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AN APPROACH FOR A MORE OBJECTIVE EVALUATION OF PRACTICAL PROJECTS, USED IN THE TRAINING PROCESS

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Abstract. Well–prepared, adaptive and sustainably developing specialists are an important competitive advantage, but also one of the main challenges for businesses. One option of the education system for creation and development of staff adequate to the needs is the development of projects with topics from real economy ("Practical Projects"). The objective assessment is an essential driver and motivator, and is based on a system of well-chosen, well-defined and specific criteria and indicators. An approach to a more objective evaluation of practical projects is finding more objective weights of the criteria. A natural and reasonable approach is the accumulation of opinions of proven experts and subsequent bringing out the weights from the accumulated data. The preparation and conduction of a survey among recognized experts in the field of project-based learning in mathematics, informatics and information technologies is described. The processing of the data accumulated by applying AHP, allowed us to objectively determine weights of evaluation criteria and hence to achieve the desired objectiveness.

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Key words: project based training,; evaluation, evaluation criteria, analytic hierarchy process – AHP, application of AHP, aggregating individual judgments, aggregating individual priorities.

Introduction. One of the main challenges businesses face nowadays is supplying the business model with adequate resources, including human resources. Well–prepared, adaptive and constantly developing specialists are an important competitive advantage for business and administration. Searching and finding the appropriate professionals is a difficult and important process, which is not always successfully completed. It often generates direct losses or lost profits. This is more noticeable in today's dynamic socio-economic development. As a result of their survey, Ernst & Young conclude that the German SMEs can hardly find qualified staff, which causes them to miss out on 33 billion euros a year [38]. According to the employment prospects of the Bureau of Labor Statistics [36] in 2022 in the US alone more than 15 million new jobs will be open, and along with those to be replaced, more than 50 million. The IT specialists among them will be more than 700,000, 1.3 million, respectively [37]. Many forecasts of leading companies foresee a huge lack of qualified staff. According to a report of IBM (IBM's 2012 Tech Trends), only one out of 10 organizations has professionals with the skills needed to effectively implement technologies like "business intelligence", "mobile computing", "cloud computing" and "social business" [35]. The Bulgarian business has also realized and experienced the lack of sufficient, appropriate and well-trained staff. This is particularly noticeable in areas with high added value. So business and a number of branch organizations are constantly offering initiatives to minimize the time from the occurrence of the need for knowledge to its acquisition and application in practice.

On the method of projects and their evaluation. One approach of the education system for creation and development of adequate staff is the development of projects with topics from real economy ("Practical Projects"). With this approach the trainees (school students, undergraduates, graduates, employees in companies, etc.) will be able to rapidly acquire practical knowledge and skills that are necessary and applicable in a real business environment.

According to [14] the method of projects has been created in connection to the acquisition of practical knowledge and skills. It was back in 1763 in the San Luca School of Architecture in Rome when students/scholars worked on projects. Substantial development and rationalization of this method has been done by the American educator and psychologist John Dewey and his student William Kilpatrick [22]. In 1911 the US Bureau of Education legalized the term "project".

Over the past 25 years the method of projects drew the attention of a number of authors, incl. Bulgarian ones. The key issues of project-based learning and its improvement have been actively explored. A number of researchers and teachers in different subjects (A. Rahnev, E. Angelova, K. Garov, S. Aneva, B. Toshev, A. Gendzhova, B. Yordanova, Iv. Marasheva etc. [7], [8], [9], [18], [21], [24], [25], [31]) have explored, developed and implemented project-based learning [19].

Mathematics, informatics and information technologies (IT) are sciences that form knowledge, skills and competences, necessary for the development of high-tech activities. The latter are a prerequisite for the organization of economic activities with high added value, which are the foundation of any successful economy.

Hence the need for a thorough study of these disciplines. Their direct connection to practice is not always visible for young people (high-school and university students) and this prevents them from feeling the need to learn them. Highly motivating for the students is work on projects with topics from real business. These reveal to the young people the application of sciences to real life.

The development of practical projects in mathematics, informatics, information technologies and others is an iterative process of seven phases [4]. Important preconditions for success are the close cooperation between the educators (teacher, tutor, mentor, supervisor/consultant, etc.) and the learner, as well as the motivation of the latter to create a “quality” product out of his efforts and work [17]. In this respect leading is the ability of the educator to form positive motivational attitude in the students’ minds, which is one of his/her most important tasks [1]. As a part of the whole process, the evaluation of the students has always had a very strong effect on the life and career of young people. Using it, the teenagers establish criteria for self-assessment; compare their achievements in the educational process with those of others; prepare themselves for their functions in life. It is particularly important to achieve a higher objectivity of evaluation. The topic of evaluation is one of the most studied in the international educational literature, because of its relevance. In the past few years, this country has gained a solid theoretical and practical experience. Various aspects of the evaluation are discussed in [2], [10], [11], [15], [30]. The topic of evaluation is quite important for business and management, as well. This requires even more in-depth work on the issues of forming an exact evaluation. The fair, accurate and objective evaluation is managed by a system of well-chosen, well-defined and specific criteria and indicators.

Over many years of research and experimental work by one of the authors, in collaboration with colleagues [20], we came to a system of eight criteria that we think are necessary and sufficient to give an accurate and objective assessment of projects with a practical purpose (developed by trainees) in the areas of mathematics, informatics and information technologies [5]. For their final shaping we took into account comments, opinions and recommendations of the students who the criteria were presented to and discussed with. As a basis we used some of the criteria for evaluation of mathematical projects applied in the work of the mathematical club "Sigma" in Hristo Botev 21 school in Sofia [16]. The mechanism for evaluation and self-evaluation of projects is described in [19]. Its effectiveness has been demonstrated by the analysis of more than 650 completed evaluation cards and more than 1,500 evaluated projects [20].

Fundamental in the definition of the criteria was the rule that each of them should reflect one or several important characteristics of the preparation, development, design and protection of the project. The criteria are:

Scientific rigor – reflects the degree of deepness and scientific rigor of the project.

Creativity – reflects the skills for generating new ideas and solving problems.

Applicability – reflects the practical applicability of the project.

Contemporaneity – reflects the importance of the project to economics and real life for the given moment in time.

Presentation – reflects the level of knowledge and the ability of the students to present themselves orally.

Visualization – reflects the skills to prepare a presentation and the accompanying visual materials.

Attractiveness – reflects to what extend a project has attractive elements, thus arousing interest among peers.

Styling – reflects the skills for arranging and presenting a set of documents.

For each criterion three indicators are defined that reflect a specific degree of satisfaction for it. Each indicator is accurately and comprehensively defined and this allows for the accurate determination of its corresponding numerical value $P_i \in \{1, 3, 5\}$.

For the formation of the outcome of the project evaluation E_p a linearization of the completed evaluation cards is presented by the formula:

$$E_p = \sum_{k=1}^{n} \sum_{i=1}^{8} P_i^k, \tag{1}$$

where n is the number of assessors and P_i^k is the evaluation of the i^{th} criterion by the k^{th} assessor.

If the number of assessors is different or a comparison of the results of project evaluations is required, then for the normalization of the estimates to the same basis an average or other statistical value could be used.

One approach to improve the objectivity of the evaluation of practical projects. The methodology as described does not use weights of the criteria, i.e. they are equal in weight. There are 2 main reasons for this:

1. When working with students it is much easier to adopt initially a simpler model that could be subsequently refined and improved.

2. There is no appropriate and objective method to determine the weight of the so-defined criteria.

After we decided to introduce weights, we started studying the possibilities to determine them. A natural and reasonable approach is accumulating the opinions of proven experts and subsequently extracting the weights from the data already accumulated. As most suitable to this aim we chose Saaty's method of— Analytic Hierarchy Process (AHP) [26]. The mechanism of this method, built on a matrix of pairwise comparison is one of the most common approaches for determining the weights of a set of finite number of comparable objects. In our case, the compared objects are the criteria on which one wants to assign weights (Ti) corresponding to their importance in the evaluation of the projects with practical application. So the formula written above (1) will become

$$E_p^t = \sum_{k=1}^{n} \sum_{i=1}^{8} T_i P_i^k, \qquad (2)$$

where n is the number of assessors and P_i^k is the evaluation of the i^{th} criterion by the k^{th} assessor.

The essence of the mechanism built on a matrix of pairwise comparison consists in filling a square matrix $n \times n$ (n is the number of the objects whose weights will be determined). In fact, the matrix is $(n+1)\times(n+1)$. $n+1^{st}$ row and $n+1^{st}$ column are used for title. The titles of the series are listed in the $n+1^{st}$ row (row 1) and the titles of the columns in the $n+1^{st}$ row (row 1). As titles the names of the compared objects, themselves written in rows and columns are filled in. In our case these are the names of the criteria for evaluation of practical projects. In order to give his/her opinion (judgment) on how the pairs reflect on each other, the expert should fill in the square table. It is enough to fill the part above the main diagonal. All values on the main diagonal are 1. The other values (those below the main diagonal) are obtained by reverse symmetry of the values above the "main diagonal", i.e., they have their respective reciprocal values. In determining the extent of the ratio between two criteria A and B, leading is which is written in the row of the table. For example, if the expert's assessment is that criterion A is "substantially more important" than criterion B, the expert should put 6 in the cell in which intersect the row with the name of criterion A and the column with the name of criterion B.

For the implementation of the mechanism of the AHP method the procedure is as follows:

1. A comparative table (Table 1) with several levels and their numerical measurements to compare one criterion to another:

Table 1

Meaning	**Value**
Criterion A is ***substantially less*** important than criterion B	1/6
Criterion A is ***moderately less*** important than criterion B	1/4
Criterion A is ***slightly less*** important than criterion B	1/2
Criterion A is ***equally*** important as criterion B	1
Criterion A is ***slightly more*** important than criterion B	2
Criterion A is ***moderately more*** important than criterion B	4
Criterion A is ***substantially more*** important than criterion B	6

2. A table (Table 2) with the criteria, corresponding to the mechanism for pairwise comparison:

Table 2

Criteria	Scientific rigor	Creativity	Applicability	Contemporaneity	Presentation	Visualization	Attractiveness	Styling
Scientific rigor	1							
Creativity		1						
Applicability			1					
Contemporaneity				1				
Presentation					1			
Visualization						1		
Attractiveness							1	
Styling								1

3. A table in MS Excel format, to help filling in the matrix for pairwise comparison.

4. A list of 16 experts with proven experience (such as tutors, mentors, leaders and members of national and international juries, etc.) with learners (pupils, students and others) developing projects mostly in mathematics, computer science and information technologies. The experts are part of the teams of the Institute of Mathematics and Informatics (IMI) - Bulgarian Academy of Sciences (BAS), Paisii Hilendarski University of Plovdiv , New Bulgarian University (NBU), Acad. Kiril Popov Math High School , Plovdiv, Hr. Botev 21^{st} Secondary School , Sofia, and others.

5. A letter of request to each of the experts with a brief description of the purpose of the survey and a respective instruction.

6. The letter of request, sent by e-mail to all of the experts together with the attached MS Excel table which they had to fill in and return to us again by e-mail.

7. A set of several MS Excel tables developed for the processing of the results.

We received, classified and processed the tables, completed and sent by 15 experts, containing their judgments. 14 of them were eligible for the requirements of the AHP method.

Description of the process and procedure for processing the opinions of experts, summaries and conclusions. There are various software programs implementing the AHP method (Expert Choice [33], SuperDecisions [39], etc.). Most of them are commercial and quite expensive. However, it is relatively easy to implement the AHP procedures by using MS Excel. Templates and other online resources are also available. They all have various restrictions, features and methods of application. To process the results we used MS Excel tables, developed by ourselves, to obtain the desired weights of the criteria for evaluation of practical projects. In the processing of the completed tables for pairwise comparison we applied the following algorithm for the implementation of AHP [3], [12], [13], [34]:

1. Bringing the table (matrix) from a triangular to square type. Assuming that the matrix is $A = (a_{ij})_{8x8}$ and $a_{ii} = 1$ for $i = 1, \ldots, 8$, in the formula

   $$a_{ij} = \frac{1}{a_{ji}}, \quad i = 2, \ldots, 8; j = 1, \ldots, (i-1) \tag{3}$$

   we fill in the values of the matrix elements below the main diagonal.

2. Finding the weights of each of the criteria through the following steps:

   a. Normalizing each of the matrix elements for pairwise comparison by the formula:

$$a'_{ij} = \frac{a_{ij}}{\sum_{j=1}^{8} a_{ij}} \tag{4}$$

   b. Finding the weights of each of the criteria by:

      i. Summation of the matrix elements found on the corresponding to the criterion row and

      ii. Normalization by dividing the total sum (of the amounts on the rows), which is equal to their number, viz., 8.

   i.e., we apply consecutively the following formulas:

$$T'_i = \sum_{j=1}^{8} a'_{ij}, \quad \text{for} \quad i = 1, \ldots, 8 \tag{5}$$

and

$$T_i = \frac{T'_i}{8}, \quad \text{for} \quad i = 1, \ldots, 8 \tag{6}$$

The processing was conducted in several stages:

I. Individual processing of each of the eligible tables.

After applying the above mentioned algorithm, we received 14 sets of weights for the evaluation of practical projects, viz. (Tables 3a and 3b):

Table 3a

Criteria	**Exp.1**	**Exp.2**	**Exp.3**	**Exp.4**	**Exp.5**	**Exp.6**	**Exp.7**
Scientific rigor	0.14	0.10	0.19	0.26	0.24	0.19	0.07
Creativity	0.21	0.07	0.19	0.20	0.24	0.19	0.08
Applicability	0.11	0.33	0.22	0.17	0.13	0.18	0.06
Contemporaneity	0.11	0.21	0.17	0.12	0.13	0.18	0.10
Presentation	0.17	0.09	0.07	0.07	0.13	0.10	0.15
Visualization	0.06	0.09	0.06	0.05	0.06	0.06	0.17
Attractiveness	0.11	0.03	0.07	0.06	0.03	0.04	0.17
Styling	0.10	0.08	0.04	0.06	0.03	0.04	0.21
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table 3b

Criteria	**Exp.8**	**Exp.9**	**Exp.10**	**Exp.11**	**Exp.12**	**Exp.13**	**Exp.14**
Scientific rigor	0.19	0.21	0.21	0.17	0.29	0.19	0.22
Creativity	0.22	0.27	0.19	0.20	0.18	0.06	0.09
Applicability	0.25	0.21	0.23	0.18	0.16	0.08	0.12
Contemporaneity	0.12	0.07	0.18	0.23	0.11	0.10	0.12
Presentation	0.08	0.12	0.07	0.09	0.09	0.12	0.10
Visualization	0.05	0.04	0.05	0.05	0.08	0.11	0.14
Attractiveness	0.05	0.04	0.04	0.05	0.05	0.14	0.14
Styling	0.05	0.04	0.04	0.05	0.05	0.19	0.07
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

II. Group processing of all tables. The groups were determined in advance based on the experience that the experts have had in working with students:

Group I—experts working primarily with school students developing projects and participating with them in national and international events;

Group II— experts, working primarily with university students developing projects within the educational process in universities;

Group III—experts working with scholars, university students, etc. developing projects within the educational process in schools, universities, etc., and also participating with them in national and international events;

Total—all experts participating in the survey that have sent correctly filled tables.

The grouped results are as follows: (Tables 4, 5, 6):

Table 4

Group I—experts working primarily with school students/scholars developing projects and participating with them in national and international events					
Criteria	**Exp.1**	**Exp.3**	**Exp.4**	**Exp.5**	**Exp.10**
Scientific rigor	0.14	0.19	0.26	0.24	0.21
Creativity	0.21	0.19	0.20	0.24	0.19
Applicability	0.11	0.22	0.17	0.13	0.23
Contemporaneity	0.11	0.17	0.12	0.13	0.18
Presentation	0.17	0.07	0.07	0.13	0.07
Visualization	0.06	0.06	0.05	0.06	0.05
Attractiveness	0.11	0.07	0.06	0.03	0.04
Styling	0.10	0.04	0.06	0.03	0.04

Table 5

Group II—experts, working primarily with university students developing projects within the educational process in universities					
Criteria	**Exp.2**	**Exp.7**	**Exp.11**	**Exp.13**	**Exp.14**
Scientific rigor	0.10	0.07	0.17	0.19	0.22
Creativity	0.07	0.08	0.20	0.06	0.09
Applicability	0.33	0.06	0.18	0.08	0.12
Contemporaneity	0.21	0.10	0.23	0.10	0.12
Presentation	0.09	0.15	0.09	0.12	0.10
Visualization	0.09	0.17	0.05	0.11	0.14
Attractiveness	0.03	0.17	0.05	0.14	0.14
Styling	0.08	0.21	0.05	0.19	0.07

Table 6

Group III—experts working with scholars, university students, etc. developing projects within the educational process in schools, universities, etc., and also participating with them in national and international events				
Criteria	**Exp.6**	**Exp.8**	**Exp.9**	**Exp.12**
Scientific rigor	0.19	0.19	0.21	0.29
Creativity	0.19	0.22	0.27	0.18
Applicability	0.18	0.25	0.21	0.16
Contemporaneity	0.18	0.12	0.07	0.11
Presentation	0.10	0.08	0.12	0.09
Visualization	0.06	0.05	0.04	0.08
Attractiveness	0.04	0.05	0.04	0.05
Styling	0.04	0.05	0.04	0.05

Following the consideration of the individual tables for pairwise comparison, as well as the received weights of the evaluation criteria for practical projects, we choose an approach to obtain aggregated weights (for the groups also). There are different ways of aggregation of the opinions (judgments, decisions) of the experts. They may depend on:

– The number of criteria,

– The number of experts,

– The composition (selection) of the experts and their grouping,

– The given opinions (judgments) for the mapping of the criteria to one another (in the matrices for pairwise comparison),

– The obtained results in finding the individual evaluations of each of the experts, and so on.

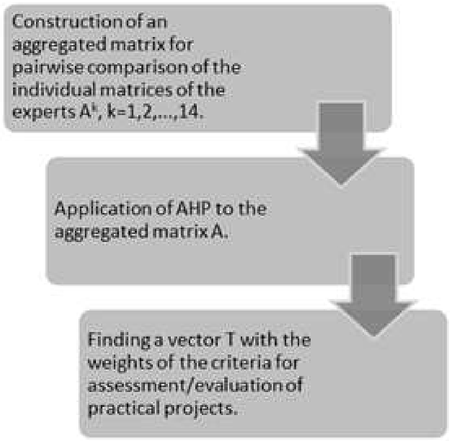

Fig. 1

In some cases an aggregation of the primary opinions (judgments) (reflected in the matrices for pairwise comparison) is used, in others is used an aggregation of the results (vectors with the weights) after application of the AHP for each of the individual contributions of the individual experts. Assuming that with $A^k = (a^k_{ij})_{8\times 8}$, $k = 1, 2, \ldots, 14$ we denote the matrices for pairwise comparison of the experts and with $T^k = (t^k_i)$, $i = 1, 2, \ldots, 8$, $k = 1, 2, \ldots, 14$ the vectors of the AHP defined weights of the criteria for evaluation of practical projects, two different approaches for aggregation could be summarized in the following ways:

1. Approach 1 (AIJ—aggregation of individual judgments). Construction of an aggregated matrix $A = (a^{aggr}_{ij})_{8\times 8}$ for pairwise comparison (with judgments) of the individual matrices of the experts A^k. Application of AHP to the aggregated matrix A and finding a vector T with the weights of the criteria for evaluation of practical projects. The scheme is presented in Fig. 1.

2. Approach 2 (AIP—aggregation of individual priorities/weights). Application of the AHP for the individual matrices A^k for pairwise comparison (with judgments) of each of the experts. Finding vectors $T^k = (t^k_i)$, $i = 1, 2, \ldots, 8$, $k = 1, 2, \ldots, 14$ with the weights of the criteria for evaluation of practical projects of each of the experts. Aggregation of the vectors with the weights and obtaining a summary vector $T = (t^{aggr}_i)$, $i = 1, 2, \ldots, 8$, with the weights of the criteria for evaluation of practical projects. If necessary, the resulting vector T is normalized further. The scheme is presented in Fig. 2.

In each of the approaches for aggregation different ways of generalizing may be used, with application of different averages. The most often used ones are

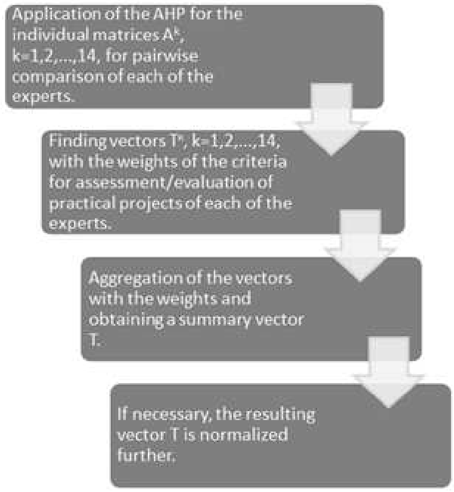

Fig. 2

arithmetic mean and geometric mean of the values of the elements of the matrices and/or the vectors. The relevant formulas are:

$$a_{ij}^{aggr} = \frac{\sum_{k=1}^{m} a_{ij}^{k}}{m} \tag{7}$$

$$a_{ij}^{aggr} = \sqrt[m]{\prod_{k=1}^{m} a_{ij}^{k}} \tag{8}$$

$$t_{i}^{aggr} = \frac{\sum_{k=1}^{m} t_{i}^{k}}{n} \tag{9}$$

$$t_{i}^{aggr} = \sqrt[m]{\prod_{k=1}^{m} t_{i}^{k}} \tag{10}$$

where $i = j = 1, 2, \ldots, n$ is the number of criteria (in our case, $n = 8$), and $k = 1, 2, \ldots, m$ is the number of experts (in our case, $m = 14$; $m = 5$; $m = 5$; $m = 4$, respectively for all experts who have given an opinion, in group I, in group II and in group III).

When choosing an approach and values for aggregation we should take into consideration the type and number of sets of experts, their specific grouping, the number of evaluation criteria, etc.

For a large number of experts (over 300) the scheme with arithmetic mean values is more appropriate [6], [32]. When working with a set of heterogeneous composition of experts the geometric mean is recommended. Saaty himself recommends its use in such cases, even though it sometimes requires additional normalization of the final vector [27], [28], [29].

When processing the matrices for pairwise comparisons (filled in by the experts) we observed various value differences in the opinions of the experts, which for some couples could be significant.

Table 7 shows the minimum and maximum values of the reference criteria to one another, as well as their mode. With shades of gray (from darker to lighter) the spread in the comparisons is shown. The largest gaps (7 levels) are observed in the pairwise comparison of the following criteria: "Scientific rigor" – "Appli-

Table 7

Criteria	Scientific rigor	Creativity	Applicability	Contemporaneity	Presentation	Visualization	Attractiveness	Styling
Scientific rigor	**1**	Min: 1/4 Max: 4 Mode: 1	Min: 1/6 Max: 6 Mode: 2	Min: 1/4 Max: 4 Mode: 4	Min: 1/6 Max: 4 Mode: 2	Min: 1/6 Max: 6 Mode: 4	Min: 1/6 Max: 6 Mode: 4	Min: 1/6 Max: 6 Mode: 6
Creativity		**1**	Min: 1/6 Max: 6 Mode: 1	Min: 1/2 Max: 4 Mode: 1	Min: 1/6 Max: 4 Mode: 2	Min: 1/6 Max: 6 Mode: 4	Min: 1/6 Max: 6 Mode: 4	Min: 1/4 Max: 6 Mode: 4
Applicability			**1**	Min: 1/2 Max: 6 Mode: 1	Min: 1/2 Max: 6 Mode: 2	Min: 1/2 Max: 6 Mode: 4	Min: 1/2 Max: 6 Mode: 4	Min: 1/4 Max: 6 Mode: 4
Contemporaneity				**1**	Min: 1/2 Max: 6 Mode: 2	Min: 1/2 Max: 6 Mode: 4	Min: 1 Max: 6 Mode: 2	Min: 1/4 Max: 6 Mode: 2
Presentation					**1**	Min: 1 Max: 4 Mode: 2	Min: 1/2 Max: 4 Mode: 2	Min: 1/4 Max: 4 Mode: 2
Visualization						**1**	Min: 1/2 Max: 4 Mode: 2	Min: 1/2 Max: 4 Mode: 1
Attractiveness							**1**	Min: 1/2 Max: 6 Mode: 1
Styling								**1**

cability"; "Scientific rigor" – "Visualization"; "Scientific rigor" – "Attractiveness"; "Scientific rigor" – "Styling"; "Creativity" – "Applicability"; "Creativity" – "Visualization" and "Creativity" – "Attractiveness". The smallest difference (3 level) is in the pairwise comparison of the criteria: "Presentation" – "Visualization".

Upon examination of the Mode values it can be seen that it very rarely coincides with one of the end values (minimum/maximum), which indicates that those extreme values are mostly exceptions.

When processing the matrices for pairwise comparison for the different groups of experts, we monitor significantly smaller differences in the opinions of the experts in the groups themselves, as should be expected.

Table 8

Criteria	Scientific rigor	Creativity	Applicability	Contemporaneity	Presentation	Visualization	Attractiveness	Styling
Scientific rigor	1	Min: 1/2 Max: 1	Min: 1/2 Max: 4	Min: 1 Max: 4	Min: 1/2 Max: 4	Min: 2 Max: 6	Min: 2 Max: 6	Min: 2 Max: 6
Creativity		1	Min: 1 Max: 4	Min: 1 Max: 4	Min: 1 Max: 2	Min: 2 Max: 4	Min: 2 Max: 6	Min: 2 Max: 6
Applicability			1	Min: 1 Max: 6	Min: 1/2 Max: 6	Min: 1 Max: 6	Min: 2 Max: 6	Min: 1/2 Max: 6
Contemporaneity				1	Min: 1/2 Max: 6	Min: 2 Max: 6	Min: 2 Max: 6	Min: 1 Max: 6
Presentation					1	Min: 1 Max: 2	Min: 1/2 Max: 4	Min: 1 Max: 4
Visualization						1	Min: 1/2 Max: 2	Min: 1/2 Max: 2
Attractiveness							1	Min: 1 Max: 6
Styling								1

In Tables 8, 9 and 10 we present the minimum and maximum values of the criteria referring to one another, as well as a trial of finding and presenting the Mode to their respective expert groups I, II and III. It is well known that for small groups the finding of the Mode is impossible or the values obtained are inaccurate and that is why it is not included in the tables.

What is seen is that the spread of groups I and III is substantially smaller than that for the whole group of experts, and for Group II the spread of 7 levels occurs quite rarely.

Table 9

Criteria	Scien-tific rigor	Creativity	Applica-bility	Contem-poraneity	Presenta-tion	Visualiza-tion	Attractive ness	Styling
Scientific rigor	1	Min: 1/4 Max: 4	Min: 1/6 Max: 6	Min: 1/4 Max: 4	Min: 1/6 Max: 4	Min: 1/6 Max: 4	Min: 1/6 Max: 4	Min: 1/6 Max: 6
Creativity		1	Min: 1/6 Max: 6	Min: 1/2 Max: 1	Min: 1/6 Max: 2	Min: 1/6 Max: 4	Min: 1/6 Max: 4	Min: 1/4 Max: 4
Applicability			1	Min: 1/2 Max: 2	Min: 1/2 Max: 4	Min: 1/2 Max: 6	Min: 1/2 Max: 6	Min: 1/4 Max: 4
Contem-poraneity				1	Min: 1 Max: 4	Min: 1/2 Max: 4	Min: 1 Max: 6	Min: 1/4 Max: 4
Presentation					1	Min: 1 Max: 2	Min: 1 Max: 4	Min: 1/4 Max: 2
Visualization						1	Min: 1/2 Max: 4	Min: 1/2 Max: 1
Attractive-ness							1	Min: 1/2 Max: 2
Styling								1

In Group I the most serious discrepancies (5 levels) in the values occur in the pairwise comparison of the criteria: "Applicability" – "Presentation"; "Applicability" – "Styling" and "Contemporaneity" – "Presentation". The smallest difference (1 level) in the values in pairwise comparison is for the criteria: "Scientific rigor" – "Creativity"; "Creativity" – "Presentation"; "Creativity" – "Visualization" and "Presentation" – "Visualization".

In group II the most serious discrepancies (7 levels) in the values are observed in the pairwise comparison of criteria: "Scientific rigor" – "Applicability"; "Scientific rigor" – "Styling" and "Creativity" – "Applicability". The smallest difference (1 level) is in the pairwise comparison of the criteria: "Creativity" – "Contemporaneity"; "Presentation" - "Visualization" and "Visualization" – "Styling".

In group III the most serious discrepancies (only 3 levels) in the values during pairwise comparison is for the criteria: „Scientific rigor" – "Creativity"; "Scientific rigor" - "Applicability"; "Scientific rigor" – "Contemporaneity"; "Creativity" – "Topicality"; "Creativity" – "Visualization"; "Applicability" – "Contemporaneity"; "Applicability" – "Visualization"; "Contemporaneity" – "Presentation"; "Contem-

Table 10

Criteria	Scientific rigor	Creativity	Applicability	Contemporaneity	Presentation	Visualization	Attractiveness	Styling
Scientific rigor	1	Min: 1/2 Max: 2	Min: 1/2 Max: 2	Min: 1 Max: 4	Min: 2 Max: 4	Min: 4 Max: 4	Min: 4 Max: 4	Min: 4 Max: 6
Creativity		1	Min: 1 Max: 2	Min: 1 Max: 4	Min: 2 Max: 4	Min: 2 Max: 6	Min: 4 Max: 6	Min: 4 Max: 6
Applicability			1	Min: 1 Max: 4	Min: 2 Max: 4	Min: 2 Max: 6	Min: 2 Max: 4	Min: 4 Max: 4
Contemporaneity				1	Min: 1/2 Max: 2	Min: 1 Max: 4	Min: 2 Max: 4	Min: 2 Max: 4
Presentation					1	Min: 2 Max: 4	Min: 2 Max: 4	Min: 2 Max: 4
Visualization						1	Min: 1/2 Max: 2	Min: 1 Max: 4
Attractiveness							1	Min: 1/2 Max: 2
Styling								1

poraneity" – "Visualization"; "Visualization" – "Attractiveness"; "Visualization" – "Styling" and "Attractiveness" – "Styling". There is no difference in the values when comparing in pairs the following criteria: "Scientific rigor" – "Visualization"; "Scientific rigor" – "Attractiveness" and "Applicability" – "Styling". Taking into account the composition and the number of the sets of experts, their grouping, and the number of evaluation criteria, we decided to do an aggregation using both approaches as well as both averages and other values. In tables 11, 12, 13 and 14 we presented the aggregated results for all experts and for groups I, II, and III, respectively, using:

– Arithmetic mean, geometric mean and Mode (if applicable) of the values in the matrices for pairwise comparison (i.e. rough estimates for individual referencing criteria to each other);

– Arithmetic mean, geometric mean and Mode (if available) of the values of the vectors with the weights (of the criteria for evaluation of practical projects, derived from the matrices for comparisons of each of the experts). The Geometric mean of some of the vectors required a further normalization;

– The last column presents also the geometric mean of the resulting vectors from the previous methods (the vector-columns on the left of the table).

Table 11

Aggregated results for all experts							
Criteria	**Arith-metic mean AIJ**	**Arith-metic mean AIP**	**Geo-metric mean AIJ**	**Norma-lized Geometr ic mean AIP**	**Mode AIJ**	**Norma-lized Mode AIP**	**Geomet-ric mean (vectors left of the table)**
Scientific rigor	0.23	0.19	0.19	0.20	0.26	0.21	0.21
Creativity	0.19	0.17	0.17	0.17	0.19	0.21	0.18
Applicability	0.18	0.17	0.18	0.17	0.17	0.20	0.18
Contemporaneity	0.14	0.14	0.15	0.14	0.14	0.13	0.14
Presentation	0.09	0.10	0.11	0.11	0.09	0.10	0.10
Visualization	0.06	0.08	0.08	0.07	0.05	0.07	0.07
Attractiveness	0.05	0.07	0.07	0.07	0.05	0.04	0.06
Styling	0.05	0.08	0.07	0.07	0.05	0.04	0.06
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 12

Aggregated results for experts in group I							
Criteria	**Arith-metic mean AIJ**	**Arith-metic mean AIP**	**Geo-metric mean AIJ**	**Norma-lized Geomet-ric mean AIP**	**Mode AIJ**	**Norma-lized Mode AIP**	**Geometric mean (vectors left of the table)**
Scientific rigor	0.22	0.21	0.21	0.21	–	–	0.21
Creativity	0.22	0.21	0.22	0.21	–	–	0.21
Applicability	0.18	0.17	0.17	0.17	–	–	0.17
Contemporaneity	0.14	0.14	0.14	0.14	–	–	0.14
Presentation	0.09	0.10	0.10	0.10	–	–	0.10
Visualization	0.05	0.06	0.06	0.06	–	–	0.06
Attractiveness	0.05	0.06	0.06	0.06	–	–	0.06
Styling	0.04	0.05	0.05	0.05	–	–	0.05
Total	1.00	1.00	1.00	1.00	–	–	1.00

A number of conclusions can be made based on the results received. The most important of them are:

- The results to a great extend confirm the expectations we had intuitively and based on empirically collected, but not systematized impressions from our continuous practice in project-based learning.
- The results obtained allow us to formalize and achieve an objective assessment of “Practical Projects” in the learning process (and not only), based on subjective assessments of selected experts in project-based learning.
- The calculated weights of the evaluation criteria derived from the aggre-

Table 13

Aggregated results for experts in group II							
Criteria	**Arith-metic mean AIJ**	**Arith-metic mean AIP**	**Geo-metric mean AIJ**	**Norma-lized Geome-tric mean AIP**	**Mode AIJ**	**Norma-lized Mode AIP**	**Geometric mean (vectors left of the table)**
Scientific rigor	0.22	0.15	0.14	0.15	–	–	0.16
Creativity	0.13	0.10	0.10	0.10	–	–	0.11
Applicability	0.15	0.15	0.14	0.14	–	–	0.15
Contemporaneity	0.17	0.15	0.16	0.16	–	–	0.16
Presentation	0.10	0.11	0.12	0.12	–	–	0.11
Visualization	0.09	0.11	0.12	0.11	–	–	0.11
Attractiveness	0.07	0.11	0.10	0.10	–	–	0.09
Styling	0.08	0.12	0.11	0.11	–	–	0.11
Total	1.00	1.00	1.00	1.00	–	–	1.00

Table 14

Aggregated results for experts in group III							
Criteria	**Arith-metic mean AIJ**	**Arith-metic mean AIP**	**Geo-metric mean AIJ**	**Norma-lized Geometri c mean AIP**	**Mode AIJ**	**Norma-lized Mode AIP**	**Geometric mean (vectors left of the table)**
Scientific rigor	0.23	0.22	0.22	0.22	0.21	–	0.22
Creativity	0.22	0.22	0.22	0.22	0.20	–	0.21
Applicability	0.20	0.20	0.20	0.20	0.22	–	0.21
Contemporaneity	0.11	0.12	0.11	0.12	0.12	–	0.12
Presentation	0.10	0.10	0.10	0.10	0.10	–	0.10
Visualization	0.06	0.06	0.06	0.06	0.05	–	0.06
Attractiveness	0.05	0.05	0.05	0.05	0.04	–	0.05
Styling	0.04	0.05	0.04	0.05	0.05	–	0.04
Total	1.00	1.00	1.00	1.00	1.00	–	1.00

gation of the various groups and different approaches can be applied to the specific requirements of the evaluated projects depending on the forum (school, national, international, etc.) on which they are presented, depending on the purpose of the training process (class, extracurricular, etc.), etc.

– The most important (with the greatest weight) is the criterion "Scientific rigor". The result is to a great extend expected, since this criterion reflects the depth and consistency of knowing the matter related to the nature of the project. It shows how serious the attitude of the developer is and his efforts for research and absorption of new knowledge, which is one of the main objectives of project development in the learning process. The aggregated weight of the criterion in group I, III and for all experts is about 20%, i.e., 1/5 of the total weight falls on this criterion. For the group of experts working primarily with university students, the weight of this criterion is less (about 5% in some of the options for aggregation). The difference is redistributed to the logical criteria “Applicability in practice” and “Contemporaneity of the project”. These criteria reflect the applicability in practice of the development, especially at the time of the development of the project. This is exactly the expectation, as students should be more practical and adequate to the practice they are already bound to or will soon have to be implemented. Their training is aimed in this direction.

– Logically, the next three positions (second, third and fourth) are for the criteria “Creativity”, “Applicability in practice” and “Contemporaneity of the project”. In the different groups of experts, their places are interchanged, which is explained by the different aims, objectives and expectations of the training and the assessors. On one hand it comes to assessing “Practical Projects”. The expectation is for the projects to be practically oriented. The weight of criterion “Applicability in practice” is 15%—18%, and for group III (work with students, undergraduates, etc.)—about 20%. The criterion “Creativity of the project”, which reflects the creativity of the developer (by generating new ideas and solving problems), logically takes the second place (for the biggest part of the groups of experts) and for the group of experts (group I), working primarily with outstanding school students, this criterion takes the first place together with the criterion “Scientific rigor”. It is so, because in the developments of this type of trainees it is expected that along with the in-depth knowledge of the matter, they should include a lot of creative elements.

– The Criteria “Presentation”, “Visualization”, “Attractiveness” and “Styling” are almost equal in weight and their weight in determining the assessments of the projects is much smaller. It should be noted that for the different groups of experts some criteria are more significant and this again is related to the fact that the aims, objectives and expectations of the development of projects with practical use are different. For example, for the groups working with school students the criterion “Presentation” is more significant than others, as one of the main tasks in school is that students learn to express themselves clearly and accurately, and to communicate understandably. Such projects are usually presented in front of peers and supporters, as well as a jury. In these cases not only what you did is taken into account, but also how it is presented in front of an audience. This experience will be important for future work on projects in real work environment. For the experts working primarily with university students, the other 3 criteria are almost as important. The explanation could be sought in two directions. First, because the projects are assessed most often without the presence of the developer. Second, because the students are "a step away" from the real work. Hence, the preparation of the documentation accompanying the project is very essential and so are the skills to present the material clearly and attractively.

Conclusion. The main goal of the research was to find the most objective weights of the criteria for evaluation of practical projects and thus to obtain a more objective evaluation of these projects. The preparation and conduction of a survey among recognized experts in the field of project-based learning in mathematics, informatics and information technologies is described, as well as the post-processing and aggregation of expertise concerning the evaluation criteria applied. The processing of the data accumulated through AHP, allowed us to objectively determine weights of the evaluation criteria and hence to achieve the desired objectiveness.

The output data may be further processed also with AHP modifications (for example, as described in [23]) and with other suitable methods.

The weights calculated by using different approaches, with the different values and for the different groups of experts, could be used to evaluate student and other projects.

In our future work we plan to conduct an experimental evaluation of the project by applying the weights we obtained.

The use of the Mode for summarizing the opinions/judgments of the experts in both approaches (AIJ and AIP), shows results that differ significantly from the results obtained by the use of the average (arithmetic and geometric) values. It would be worthwhile to explore and assess whether the use of the mode gives sufficiently reliable results. If the level of authenticity is satisfactory, then the use of the Mode could be applied wherever the application of averages is more difficult. For example, for a large number of experts the use of a geometric mean (aggregation) could be replaced by the use of a Mode.

It would also be good to explore and assess how useful the input of yet another generalization of the results already aggregated (with other approaches and statistical values) could be. In our case, the group of experts is relatively homogeneous, but this is not always the case.

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