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# SHAPING PRO-ENGINEERING ATTITUDES OF YOUNG PEOPLE – RESEARCH RESULTS

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**Research background:** For many years, the authors have been dealing with the issues of student inventiveness and the related innovation and creativity. The presented work refers to the sources, understood as shaping the pro-engineering attitudes of young people, which in effect translates into the creation of new, often innovative solutions in the field of technology.
**Purpose:** The aim of the research is to identify activities related to knowledge in the field of science and technology during the period of attendance at secondary school. These activities include knowledge and skills acquired at school and other relationships between young people and science and technology resulting from passions and passions. An additional goal is to indicate proposals for development in this area, mainly concerning the teaching process.
**Methodology:** The source of data for the conducted analyses are the results of surveys conducted in 2021. The analysis of the acquired data was carried out using the AHP (Analytic Hierarchy Process) method. The AHP method, by incorporating expert opinions, allows you to achieve an additional goal. This is an original approach to the analysis and interpretation of survey results. It will not replace classical statistical analyses of varying complexity, but it can be a kind of complement.
**Findings**: The implementation of the research indicated a significant interest of young people in the issues of science and technology, and the obtained data allowed to take a comprehensive look at the education of young people in this area and present suggestions for the modification of teaching forms. This may contribute to reducing the shortage of engineering staff and researchers creating new innovative solutions in many countries. This will be an important factor in economic development based on innovative technologies.

**Keywords:** Youth education, science and technology, survey research, innovative solutions, AHP method.

**Category of the paper:** research paper.

## 1. Introduction

The time spent at a university is very important for the development of young people entering their adult life. In addition to acquiring knowledge and skills, interests and passions are developed. They form the basis for later activities in professional life, which ultimately affects the personal material status and economic development of regions. In this aspect, an important area of interest is issues related to science and technology. They are important for engineering activities that are the basis of economic development, as well as for conducting scientific research in many cases linked to creativity, which sometimes results in inventions (https://tu.kielce.pl/start/wspolpraca/ksw). Associated with this interesting issue is the acquisition of knowledge about students' interest in issues related to issues of science and technology, also considering the influence of the university on this process. One way to learn about students' connections to science and technology is through surveys. The completed questionnaires contain data, the processing of which gives a set of information concerning the analyzed issues. Then, using imagination, the ability to think abstractly while maintaining the logic of inference, acquired information can be transformed into knowledge, the essential element of which is the diagnosis taking into account the context understood as the relationship with the environment (Trajer, Paszek, Iwan, 2012; Gierulski, Santarek, Winiewska, 2020).

The survey was conducted in 2021 using an online form on students' relationship with science and technology. The target population for the study was university students and recent graduates. The results of the study, mainly as frequencies of occurrence, which is a form of research report, are presented in (Kaczmarska, Gierulski, 2022b). Transforming the information thus obtained into knowledge requires further analysis, which often relies on advanced statistical methods. In the presented work, traditional statistical methods were abandoned, instead, the method of AHP (*Analytic Hierarchy Process*) was used (Prusak, Stefanów, 2014), with the conviction that this will allow to extend the knowledge of the analyzed issue with elements beyond the information directly obtained in the research.

## 2. Analytic Hierarchy Process – the essence

Among the multi-criteria decision support methods, AHP (*Analytic Hierarchy Process*), developed in 1970 by Thomas L. Saaty (Saaty, 1980, 1990), occupies a significant position. Its great versatility, simplicity, and accessibility result in it finding use in many areas of science and practice, also by users without specialized mathematical education. In addition to direct decision support, it is also used for cognitive purposes, to better knowledge and understand the problem being analyzed.

In the first step, a model of a hierarchical structure is created, with the decision or cognitive goal at the top, the influencing criteria below it, and the decision options at the bottom of this arrangement. Figure 1 shows an example of an elaborate hierarchical structure with additional lower-level criteria (sub-criteria) in addition to the main criteria and the options necessary to achieve the objective of the decision. The number of main criteria, additional criteria, and decision options depends on the complexity of the problem being analyzed.

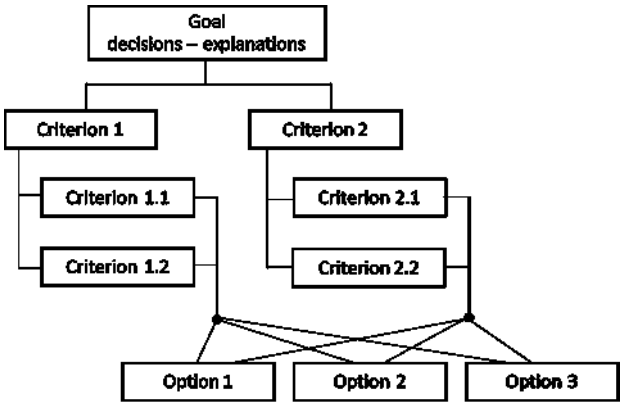


**Figure 1.** Example of hierarchical structure.

Source: Own elaboration.

In a second step, a pair of criteria and options are compared using a relative rating scale. A nine-point comparison scale is used to determine the relationship between the factors being evaluated (Table 1), called the Saaty's Fundamental Scale.

**Table 1.**
*Scale of comparison in the AHP method*

| Verbal – qualitative evaluation | Numerical evaluation |
|---|---|
| Complete advantage | 9 |
| Very large advantage | 7 |
| Large advantage | 5 |
| Small advantage | 3 |
| Same meaning. | 1 |

Source: Own elaboration based on (Prusak, Stefanów, 2014).

If there is difficulty in evaluation using the basic set (1, 3, 5, 7, 9) then intermediate values (2, 4, 6, 8) are also used in special cases.

The results of pairwise comparisons are entered into a matrix in mathematical notation or a corresponding array symbolically representing that matrix. Fig. 2 shows an example matrix in symbolic form for the three factors being compared ($x_1, x_2, x_3$).

| $X$ | $x_1$ | $x_2$ | $x_3$ |
|---|---|---|---|
| $x_1$ | $1$ | $a_{12}$ | $a_{13}$ |
| $x_2$ | $a_{21}$ | $1$ | $a_{23}$ |
| $x_3$ | $a_{31}$ | $a_{32}$ | $1$ |

| $X$ | $x_1$ | $x_2$ | $x_3$ |
|---|---|---|---|
| $x_1$ | $1$ | $a_{12}$ | $a_{13}$ |
| $x_2$ | $1/a_{12}$ | $1$ | $a_{23}$ |
| $x_3$ | $1/a_{13}$ | $1/a_{23}$ | $1$ |

**Figure 2.** Example matrix for pairwise comparison.

Source: Own elaboration.

Fig. 2. shows an example matrix in symbolic form for the three factors being compared (x1, x2, x3) including the relationship between the scores:

$$a_{21} = \frac{1}{a_{12}}\ a_{31} = \frac{1}{a_{13}}\ a_{32} = \frac{1}{a_{23}}$$

In the third stage, a formal verification is performed to check whether the pairwise comparison matrix is inconsistent, which is also referred to as inconsistency. It only makes sense to formulate a conclusion if all pairwise comparisons have been made obeying the laws of logic. An example of not maintaining logic in defining relationships is:

$$x_1 > x_2 \wedge x_2 > x_3 \wedge x_3 > x_1$$

It follows from this relation that x3 is both smaller and larger than x1, which leads to a contradiction. The consistency testing is done individually for each matrix using a special measure called consistency ratio (CR) (Prusak, Stefanów, 2014). It is assumed that a value of this coefficient above 10% indicates a lack of consistency resulting from a contradiction in the pairwise comparison matrix.

In the fourth step of the analysis, the weighting factors are determined for each pairwise comparison matrix. For this purpose, methods are used that employ the following in the calculations:

- matrix calculus,
- geometric mean,
- arithmetic mean.

The results obtained by each of these methods are slightly different, with differences occurring only beyond two significant digits in the decimal. A good solution is to use specialized computer programs that determine the value of the CR compliance coefficient in addition to the weighting coefficients. However, it is necessary to learn the functionality of these programs, and their use does not allow us to follow the intermediate steps of the calculations.

Figure 3 shows the calculations, for example, numerical values of the comparison matrices of the three factors (x1, x2, x3). In the pairwise comparison matrix, the following relationships (T1) were defined:

- $x_1$ shows a complete advantage over $x_2$ ($x_1 = 9*x_2$),
- $x_1$ shows a large advantage over $x_3$ ($x_1 = 5*x_3$),
- $x_3$ shows a small advantage over $x_2$ ($x_3 = 3*x_2$).

The last row of this table contains the sums of the values in each column.

| T1 - Pairwise comparison | | | |
|---|---|---|---|
| X | $x_1$ | $x_2$ | $x_3$ |
| $x_1$ | 1 | 9 | 5 |
| $x_2$ | 0.1111 | 1 | 0.3333 |
| $x_3$ | 0.2 | 3 | 1 |
| Total: | 1.3111 | 13 | 6.3333 |

| T2 - Normalization and weighting coefficients | | | | | |
|---|---|---|---|---|---|
| X | $x_1$ | $x_2$ | $x_3$ | weights | weights % |
| $x_1$ | 0.7627 | 0.6923 | 0.7895 | 0.7482 | 74.8% |
| $x_2$ | 0.0847 | 0.0769 | 0.0526 | 0.0714 | 7.1% |
| $x_3$ | 0.1525 | 0.2308 | 0.1579 | 0.1804 | 18.0% |
| Total: | 1 | 1 | 1 | 1 | 100% |

**Figure 3.** Example calculation of weighting factors.

Source: Own elaboration.

The next matrix (T2) is the normalization and weighting factors. The values in successive cells of the T1 matrix are divided by the sum of the values of each column. The weighting factors (weights), on the other hand, are the average values from each row (T2) – presented as a number or percentage. The consistency coefficient takes a small value of CR = 2.8% (the computational procedure is not shown here) which indicates that the pairwise comparison matrix is not contradictory.

For an extended hierarchical structure, this kind of calculation is performed repeatedly, and the determined weights are treated as local. From these, global weights relating to the whole issue are determined.

## 3. Implementation of research

A survey was conducted in 2021 using an online form on students' connection to science and technology issues. 190 respondents, students and recent graduates, took the survey. The results of the survey, mainly as frequencies of occurrence, are presented in (Kaczmarska, Gierulski, 2022b), which should be regarded as information only. 190 respondents took part in the survey, mostly engineering students (85%), while graduate participation in the survey did not exceed 3%.

The survey form (Table 2) contains three groups of questions. Two of them deal with sources of knowledge about history and the current level of development of science and technology. The third group concerns information on practical activities that confirm students' connection to technology.

**Table 2.**
*Survey form*

| Survey form | | Evaluation scale | | | | |
|---|---|---|---|---|---|---|
| **Questions: groups A – B – C** | | *1* | *2* | *3* | *4* | *5* |
| **A. Interest in the history of science and technology – sources of knowledge** | | | | | | |
| | A.1. Books – biographies of the creators | | | | | |
| | A.2. Internet – biographies of the creators | | | | | |
| | A.3. Museums of technology and exhibitions | | | | | |
| | A.4. Copernicus Science Center. Leonardo da Vinci Center and others | | | | | |
| | A.5. Science fiction literature | | | | | |
| **B. Current level of development of science and technology – sources of knowledge** | | | | | | |
| | B.1. Literature on new technological solutions | | | | | |
| | B.2. Internet – searching for and following new solutions | | | | | |
| | B.3. TV shows – e.g. How Things Work | | | | | |
| | B.4. University – lectures, online forum, Facebook, etc. | | | | | |
| | B.5. Enterprises – employment or study visits | | | | | |
| **C. Practical measures** | | | | | | |
| | C.1. Disassembling devices to learn how they work | | | | | |
| | C.2. Build various devices and mechanisms on one's own | | | | | |
| | C.3. Repairing home appliances and other devices on one's own | | | | | |
| | C.4. Interest in computer science beyond the curriculum | | | | | |
| | C.5. University – science clubs and practice, e.g. SolidWorks, FlexSim | | | | | |

Source: Own elaboration.

The form uses a five-point rating scale (Likert scale). For each group, the cumulative shares of the answer options to the following questions were determined $(\gamma_i)_k$ calculated with weighting factors corresponding to the Likert scale according to the formula (development paths):

$$(\alpha_i)_k = 1 \cdot \left(n_{i,1}\right)_k + 1 \cdot \left(n_{i,2}\right)_k + 1 \cdot \left(n_{i,3}\right)_k + 1 \cdot \left(n_{i,4}\right)_k + 1 \cdot \left(n_{i,5}\right)_k$$

$$\beta_k = \sum_{i=1}^{5} (\alpha_i)_k \;\; (\gamma_i)_k = \frac{(\alpha_i)_k}{\beta_k}$$

And the cumulative shares for each group of questions:

$$\delta_k = \frac{\beta_k}{\sum_{k=1}^{3} \beta_k}$$

where:

$k$ – number of the subsequent group of questions ($k$ = 1, 2, 3),

$i$ – number of question in the group ($i$ = *1, 2, 3, 4, 5*),

$n_{i,1}, n_{i,2} \ldots\ldots n_{i,5}$ – the Likert scale scores for questions in subsequent groups.

**Table 3.**
*Cumulative shares*

| **Groups** | **A** | | | | | **B** | | | | | **C** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\delta_k$ % | 30.3 | | | | | 37.2 | | | | | 32.5 | | | | |
| Questions | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | C1 | C2 | C3 | C4 | C5 |
| $(\gamma_i)_k$ % | 15.8 | 23.5 | 18.2 | 21.5 | 21.0 | 17.4 | 23.6 | 19.9 | 21.5 | 17.6 | 21.1 | 18.9 | 23.8 | 19.5 | 16.7 |

Source: Own elaboration.

The main purpose of the research conducted was to gain an understanding of the interest of students in issues related to science and technology. An additional goal is to identify the selected measures that increase student interest in these issues. These measures relate to the curriculums understood as proposals for students regarding the subjects and forms of courses to be implemented.

The indicated secondary objective will be implemented using the AHP method. This requires that the issue under study be presented as a hierarchical structure (Figure 4). Groups of questions A, B, C are the main criteria, while further questions assigned to groups A, B, C are additional criteria. The primary and secondary criteria correspond to the questions in the survey form (Table 2). The additional element consists of options (W.1, W.2, W.3) defining additional activities related to the realization of the goal – increasing students' interest in issues related to science and technology.

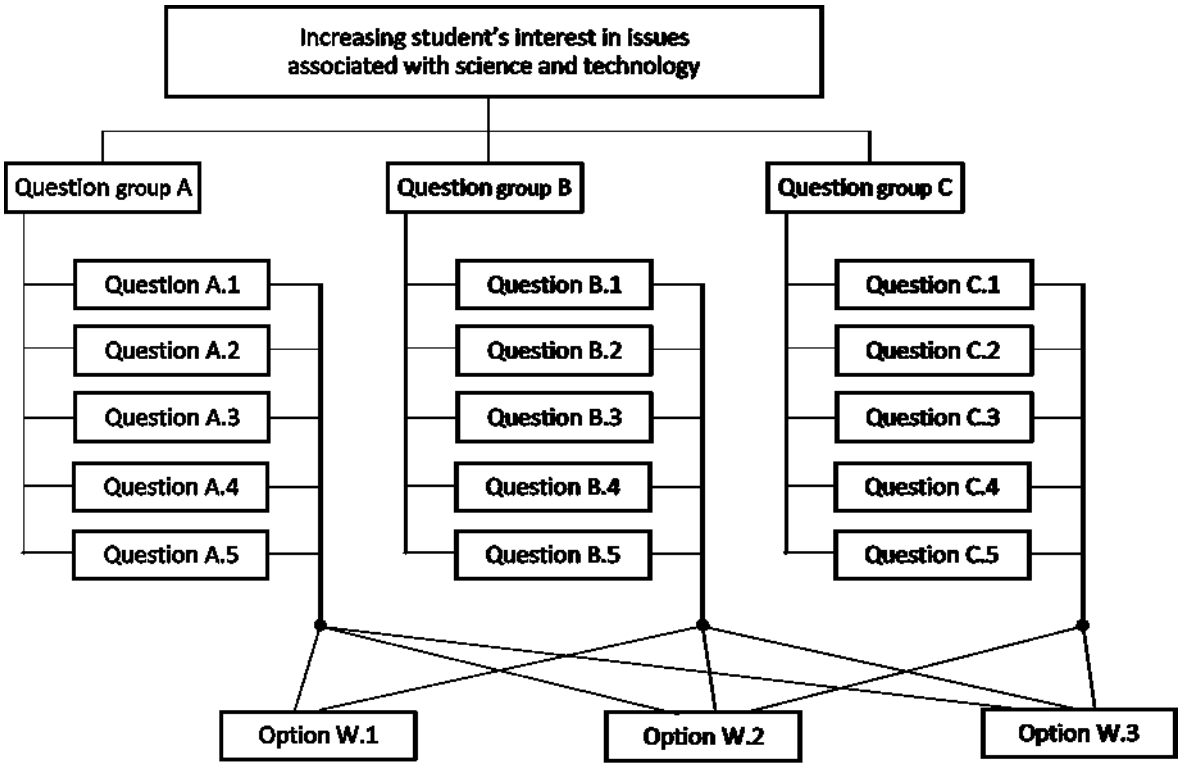


**Figure 4.** Hierarchical structure for the issue under study.

Source: Own elaboration.

Additional options address changes to the study system by increasing the role of the following elements:

W.1. Theoretical papers – interdisciplinary projects with a choice of topics in the area of technical sciences.

W.2. Experimental work – laboratories with workshop facilities with choice of research plan in the area of technical sciences.

W.3. Choice – reducing the number of compulsory subjects and increasing choice, also in other faculties and fields of study.

With these changes, students are able to shape their path of development to a greater extent according to their interests and passions. There will be an increased chance that the projects developed and the work done in the labs will actually be of a practical and research nature and not just a way to pass another mandatory course.

## 4. Analysis using the AHP method – pairwise comparisons

According to the procedure of the AHP method, the pairwise comparison process involves several steps. The first stage concerns the group of questions A-B-C. Taking into account the values of the coefficients $\delta_k$ (Table 3), which determine the relationship between the compared groups $(B > C > A)$ , an evaluation was made using Saaty's fundamental scale in its full version, including even values (Table 4).

**Table 4.**
*Pairwise comparisons A-B-C*

| ABC | A | B | C | weights | weights% |
|---|---|---|---|---|---|
| A | 1 | 0.3333 | 1 | 0.2106 | 21.06% |
| B | 3 | 1 | 2 | 0.5485 | 54.85% |
| C | 1 | 0.5 | 1 | 0.2409 | 24.09% |

Source: Own elaboration.

The next step was the calculation of the weighting coefficients and the compliance coefficient (CR = 1.8%) whose small value confirms that the matrix is not contradictory.

The second stage involves questions in each of the three groups. The relationships between the compared questions for each group are determined by the coefficients $\gamma_i$ (Table 3) and are as follows:

$$A2 > A4 > A5 > A3 > A1 \; B2 > B4 > B3 > B5 > B1 \; C3 > C1 > C4 > C2 > C5$$

The pairwise comparison used Saaty's fundamental scale without even values, then the weighting factors were calculated (Table 5, 6, 7). The CR compliance coefficients did not exceed the value of 5.5% which indicates that the matrix is not contradictory.

Table 5.
*Pairwise comparisons – group A*

| Group A | A1 | A2 | A3 | A4 | A5 | weights | weights% |
|---|---|---|---|---|---|---|---|
| A1 | 1 | 0.1111 | 0.3333 | 0.1429 | 0.2 | 0.0435 | 4.35% |
| A2 | 9 | 1 | 7 | 3 | 5 | 0.6285 | 62.85% |
| A3 | 3 | 0.1429 | 1 | 0.2 | 0.3333 | 0.0847 | 8.47% |
| A4 | 7 | 0.3333 | 5 | 1 | 3 | 0.3253 | 32.53% |
| A5 | 5 | 0.2 | 3 | 0.3333 | 1 | 0.1679 | 16.79% |

Source: Own elaboration.

**Table 6.**
*Pairwise comparisons – group B*

| Group B | B1 | B2 | B3 | B4 | B5 | weights | weights% |
|---|---|---|---|---|---|---|---|
| B1 | 1 | 0.1111 | 0.2 | 0.1429 | 0.3333 | 0.0435 | 4.35% |
| B2 | 9 | 1 | 5 | 3 | 7 | 0.6285 | 62.85% |
| B3 | 5 | 0.2 | 1 | 0.3333 | 3 | 0.1679 | 16.79% |
| B4 | 7 | 0.3333 | 3 | 1 | 5 | 0.3253 | 32.53% |
| B5 | 3 | 0.1429 | 0.3333 | 0.2 | 1 | 0.0847 | 8.47% |

Source: Own elaboration.

**Table 7.**
*Pairwise comparisons – group C*

| Group C | C1 | C2 | C3 | C4 | C5 | weights | weights% |
|---|---|---|---|---|---|---|---|
| C1 | 1 | 5 | 0.3333 | 3 | 7 | 0.3253 | 32.53% |
| C2 | 0.2 | 1 | 0.1429 | 0.3333 | 3 | 0.0847 | 8.47% |
| C3 | 3 | 7 | 1 | 5 | 9 | 0.6285 | 62.85% |
| C4 | 0.3333 | 3 | 0.2 | 1 | 5 | 0.1679 | 16.79% |
| C5 | 0.1429 | 0.3333 | 0.1111 | 0.2 | 1 | 0.0435 | 4.35% |

Source: Own elaboration.

Pairwise comparisons require expert evaluation. Ratings for groups and questions within each group were determined using survey results (coefficients $\delta_k, \gamma_i$) which increases the degree of objectivity.

In the third stage, pairwise comparisons included options (W.1, W.2, W.3) for the following group A, B, and C questions. As before, Saaty's fundamental scale without even values was used, then the weighting factors were calculated (Table 8, 9, 10).

The highest value of the compliance coefficient for pairwise comparisons in stage three was CR = 6.3%, so it was less than the cut-off value (CR = 10%) which indicates that the matrix was not contradictory. In this case, the evaluations, concerning the connection of the variants (W.1, W.2, W.3) with the following questions, were determined by the experts without the support of the survey results.

**Table 8.**
*Pairwise comparisons: group A questions – options W.1, W.2, W.3*

| A.1. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 3 | 0.3333 | 0.2605 | 26.05% |
| W2 | 0.3333 | 1 | 0.2 | 0.1062 | 10.62% |
| W3 | 3 | 5 | 1 | 0.6333 | 63.33% |

| A.2. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 3 | 0.3333 | 0.2431 | 24.31% |
| W2 | 0.3333 | 1 | 0.1429 | 0.0882 | 8.82% |
| W3 | 3 | 7 | 1 | 0.6687 | 66.87% |

| A.3. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 3 | 1 | 0.4286 | 42.86% |
| W2 | 0.3333 | 1 | 0.3333 | 0.1429 | 14.29% |
| W3 | 1 | 3 | 1 | 0.4286 | 42.86% |

| A.4. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 3 | 0.3333 | 0.2431 | 24.31% |
| W2 | 0.3333 | 1 | 0.1429 | 0.0882 | 8.82% |
| W3 | 3 | 7 | 1 | 0.6687 | 66.87% |

| A.5. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 3 | 0.3333 | 0.2605 | 26.05% |
| W2 | 0.3333 | 1 | 0.2 | 0.1062 | 10.62% |
| W3 | 3 | 5 | 1 | 0.6333 | 63.33% |

Source: Own elaboration.

**Table 9.**
*Pairwise comparisons: group B questions – options W.1, W.2, W.3*

| B.1. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 3 | 1 | 0.4286 | 42.86% |
| W2 | 0.3333 | 1 | 0.3333 | 0.1429 | 14.29% |
| W3 | 1 | 3 | 1 | 0.4286 | 42.86% |

| B.2. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 5 | 0.3333 | 0.2828 | 28.28% |
| W2 | 0.2 | 1 | 0.1429 | 0.0738 | 7.38% |
| W3 | 3 | 7 | 1 | 0.6434 | 64.34% |

| B.3. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 0.3333 | 1 | 0.2000 | 20.00% |
| W2 | 3 | 1 | 3 | 0.6000 | 60.00% |
| W3 | 1 | 0.3333 | 1 | 0.2000 | 20.00% |

| B.4. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 3 | 1 | 0.4055 | 40.55% |
| W2 | 0.3333 | 1 | 0.2 | 0.1150 | 11.50% |
| W3 | 1 | 5 | 1 | 0.4796 | 47.96% |

| B.5. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 0.2 | 3 | 0.1932 | 19.32% |
| W2 | 5 | 1 | 7 | 0.7235 | 72.35% |
| W3 | 0.3333 | 0.1429 | 1 | 0.0833 | 8.33% |

Source: Own elaboration.

**Table 10.**
*Pairwise comparisons: group C questions – options W.1, W.2, W.3*

| C.1. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 1 | 3 | 0.4055 | 40.55% |
| W2 | 1 | 1 | 5 | 0.4796 | 47.96% |
| W3 | 0.3333 | 0.2 | 1 | 0.1150 | 11.50% |

| C.2. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 0.3333 | 3 | 0.2431 | 24.31% |
| W2 | 3 | 1 | 7 | 0.6687 | 66.87% |
| W3 | 0.3333 | 0.1429 | 1 | 0.0882 | 8.82% |

| C.3. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 0.3333 | 5 | 0.2674 | 26.74% |
| W2 | 3 | 1 | 9 | 0.6689 | 66.89% |
| W3 | 0.2 | 0.1111 | 1 | 0.0637 | 6.37% |

| C.4. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 0.3333 | 0.1429 | 0.0833 | 8.33% |
| W2 | 3 | 1 | 0.2 | 0.1932 | 19.32% |
| W3 | 7 | 5 | 1 | 0.7235 | 72.35% |

| C.5. | W1 | W2 | W3 | weights | weights% |
|---|---|---|---|---|---|
| W1 | 1 | 1 | 3 | 0.4055 | 40.55% |
| W2 | 1 | 1 | 5 | 0.4796 | 47.96% |
| W3 | 0.3333 | 0.2 | 1 | 0.1150 | 11.50% |

Source: Own elaboration.

In all evaluations, experts were the authors of the article – experienced academics involved in student invention (Kaczmarska, 2020; Kaczmarska, Gierulski, 2018a; Kaczmarska, Gierulski et al., 2018b). The evaluation process used a logical analysis and construction method supported by interviews with students and consultation with other university staff.

The method of analysis and logical construction also supports the interpretation of the results obtained. An example interpretation of three selected cases for this stage of pairwise comparisons is shown in the following examples:

**Example 1, question A.1: Books – biographies of the creators**

Interpretation: Reducing the number of compulsory subjects and increasing the number of choices, also in other faculties and fields of study (Option W.3) to the greatest extent among the three options (weight = 63.33%) will contribute to increasing the importance of books as a source of knowledge regarding the history of science and technology (Question A.1).

**Example 2, question B.5: Enterprises – employment or study visits**

Interpretation: Performing experimental work in laboratories with workshop facilities with the possibility of creating one's own research plan in the field of technical sciences (Option W.2) will contribute to the greatest extent among the three options (weight = 72.35%) to

increasing the importance of contact with enterprises (employment or study visits) as sources of knowledge about the current level of science and technology development (Question B.5).

**Example 3, question C.4: Interest in computer science beyond the curriculum**

Interpretation: Performing interdisciplinary projects in the form of theoretical papers with a choice of topics in the area of technical sciences (Option W1) will contribute the least among the three options (weight = 8.33%) to increasing interest in computer science issues beyond the standard curriculum (Question C.4).

## 5. Analysis using the AHP method – final results

The AHP-pairwise comparison analysis presented in chapter 4 yields results of a local nature for 3 groups of questions, for 5 questions in each group, and 3 variants associated with 15 questions. The results are local weighting factors (weights), which does not take into account the interrelationships shown in the hierarchical structure diagram (Fig. 4). The next step is to determine the global weighting factors as products of the corresponding local factors (Table 11). Column k5 of this table shows the calculated global coefficients for the two stages of pairwise comparisons: groups of questions (A-B-C) and consecutive questions (Ai-Bi-Ci). The values of these global coefficients (column k5) are equal to the product of the local coefficients in column k2 and the local coefficients in column k4. They illustrate the survey results in terms of AHP analysis (explanatory purpose) rather than standard statistical analyses. Global coefficients that include options W.1, W.2, W.3 are shown in columns k9, k10, and k11. They are calculated as the products of the global coefficients for the surveys (column k5) and the local coefficients for options W.1, W.2, W.3 (columns k6, k7, k8). These coefficients, in addition to the survey results, take into account the experts' evaluations of options W.1, W.2, W.3 and realize the decision-making objective of the AHP analysis. They can support decisions about modifications to the study system that promote the goal of increasing student interest in science and technology issues.

**Table 11.**
*AHP method – final results*

| k1 | k2 | k3 | k4 | k5 | k6 | k7 | k8 | k9 | k10 | k11 |
|---|---|---|---|---|---|---|---|---|---|---|
| Question groups | local | Question | local | global | local | local | local | global | global | global |
| | A - B - C | | $A_i$ - $B_i$ - $C_i$ | $A_i$ - $B_i$ - $C_i$ | W1 | W2 | W3 | W1 | W2 | W3 |
| A | 0.2106 | A1 | 0.0435 | 0.0092 | 0.2605 | 0.1062 | 0.6333 | 0.0024 | 0.0010 | 0.0058 |
| | 0.2106 | A2 | 0.6285 | 0.1324 | 0.2431 | 0.0882 | 0.6687 | 0.0322 | 0.0117 | 0.0885 |
| | 0.2106 | A3 | 0.0847 | 0.0178 | 0.4286 | 0.1429 | 0.4286 | 0.0076 | 0.0025 | 0.0076 |
| | 0.2106 | A4 | 0.3253 | 0.0685 | 0.2431 | 0.0882 | 0.6687 | 0.0167 | 0.0060 | 0.0458 |
| | 0.2106 | A5 | 0.1679 | 0.0354 | 0.2605 | 0.1062 | 0.6333 | 0.0092 | 0.0038 | 0.0224 |
| B | 0.5485 | B1 | 0.0435 | 0.0239 | 0.4286 | 0.1429 | 0.4286 | 0.0102 | 0.0034 | 0.0102 |
| | 0.5485 | B2 | 0.6285 | 0.3447 | 0.2828 | 0.0738 | 0.6434 | 0.0975 | 0.0254 | 0.2218 |
| | 0.5485 | B3 | 0.1679 | 0.0921 | 0.2000 | 0.6000 | 0.2000 | 0.0184 | 0.0553 | 0.0184 |
| | 0.5485 | B4 | 0.3253 | 0.1784 | 0.4055 | 0.1150 | 0.4796 | 0.0723 | 0.0205 | 0.0856 |
| | 0.5485 | B5 | 0.0847 | 0.0465 | 0.1932 | 0.7235 | 0.0833 | 0.0090 | 0.0336 | 0.0039 |
| C | 0.2409 | C1 | 0.3253 | 0.0784 | 0.4055 | 0.4796 | 0.1150 | 0.0318 | 0.0376 | 0.0090 |
| | 0.2409 | C2 | 0.0847 | 0.0204 | 0.2431 | 0.6687 | 0.0882 | 0.0050 | 0.0136 | 0.0018 |
| | 0.2409 | C3 | 0.6285 | 0.1514 | 0.2674 | 0.6689 | 0.0637 | 0.0405 | 0.1013 | 0.0097 |
| | 0.2409 | C4 | 0.1679 | 0.0405 | 0.0833 | 0.1932 | 0.7235 | 0.0034 | 0.0078 | 0.0293 |
| | 0.2409 | C5 | 0.0435 | 0.0105 | 0.4055 | 0.4796 | 0.1150 | 0.0043 | 0.0050 | 0.0012 |
| | | | | | | | | Total W1 | Total W2 | Total W3 |
| | | | | | | | Final evaluation: | **0.3604** | **0.3286** | **0.5610** |
| | | | | | | | Final evaluation %: | **28.83%** | **26.29%** | **44.88%** |

Source: Own elaboration.

The sums of the global coefficients W.1, W.2, W.3 for the set of 15 questions (Table 11) are the final measure of the AHP analysis. These results show a clear dominance of option W.3, which is confirmed by the relationships:

$$W3 = 0.5610 \gg W1 = 0.3604 > W2 = 0.3286$$

Or after normalization with percentages included:

$$W3 = 44.88\% \gg W1 = 28.83\% > W2 = 26.29\%$$

It follows that the introduction of changes compliant with option W.3 – "Choice – reducing the number of compulsory subjects and increasing choice, also in other faculties and fields of study" is definitely a priority action.

The results in numerical notation for the global coefficients (Table 11) were recalculated to show percentages (Table 12). Here, too, normalization was performed by relating the values of successive indicators to the sum of indicator values in the corresponding column.

**Table 12.**
*AHP method – final results %*

| k1 | k3 | k9 | k10 | k11 |
|---|---|---|---|---|
| Question groups | Question | global | global | global |
| | | W1 | W2 | W3 |
| A | A1 | 0.66% | 0.30% | 1.03% |
| | A2 | 8.93% | 3.55% | 15.78% |
| | A3 | 2.12% | 0.78% | 1.36% |
| | A4 | 4.62% | 1.84% | 8.17% |
| | A5 | 2.56% | 1.14% | 3.99% |
| B | B1 | 2.84% | 1.04% | 1.82% |
| | B2 | 27.05% | 7.74% | 39.54% |
| | B3 | 5.11% | 16.82% | 3.28% |
| | B4 | 20.07% | 6.24% | 15.25% |
| | B5 | 2.49% | 10.23% | 0.69% |
| C | C1 | 8.82% | 11.44% | 1.61% |
| | C2 | 1.38% | 4.15% | 0.32% |
| | C3 | 11.23% | 30.82% | 1.72% |
| | C4 | 0.94% | 2.38% | 5.22% |
| | C5 | 1.18% | 1.53% | 0.21% |

Source: Own elaboration.

The global coefficient rankings W1, W2, W3 were drawn from the data (Table 12, Fig. 5, 6, 7). This allows us to assess the importance of the measures identified as options W1, W2, and W3 for the realization of the goal – to increase student interest in issues related to science and technology.

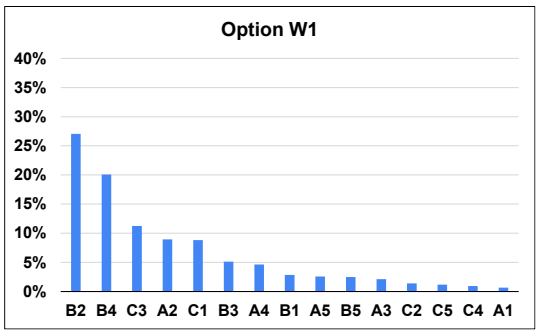


**Figure 5.** Ranking of global coefficients W1.
Source: Own elaboration.

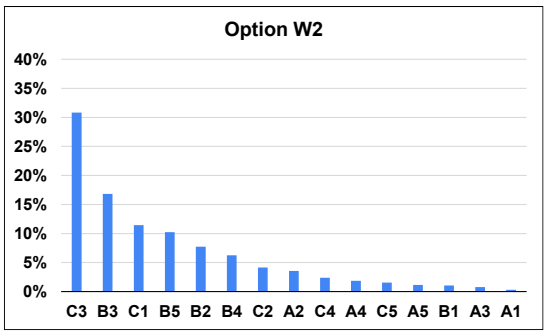


**Figure 6.** Ranking of global coefficients W2.
Source: Own elaboration.

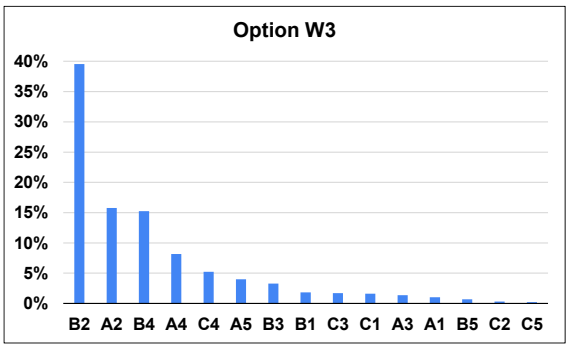


**Figure 7.** Ranking of global coefficients W3.
Source: Own elaboration.

The presented rankings show the connection of the variants (W1, W2, W3) with the questions Ai, Bi, Ci, which in the conducted AHP analysis play the role of additional criteria. They show to what extent the changes presented in subsequent options will increase students' interest in issues related to science and technology, and, in particular, in sources of knowledge and practical activities. Therefore, it is an additional element supporting decisions concerning the implementation of activities presented in options W1, W2, W3, or the development of other proposals supporting the realization of the set objective.

## 6. Conclusions

Conducting surveys in many cases is designed to identify the current state of affairs. Classical statistical methods (Kaczmarska, Gierulski et al., 2021) from simple ones like frequency of occurrence, cross-correlations to more complex ones that include association analysis (Gierulski, Kaczmarska et al., 2018a), or factor analysis (Gierulski, Kaczmarska, 2020) are used to analyze the collected data. It can also be a completely different type of analysis, for example, using Data Envelopment Analysis (DEA) (Gierulski, Kaczmarska, 2012; Kaczmarska, 2010), or AHP, sometimes classified as an informal optimization method. A special feature of the AHP method is the inclusion of expert opinion in the analysis process. In the paper presented here, it is an analysis in which the results of the survey and the opinions of experts intersect, resulting in a sort of synergy. As a result, proposals have been formulated for changes in curriculums and forms of instruction in higher education. These suggestions can support decisions to modify and create unconventional ways of learning. The proposal that was ranked highest in the survey gives students more freedom to shape their individual path of knowledge acquisition. This will ensure that these are choices that match their interests, so they are pursued with passion and commitment, which will contribute to a solid education. This will allow them to act on the idea found in this Pablo Picasso quote: “I am always doing that which I cannot do, in order that I may learn how to do it.” Another quote, this time by Albert Einstein, “Education is what remains after one has forgotten what one has learned in school”, alleviates the fears that freedom and choice will result in poorer education outcomes (Why is lifelong learning worthwhile? 11 quotes – www.edukacja.senior.pl).

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