5].

The methods presented allow us to identify hidden significant connections between selected objects and the personality traits of students, and in the same way – an additional assessment of the quality of their education. Thanks to this, the proposed examination will complement the knowledge about the quality of education that is obtained using a typical research survey of subjects taught.

4. Example of the application of the proposed method

The survey matrix presents groups of subjects in rows and character traits in columns. The groups of subjects are:

- military subjects (P1),
- economic (P2),
- management (P3),
- finance (P4),
- formal sciences (P5),
- foreign languages (P6),
- physical education (P7),
- social sciences (P8),
- modern information technologies (P9),
- individual studies and free time (P10).

The impact of each of the above-mentioned subjects on the evolution of the following personality traits was determined:

- knowledge (C1),
- thinking (C2),
- decisions (C3),
- discipline (C4),
- tolerance (C5),
- fellowship (C6),
- character (C7),
- fitness (C8).

The resulting structure of the data resulted from the personality traits and groups of subjects adopted. The analysis began with the calculation of Pearson's correlation coefficient for each pair of traits. This indicates the most highly correlated traits.

In addition, analysis of these correlations enables us to define more general traits, such as mental ability, ability to operate in a social group and individual behaviour.

However, Pearson's correlation coefficients do not fully reflect the actual nature of the relations occurring between traits, since only individual pairs are considered. In view of the varying degree of common connections (restraining, stimulating) between features, groups of more than two traits may be associated. This means that the one trait may affect the relation between two other traits. Therefore, additionally, the partial correlation coefficients were calculated. These measures capture the real nature of an association between a given pair of traits, i.e. the impact of other variables on a given correlation is reduced. The results obtained by the use of ordinary and partial coefficients were compared and it proved that there are substantial differences between the values obtained.

Table 1. Pearson's correlation coefficients between pairs of personality traits

Trait	Know- ledge	Thinking	Decisions	Discipline	Tolerance	Companionship	Character	Fitness
Knowledge	1.00	0.83	-0.24	0.02	0.35	0.54	-0.08	0.03
Thinking	0.83	1.00	-0.47	-0.27	-0.01	0.44	-0.13	-0.26
Decisions	-0.24	-0.47	1.00	0.91	0.20	0.43	0.83	0.81
Discipline	0.02	-0.27	0.91	1.00	0.57	0.48	0.87	0.97
Tolerance	0.35	-0.01	0.20	0.57	1.00	0.13	0.34	0.71
Companionship	0.54	0.44	0.43	0.48	0.13	1.00	0.43	0.42
Character	-0.08	-0.13	0.83	0.87	0.34	0.43	1.00	0.84
Fitness	0.03	-0.26	0.81	0.99	0.71	0.42	0.84	1.00

Source: author's calculations. Note: The critical value of the correlation coefficient r^* for 8 degrees of freedom and $\alpha = 0.05$ is 0.63, and for $\alpha = 0.1$ $r^* = 0.55$.

Table 2. Partial correlation coefficients between pairs of personality traits

Trait	Know- ledge	Thinking	Decisions	Discipline	Tolerance	Companionship	Character	Fitness
Knowledge	-1.00	0.95	0.90	-0.77	0.91	-0.66	-0.84	-0.19
Thinking	0.95	-1.00	-0.97	0.89	-0.89	0.84	0.92	-0.01
Decisions	0.90	-0.97	-1.00	0.95	-0.94	0.80	0.84	0.03
Discipline	-0.77	0.89	0.95	-1.00	0.83	-0.79	-0.78	0.20
Tolerance	0.91	-0.89	-0.94	0.83	-1.00	0.59	0.67	0.35
Companionship	-0.66	0.84	0.80	-0.79	0.59	-1.00	-0.86	0.37
Character	-0.84	0.92	0.84	-0.78	0.67	-0.86	-1.00	0.28
Fitness	-0.19	-0.01	0.03	0.20	0.35	0.37	0.28	-1.00

Source: author's calculations.

Tables 1 and 2 present the values of these correlation coefficients, which show significant differences in many places. This indicates a high degree of complexity of the connections between the traits. From Table 1 it can be noted that the most highly correlated pairs of traits are: knowledge–thinking, discipline–decisions, discipline–character, discipline–fitness, fitness–character.

Analyzing Table 1 using statistically significant values of Pearson’s correlation coefficients, a division of these traits is obtained in the form of a graph, where the edges show the links that occur between traits (the vertices in the graph). Figure 2 shows the links between the groups of traits based on the statistically significant values of Pearson’s correlation coefficients.

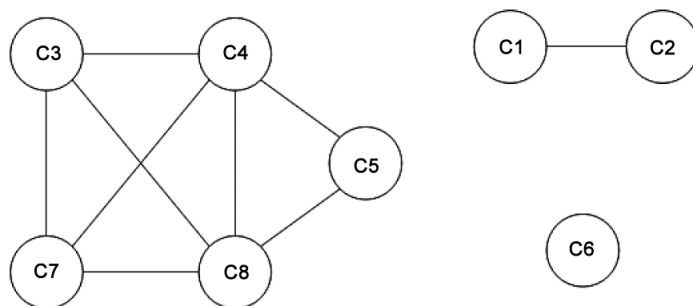


Fig. 2. Relation between traits based on statistically significant values of Pearson’s correlation coefficients. Source: author’s work

According to this classification, the traits form three homogeneous groups. The largest group is: C3 – discipline, C4 – character, C5 – tolerance, C7 – fitness and C8 – companionship. This is a group of traits expressing a cadet’s psychophysical activity, and thus the ability to behave in a social group – an important trait of a soldier on the battlefield. The second group is formed by two important, as proved in the statistical analysis, traits, namely, C1– thinking and C2 – knowledge. These are traits expressing mental ability. The last group is created by a single trait C6 – decisions. Psychologically, this represents assertive behaviour – individuality. According to this classification, a cadet’s personality represents the ability for individual behaviour, skills of associating within a social group and mental ability.

To check that the results of this classification of traits are reliable, it is advisable to use another method for grouping the traits, i.e. to verify the classification described above. In order to determine the traits that constitute homogeneous groups, the method of principal component analysis was used for the reason that both methods (the graphical approach and principal components) are applied to the concept of the correlation coefficient, but each in its own way. The method of principal components allows evaluation of a cadet’s personality, which will be represented by certain groups of traits. Table 3 and Fig. 2 show the results obtained by applying principal component analysis.

Table 3. Loads of the factors obtained using principal component

Feature	Component Loads of factors			
	1	2	3	4
Knowledge	-0.01	0.96	0.08	0.23
Thinking	-0.23	0.86	-0.27	0.57
Discipline	0.91	-0.19	0.06	-0.18
Character	0.98	0.06	0.37	-0.67
Tolerance	0.5	0.31	0.91	-0.13
Decisions	0.51	0.69	-0.27	-0.43
Fitness	0.93	0.007	0.12	-0.38
Companionship	0.95	0.08	0.53	-0.58
Percentage of variance explained	70	14.5	9	5
Cumulated variance percent	70	84.5	93.5	98.5
Eigenvalue for component (relative variance)	21.7	4.5	2.7	1.6

Source: author’s calculations. Note: for $\alpha = 0.05$ and $n - 2 = 8$ degrees of freedom, the critical value of the correlation coefficient r^* is 0.63.

As can be seen from Table 3, the first component correlates most strongly with such features as: discipline, character, fitness and companionship. Thus this component can be defined as temperament. The second component is formed by: knowledge, thinking and decisions. This is reflected by the personality factor which produces a cadet’s intellect. The third component is strongly correlated with tolerance, which we called humanism. The fourth component only explains 5% of the impact of the education process. Therefore, the association of the three principal components with the classification of groups of features can be illustrated as in Fig. 3.

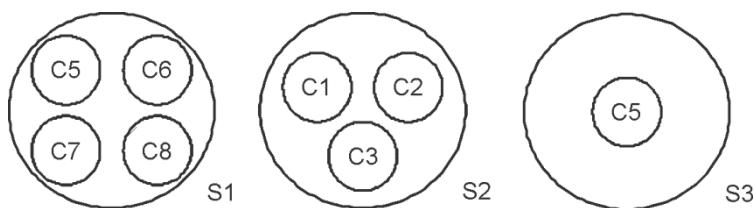


Fig. 3. Groups of features extracted based on the principal component analysis.
Source: author’s work

The classifications of features carried out using a) the method of correlation coefficients and b) principal component analysis differ slightly from each other and therefore each category has different names. A comparison is shown in Table 4.

Table 4. Comparison of the classification of features obtained using two methods.

Principal component		Group of features		
		Temperament	Intellect	Humanism
Groups of features	social behaviour	C_3, C_4, C_7, C_8	–	–
	mind	–	C_1, C_2, C_6	–
	assertive behaviour	–	–	C_5

Source: author’s work.

Figure 4 shows the placement of the eight tested features in the space spanned by the first two principal components. The longer the vector, representing the given factor, the greater its importance in the values of the first two components. A small angle between features indicates that the influence of the features on the value of the first two principal components is similar.

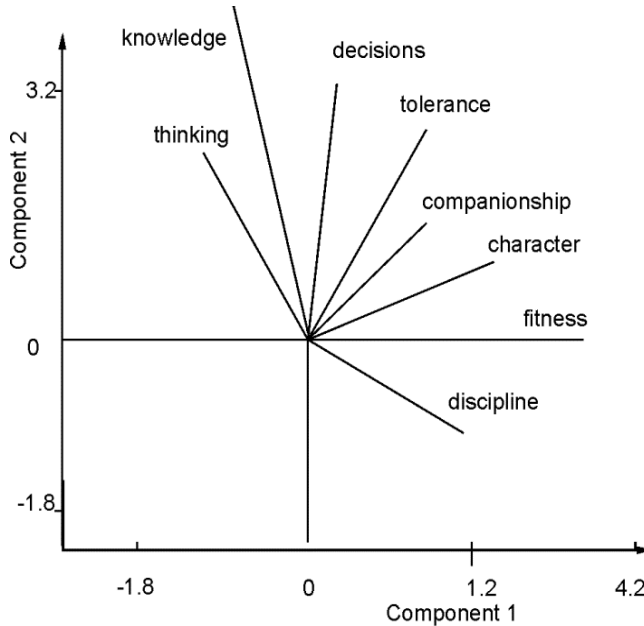


Fig. 4. Location of features in the space spanned by the first two principal components. Source: author’s work

In addition, some descriptive statistics calculated for the features of personality adopted are shown in Table 5.

Table 5. Basic descriptive statistics of features

Feature	Know- ledge	Thinking	Discipline	Character	Tolerance	Decisions	Fitness	Companionship
Mean	5.76	5.38	3.05	3.70	2.88	4.41	2.45	3.03
Median	5.70	5.30	2.00	3.25	2.70	4.15	0.60	2.75
Variance	1.92	1.15	4.13	4.16	2.18	3.03	10.86	3.48
Standard deviation	1.38	12.07	2.03	2.04	1.48	1.74	3.30	1.86
Coefficient of variation	24.03	19.92	66.64	55.15	51.31	39.44	134.51	61.55

Source: author's work.

By analyzing the values of the basic statistics, such as mean, variance, standard deviation and the coefficient of variation, calculated for the individual features, it can be concluded that the respondents answered the survey questions consistently. For example, a very large standard deviation was obtained for fitness, which exceeded the average value which, in turn, gave a high coefficient of variation (134%). For the group of subjects "modern information technologies", the impact on physical fitness was estimated to be 0.1.

Principal component analysis showed that one may specify four essentially independent factors arising from the teaching process and affecting a cadet's personality. Therefore, it may well be interesting to divide these subjects into groups, which show the relations between them. One method enabling classification into such groups is analysis of agglomerates. Since the assessments were measured on a continuous scale, each subject can be represented by a point in eight-dimensional Euclidean space. For this analysis, the method of *k*-means* was adopted using the Euclidean metric. Figure 5 shows the division of the subjects into homogeneous groups. Assuming a division into four homogeneous groups, the following classification of subjects was obtained:

- P1, P7,
- P10,
- P3,
- P2, P4, P5, P6, P8, P9.

Divisions into any number of homogeneous groups can be made in order to obtain more general (with 2 or 4 groups) or more detailed information (with more than 4 groups). In this case, it is possible to split into 2, 4, ..., 10 groups. Interpretation of this figure indicates a clear separation of the subjects taken by cadets into military and civilian.

*Analyzing the basic descriptive statistics contained in Table 4, we see that for each of the features, the mean and median only differ slightly (with the exception of fitness), and the mean is a better, statistically speaking, estimator of the expected value of a feature's distribution than the median. Hence this method has been used. For the study individuals, the mean value of physical fitness is high compared to the median value. Therefore, this feature should be examined by means of an additional questionnaire survey.

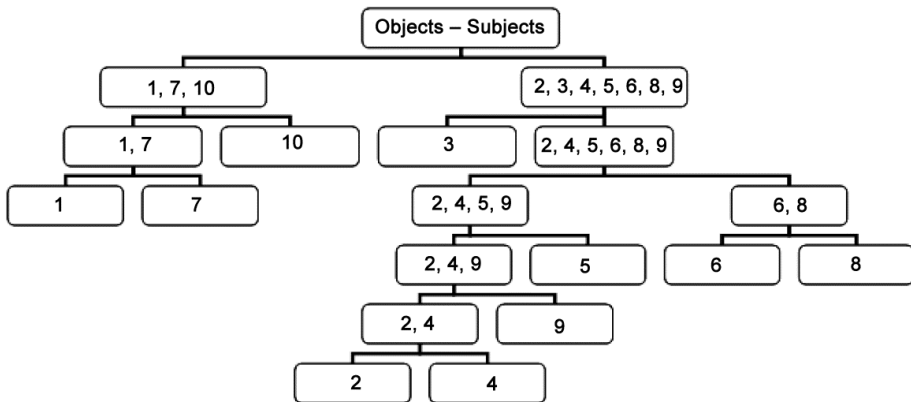


Fig. 5. Division of subjects into homogeneous groups. Source: author's work

The respondents entered answers into the matrix, in which the rows corresponded to the subjects, and the columns to the features of personality. They selected the subjects they considered to have an influence on the formation of each specific feature. The following question could be asked: what value can be attributed to the relation between a subject and a feature and how can a weight be ascribed to the strength of such an association. This is done by smoothing based on the median. The data included in the form of a matrix (Table 9) are processed according to the following algorithm:

A. The median is calculated for each of the columns (in this case, for each of the features). Table 7 presents median for each of the features.

B. The column median is deducted from each value (these differences are the so called residuals from the first iteration).

C. The median is calculated for each row (in this case, for each of the subjects). Table 8 presents median for each of the subjects.

D. The row median is deducted from each value (these differences are the so called *residuals from the second iteration*).

The result is an array of the residuals (Table 6).

Each value in the answers matrix can be expressed as the sum of the so-called typical value, the impact (effect) of the row and the impact (effect) of the column and the residual. This can be expressed as follows:

$$\text{Response value} = \text{main effect} + \text{subject effect (of the row)} \\ + \text{feature effect (of the column)} + \text{remainder value}$$

The calculations gave a typical value (main effect) of $E = 3.125$.

The results obtained after two iterations using the smoothing method based on the median are as follows:

- for the rows:

1.825, -0.9375, 0.375, -1.2875, -1.2625, -0.525, 2.2625, 0.0375, -1.275, 2.15,

- for the columns:
3.025, 2.61875, -0.375, 0.275, -0.41875, 1.2375, -1.35, -0.40625.

Table 6. Response results (average)

Subject	Knowledge	Thinking	Discipline	Character	Tolerance	Decisions	Fitness	Companionship
Military subjects	5.0	4.0	7.0	6.4	2.1	6.0	4.7	4.5
Economics	5.3	5.6	1.5	1.6	1.8	4.1	1.0	1.1
Management	7.8	6.5	2.5	3.5	3.3	7.0	0.6	3.0
Finance	5.8	5.9	1.7	1.6	1.1	4.6	0.6	1.2
Formal sciences	4.0	4.8	1.8	2.0	1.6	2.6	0.4	1.5
Foreign languages	6.2	4.9	2.0	3.0	3.8	1.6	0.5	2.5
Fitness	3.8	3.9	6.3	6.8	4.0	4.2	8.7	6.3
Social sciences	6.1	5.0	2.0	4.1	5.5	4.0	0.3	4.1
Modern information technologies	5.6	5.9	1.7	2.0	1.4	3.3	0.1	1.1
Individual study and free time	8.0	7.3	4.0	6.0	4.2	6.7	7.6	5.0

Source: author’s work.

The following shows how the value in row 1 and column 1 of Table 6 (corresponding to military subjects and knowledge, respectively) can be expressed using this model: $5 = 3.125 + 1.825 + 3.025 + (-2.975)$.

Table 7. Median values for the features

Feature	Median
Knowledge	5.70
Thinking	5.30
Discipline	2.00
Character	3.25
Tolerance	2.70
Decisions	4.15
Fitness	0.60
Companionship	2.75

Source: author’s work.

Table 8. Median values for subject groups

Subject	Median
Military subjects	4.85
Economics	1.70
Management	3.40
Finance	1.65
Formal sciences	1.90
Foreign languages	2.75
Fitness	5.25
Social sciences	4.10
Modern information technologies	1.85
Individual study and free time	6.35

Source: author's work.

Table 9. Residuals obtained by smoothing based on the median

Subject	Knowledge	Thinking	Discipline	Character	Tolerance	Decisions	Fitness	Companionship
Military subjects	-2.975	-3.569	2.425	1.175	-2.431	-0.188	1.100	-0.044
Economics	0.088	0.794	-0.313	-0.863	0.031	0.675	0.163	-0.681
Management	1.275	0.381	-0.625	-0.275	0.219	2.263	-1.550	-0.094
Finance	0.938	1.444	0.238	-0.513	-0.319	1.525	0.113	-0.231
Formal sciences	-0.888	0.319	0.313	-0.138	0.156	-0.500	-0.113	0.044
Foreign languages	0.575	-0.319	-0.225	0.125	1.619	-2.238	-0.750	0.306
Sports	-4.613	-4.106	1.288	1.138	-0.969	-2.425	4.663	1.319
Social sciences	-0.088	-0.781	-0.788	0.663	2.756	-0.400	-1.513	1.344
Modern information technologies	0.725	1.431	0.225	-0.125	-0.031	0.213	-0.400	-0.344
Individual study and free time	-0.300	-0.594	-0.900	0.450	-0.656	0.188	3.675	0.131

Source: author's elaboration.

Furthermore, by analyzing the row effects it can be seen that the people tested attribute a very high weight to sport (it does not require too much mental effort – compare the coefficient of variation), while a negative value is assigned to the formal sciences (large mental effort). Analysis of the residual matrix also leads to the conclusion that there is no feature which subjects would form on their own, although there are high individual residuals, both negative and positive. It can also be noted that on average each subject influences the formation of a given feature by about one third of the maximum possible (the scale has a range from 0 to 10).

Application of the principal component analysis specifies factors that are not correlated with each other (they are orthogonal). Here, e.g. the first component represents

features such as discipline, character, physical fitness and companionship. These are features that make up the temperament of the tested individual. Therefore, independently of the overall matrix, using this method, that portion of the matrix can be isolated for a more detailed analysis. Therefore, it is a very useful procedure for analyzing the test results from a survey, i.e. the matrix can be analyzed in blocks, depending on the purpose of the analysis (the matrices are of a block form).

Since the subjects have certain common features and affect the formation of individual features, two-factor analysis of variance was used for the purpose of examining the interactive relations between them. For this analysis the following classes were adopted:

- groups of subjects, such as: military (P1), economics (P2, P3, P4), science (P5, P6, P8), practice (P7, P9, P10),
- groups of features: knowledge (C1, C2, C6), honor (C3, C4, C5), health (C7, C8).

Table 10. Two-factor analysis of variance (ANOVA)

Source of variation	Sum of squares	Degrees of freedom	Variance	F-Statistics (Snedecor's)	p-Value
Factor <i>A</i> – groups of subjects	198.91	3	66.304688	1.41	0.25
Factor <i>B</i> – feature groups	58.74	2	29.37	0.623	0.54
<i>A</i> × <i>B</i> Interaction	196	6	32.67	0.69	0.66
Reminders	3205	68	47		

Source: author's work.

Analyzing the results obtained in Table 10, it can be concluded that there is no interaction between this adopted partition and the groups of subjects and features. In addition, there are no statistically significant differences between the means for both the individual groups of objects and the groups of features, at the adopted significance level, $\alpha = 0.05$. The assumptions of the analysis of variance test regarding normality and the homogeneity of variance between groups were examined. The data fulfil the assumptions regarding normality at the significance level $\alpha = 0.05$ but the homogeneity of variance assumption was only met at the significance level $\alpha = 0.001$. Homogeneity of variance was examined using Bartlett's test and the normality of the distributions was tested using Hellwig's blank cells test and the Shapiro–Wilk test.

A canonical analysis of the distribution of features within two subsets was also undertaken. The relation between the following groups of features was examined:

- group 1: discipline, character, tolerance and decisions,
- group 2: knowledge and thinking.

The previously conducted statistical analysis indicated that knowledge and thinking may dominate the first group of features. The results shown in Table 11 confirm this assumption.

Table 11. Results of the canonical analysis

Group number	Eigenvalue	Canonical correlation	Wilk's λ statistics	X^2 statistics	Degrees of freedom	p -Value
1	0.93	0.97	0.03	19.360	8	0.014
2	0.56	0.75	0.44	4.490	3	0.21

Source: author's work.

Tables 12 and 13 present canonical variable coefficients for both groups of features which have a similar interpretation to the analysis of principal components with the following difference: the canonical variables do not need to be orthogonal. In the analysis based on principal components, knowledge and thinking are independent of features such as discipline, character, tolerance and decisions. However, the canonical analysis revealed dependence between these features. It can therefore be concluded that in this kind of research one should be careful in formulating conclusions based on only one method.

Table 12. Coefficients of canonical variables for the set of features in the first principal component

Feature	Canonical variable	
	1	2
Discipline	-3.82	1.67
Character	3.78	-2.33
Tolerance	-1.56	1.73
Decisions	0.40	0.71

Source: author's work.

Table 13. Coefficients of canonical variables for the set of features in the second principal component

Feature	Canonical variable	
	1	2
Discipline	-0.34	1.75
Character	1.26	-1.26

Source: author's work.

Tables 12 and 13 allow us to give interpretations of the canonical variables based on the coefficients obtained.

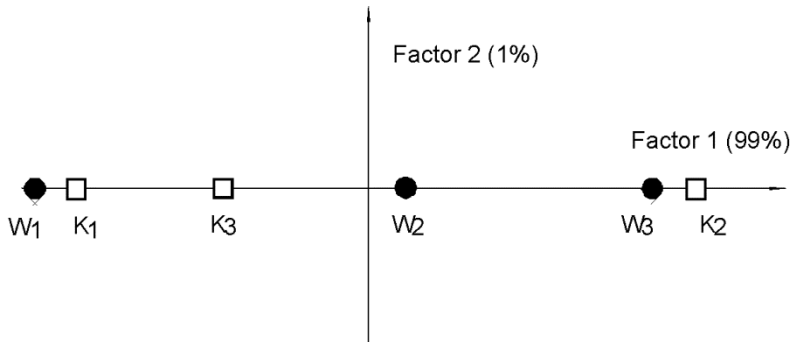


Fig. 6. Results of the analysis of the correspondence factor on classes of subjects and features. Source: author's work

Correspondence factor analysis was also used [4], [13] with respect to a two-dimensional vector (X, Y) . The variable X is represented by three categories of subjects: a) professional, b) general, c) free time and individual study. On the other hand, the features are represented by three principal components, i.e. intellect, temperament and humanism. Contingency tables were created based on classifying whether a response was higher than 5 on a scale of [0, 10]. The results of the analysis are shown in Fig. 6 which can be interpreted as follows. The dimension of quantitative analysis is reduced virtually to one factor (99%). This factor describes features and subjects in a single dimension. By analyzing the figure, we see that the pairs $(W1, K1)$ and $(W3, K2)$ have the largest share in this factor. However, other elements, $W2$, and $K3$, are fairly distant from each other. Due to the proximity of the listed pairs, this factor is named education.

5. The teaching process as a decision game

The teaching process can be considered as a two-player zero-sum game (Table 14). The players are: the teacher (the player G1, more generally, the sender of information – knowledge) and the student (the player G2, more generally, the information receiver). The strategies for player G1 are the subjects, and for player G2, the strategies are the personality features shaped on the basis of the knowledge acquired in the teaching process. Why can this process be treated in the easiest way as a zero-sum game? During the teaching process essential material is forwarded to the recipient. At each stage of the process a certain portion of the content of substantive teaching material is handed on. Ideally speaking, what has been communicated by player G1 increases the knowledge of player G2 and reduces the quantity of material needed for knowledge transmission. Hence, this process constitutes a zero-sum game. Having the

data matrix, the numerical values of payments (utilities) in such a game can be substantially interpreted.

Table 14. An example of a zero-sum game for the teaching process considered

G1	G2		
	β_1	β_2	β_3
α_1	4.5	4.9	6.1
α_2	5.9	2.0	1.2
α_3	3.4	2.6	1.7

Source: author's work.

Player G1's strategies represent subject groups, respectively: professional, free time and individual studies, general. But Player G2's strategies are the principal components derived from the previous analysis. The solution for player G1 is $\{0.9, 0.09, 0.01\}$, and for player G2 is $\{0.6, 0.3, 0.1\}$. The value of the game is $V = 4.6$.

One possible substantial interpretation of the game is as follows: the professional subjects have the greatest influence on the teaching process and the features related to temperament (the first component) are formed to the highest degree.

6. Conclusions

The applied method of testing the teaching process allows us to draw conclusions of a detailed character related to the investigated problem and also proposals of a general nature. Thanks to the adopted methods of analysis, for example, hidden properties can be detected. In relation to the survey carried out, such detailed conclusions, among other things, are the following:

- division of the features into several moderately independent groups,
- main factors forming the personality of a future officer were named,
- teaching can be considered as an element of the social communication process and also analyzed in terms of game theory.

The conclusions of a general nature, which arise from the test method used can be formed as follows:

- the type of survey presented allows us to use the statistical methods of multidimensional comparative analysis for the analysis of the tested process,
- to formulate hidden relations between tested objects and features,
- to create homogeneous groups of features and objects,

- to examine any part of the matrix,
- to create metafeatures or metaobjects,
- to examine the usefulness of subjects as objects forming the information receiver in the teaching process.

Forming detailed conclusions in a meaningful way is a much more difficult procedure than making general conclusions, which, irrespective of the nature of the problem analyzed are, to a certain extent, a consequence of the methodology applied. Detailed proposals concern the survey results. It is advisable to have a greater number of repetitions, in order to compare the results and then the detailed conclusions will have a significant, substantial character.

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