Multi-Criteria Recommender System to Ensure the Professional Orientation for Engineering Degree Applicants

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Abstract

In context the weighted feature vector of interdisciplinary links and professional inclination of engineering degree applicants, the four-level model for personalization and further priority determining of variable components in educational trajectory hierarchy with the aim of forming dominant subject competencies was developed. Next, professional orientation is formalized through normative content of related elective disciplines by concluding the multi-criteria rating to form their total importance. The analytical apparatus is proposed and a computerized intelligent system of issuing recommendations on the selection of educational trajectory segments is developed, taking into account the structural and logical sequence of the disciplines studying in parallel and consecutive blocks, which determine the content of training in the chosen speciality. Herewith, the integrated academic educational documentation base and a model from applicant's past behaviour were used to solve problems and provide suggestions in the selection of components of the educational trajectory covering disciplines of different levels of compliance with a professional orientation. The toolkit has been compiled and algorithms for determining the skilful suitability of the engineering degree applicant for chosen professional orientation and further coaching support for the work off of missing subject competencies have been built.

Keywords

Personalized recommendations, decision-making support, weighted feature vector, multi-criteria rating, global preference model, engineering education.

1. Introduction

The modernization of higher education is aimed at building an educational ecosystem based on modern methodological and technological foundations. This primarily involves the use of adequate educational technologies, forms and methods of teaching, changing access to information and ways of interacting with it, which inevitably affects the organization of the educational process. The growth of students' academic mobility along with the innovative technologies spread of data mining and knowledge management has necessitated the application of new approaches to the training of qualified professionals in demand in the labour market. Today, attention is paid to how to ensure the processes of adaptation and optimization of student learning, without reducing the effectiveness of training and providing the opportunity to personalize the educational process. Addressing the methodological foundations of modern educational systems has shown the importance of personalized recommendations' mechanism, taking into account the leading psychological and pedagogical concepts, that should be the basis for their development, considering the training profiles.

The expansion of classical teacher-centred training strategies involves the development of a university environment focused on meeting the needs and interests of higher education seekers, including the provision of appropriate tools to optimize the process of acquiring professional competencies.

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In certain areas of activity, including engineering, such optimization covers the key benefits of student-centeredness and integrates others, which are the basis for the formation of engineering skills. It is the main catalyst of modern technologies, an important factor in the formation of balanced innovation potential of modern industry, and technological progress, in turn, gives a positive impetus to global economic development.

Nowadays, UNESCO is shaping a new vision of higher education by 2030, adapted to today's challenges: sustainable development, the COVID-19 pandemic, digital transformation, and military crises. Prolonged quarantine limited the classroom presence, access to subject-spatial and subject-information laboratory environments, and the ability of applicants to gain work experience. As a result, hostilities in some areas, including Ukraine, have led to the loss of the opportunity to study at all in any form. At the same time, special attention needs to be paid to determining the best ways to support and increase student mobility, including finding academic shelter, while ensuring the processes of adaptation and optimization of learning, the ability to personalize the educational process without reducing the effectiveness of training. Thus, for optimal knowledge management during the professional training of applicants for engineering degrees, it is necessary to analyze the available educational technologies and select those that in modern conditions allow ensuring the required level of quality of acquired professional competencies. In the absence of such technologies, there is a need to develop them.

2. Analysis of the last research and problem statement

The main task of a modern engineer is to adequately interpret the existing constraints on the project to achieve a successful and functional result on time. Determining such boundary conditions for the organization of professional creativity, in which the designed technology will be manufactured and further operated, requires a specialist of scientific knowledge and practical experience in a wide range of areas of human activity. In the context of improving the quality of teaching technical specialities, this situation actualizes the phenomenon of convergence of different disciplines [1]. As a result of the process of integration of interdisciplinary approaches, the contours of previously disparate technologies are blurred, which requires systematic research and search for mechanisms to optimize engineering education.

2.1. Review of related works

The issue coverage of engineering education in the research results in publications of world scientists today covers several thematic areas. Thus, the components of the Education 4.0 concept stipulated in [2] stimulate innovative teaching-learning practices, in particular advanced case study methods [3], and the use of technological resources available during implementation, which positively affects the development of necessary critical competencies in modern engineering students. Therefore, the current needs of the economy and society should be the object of individual, continuous information processing of the technical speciality [4] as a basis for specific requirements for the successful implementation of Industry 4.0 strategies with gradual migration towards Industry 5.0. This new paradigm shift is on the verge of convergence and unification of traditional educational disciplines: the links between different disciplines are becoming the core of new technologies, in a not multi-, not inter-, but a trans-disciplinary, seamless manner [1, 5]. Ways to deepen the integration into the educational content of the basics of sustainable engineering based on technical knowledge are proposed [6] using an effective matrix of cross-disciplinary skills. The consequent link between the difficulties observed in didactic practice and the problems of preliminary structuring of educational content and planning revealed in [7] causes critical differences between expected and actual learning outcomes in engineering programs of higher education [8]. Such a clear systematization of formalized shortcomings in the future allowed to justify the directions of renewal of teaching and learning, and thus the features and nature of initiatives focused on sustainability in engineering education. The expected effectiveness of the inclusion of education for sustainable development in the educational program of technical disciplines [5, 9, 10] shows the international nature of this problem, focused on responsible consumption and production.

The integration of the considered principles of the Fourth Industrial Revolution into the educational process of training engineers is inextricably accompanied by the use of many progressive pedagogical models and their optimal combinations. For example, the development of future specialists' sustainable engineering-oriented ability to apply, analyze, evaluate, and create projects at the highest level of cognitive skills is ensured by the introduction of modern disruptive technology in the teaching of technical disciplines [11, 12]. Such strategic changes in various dimensions contribute to improving the quality of engineering education, further improving the competitiveness of graduates in market conditions, and ensuring the high productivity of employed engineers. This trend was further developed in [13] by identifying the points of intersection of smart pedagogies with mobile pedagogies as an effective mechanism for optimizing the process of training engineering personnel. The methodology of using student-centred strategies based on acquisition of knowledge through team projects [14, 15] activates the role of the student, who from the first year must be able to find a workable form to implement a script or task set by the teacher. This practice of active learning is strongly recommended for inclusion in professional and scientific programs of engineering education by some professional engineering associations. Also, the expediency of applying pedagogical models of blended and problem-based learning in a learning factory environment to the engineering course in variable and reconfigured production is proved in [16] as optimal in training engineers, as it meets the requirements of a modern production environment. Instead, the lack of problem-based learning, and therefore engineering experience and combined employment skills, can be a particular bottleneck for graduates to pursue further careers [17], which may even lead to an industrial crisis in regions with low engineers density. Thus, such measures for the use of problem-based learning in the case of continuing engineering education will help the smooth transition of research into the industry [18], creating upward initiatives of competitiveness among senior engineering staff, enhancing the attractiveness of engineering degrees.

Taking most of the technical content of engineering-oriented discipline outside the classroom, for example through an academic virtual platform, allows students to be fully independent in the comprehensive study of educational material and confidently prepare for public discussions, which promotes active learning and problem-solving in the presence of the teacher. This pedagogical flipped classroom model, described in [19], became especially relevant in the pandemic-induced lockdown [20, 21, 22] when interactive question and answer sessions were implemented as a vital element for assessing the current state of learning and students' level of conceptual understanding tracking potential misconceptions or lack of ownership of the material. At the same time, however, a certain difficulty was to achieve a practical understanding of complex processes and deepen visual competencies among students of technical education in the remote mode, which is currently a separate area of research in engineering education.

A set of interrelated analytical and action measures for the organization of technical disciplines is demonstrated in [23], where an in-depth analysis of a multidimensional approach to supporting the development of visual literacy in European engineering education as a possible solution to problem of distance learning simulation user [24, 25]. In addition to virtual learning environments to maintain the high motivation of students with visual competencies, it is important to introduce elements of gamification into the educational process [26, 27] to form the desired behaviour in a particular engineering activity with special emphasis on determining expected learning outcomes and developing design skills and analysis of production systems. The rich and realistic experience of using advanced digital tools remotely focused on students' research efforts to develop professional competencies and generally provided an opportunity to get an idea of the overall effectiveness of online learning methods.

However, the analyzed pedagogical technologies are only tools that to some extent help to implement and diversify the educational process. Academic mobility, especially at the stage of the growing problem of academic refugees, requires finding methods that can provide deep individualization of curriculum-based learning with invariant and variable specialization-oriented disciplines, with a large share of independent work and appropriate organizational and methodological support. Therefore, the quality of educational services provided primarily depends on the logical sequence of components of the educational-professional program of engineering-oriented speciality, the rational ratio of professional and practical training disciplines and the relevance of accompanying educational content.

Consequently, the implementation effectiveness of considered toolkit should be investigated in the context of the employed methodological basis of normative decision-making for assessment of the priority of simulated educational trajectories in order to ensure of target professional orientation of engineering degree applicants.

2.2. Methods and materials

The main document for higher education is the educational program, which is used to form the subject orientation of the speciality and ensure the quality of education. It is based on the content of educational standards. Due to the disciplines of free choice, a subject orientation is formed in the speciality, which should be consistent with the ability of the applicant to make an informed and responsible choice. We consider this ability as a mechanism for implementing an individual educational trajectory, which models the way to achieve program results taking into account the needs, professional orientations, opportunities, and abilities of applicants during theoretical and practical educational activities, professional development and self-improvement. The individual educational trajectory covers the whole educational process and is formalized through the components that correspond to the mandatory activities of applicants – educational and research activities, and professional self-development.

Our analysis of the current procedure for choosing the discipline of free choice of students at the Ukrainian Academy of Printing has made it possible to identify some contradictions. First of all, students strive for self-improvement in the chosen professional orientation but lack the means to gain relevant experience. Thus, educational trends show a tendency to deepen the individualization of learning, but the negative impact of lack of experience neutralizes the objectivity of assessing the content of syllabi in building an effective individual educational trajectory. Next, a pilot study was conducted on the compliance of the level of prior training and natural inclinations of students to the types of professional orientation provided by the speciality 151 "Automation and Computer Technology". Empirical methods were used for this purpose: observation of the educational process, questionnaires, testing, study of practical experience, and graphoanalytical method. Summarizing the results of this stage showed that students in choosing the disciplines of free choice are guided by the external attractiveness of the profession and prestige in the public consciousness, not always clearly aware of the importance of matching desires with their inclinations and abilities. The graphoanalytical method allowed for comparison of the profiles of the general abilities of the applicants; the questionnaire method – to find out the presence of desires and expectations, self-assessment of their capabilities; the testing method – to identify the level of prior training for professional orientations.

Typical shortcomings of the process of disciplines free choice include students' lack of awareness of various aspects of professional activity that require consideration of certain psychological characteristics and capabilities of man; low level of acquaintance with the content of disciplines before their choice; limited awareness of internal mobility in the institution. It was found that the main attention to the role of discipline in the profession is attracted by the teacher during their study when he arouses and maintains an interest in it. The existing approach to the choice of discipline leads to a situation where the applicant does not have a sufficient level of ability or the necessary base of knowledge and experience, and thus in the subsequent stages of learning decreases the motivation to study them. Accordingly, in the process of its study, there is a need to identify gaps in the knowledge and skills of applicants and further identify effective means to address them. Therefore, there is an urgent need to design an adequate knowledge management technology, which, in contrast to assessment models [28], operational design [29] and indicator system [30], etc., will ensure optimal decision-making in terms of interdisciplinary links and applicants' potential for complex choice of variable disciplines. In our study, the basis of computerized knowledge management technology is the personalized recommendations' mechanism for systematization procedures to priority learning strategy determining, which based on students' existing competencies carries out interactive coordination of university information flows regarding the solution of educational tasks, issuing recommendations for grouping alternatives into different sets of advantages when choosing components of educational trajectory, and further distribution of knowledge using the academic base of educational documentation.

3. Analytical apparatus designing for optimal variable components choosing

According to the theoretical content of the subject area of educational and professional training programs for higher education applicants of the first and second level in speciality 151 "Automation and computer-integrated technologies" students' scientific research work covers modern software and hardware and information technology. At the same time, according to the current standard of higher education, three professional orientations are distinguished within the components of the complex object of study, which is consistent with the national program of information space development in the category of automation and computer printing technologies with the support of domestic producers (Machine Industry), development of microprocessor control systems (Circuit Design), applied and service software development (Computer Programming). Long-term students' scientific research work and course and diploma design have shown that these areas are equally important and find their target audience every year.

3.1. Formalization of professional orientation

The results of the performed diagnosis of the available competencies by methods of explicit data collection, such as computerized questionnaires, checking the level of prior training or in general natural inclinations to a particular activity allow students majoring in 151 "Automation and Computer Technology" to decide on further professional orientation (Figure 1).

Also, the interest graph, which is accumulated from student's profile of academic corporate network and formalized in the model from past behaviour [24], acts as a recommendatory factor. This professional orientation further ensures the acquisition of relevant learning outcomes by strengthening subject competencies through optional constituents (variable components) of their educational program and disciplines offered for other levels of higher education, which are the same in terms of credit and form of control. Such variable component was introduced to better meet the educational and qualification requirements of the applicant, for the urgent needs of society, more efficient use of the institution, taking into account regional characteristics and more. Elective disciplines of professional and practical training provide the opportunity for in-depth training in specialities (educational programs) that determine the nature of future activities, promote academic mobility of students and their interests, and allow the implementation of specializations within the basic speciality to form the competence of the applicant by the requirements of the labour market. The student chooses the disciplines of the variable part of the educational program when forming an individual curriculum that is developed for the academic year. Students also have the right to choose elective courses for the entire period of study. However, for inexperienced applicant's, such variable components constitute the set of non-dominated solutions.

In the presented study it was decided to formalize the chosen professional orientation of PO^A through the normative content of the relevant (related) subject competencies k, defined by the standard of higher education in speciality 151 "Automation and Computer Technology" (1):

$$PO^A = \{k \mid (k \in K^M) \oplus (k \in K^C) \oplus (k \in K^P)\}, \tag{1}$$

where: K^M is the set of competencies covered by the program results of the professional orientation Machine Industry,

K^C is the set of competencies covered by the program results of professional orientation Circuit Design,

K^P is the set of competencies covered by the program results of the professional orientation Computer Programming.

Thus, it is necessary to conduct a content analysis of the educational-professional program for the selection of variable components of D^A, each of which will contain the maximum number of related competencies, that is competencies with the highest situational weight (2):

$$D_i^A = \{k \mid k \in PO^A\} \tag{2}$$

Next, among the selected variable components, the number of disciplines approved in the educational-professional program with the closest interdisciplinary links is filtered, which will form blocks of parallel disciplines in the autumn *ASem* or spring *SSem* semester.

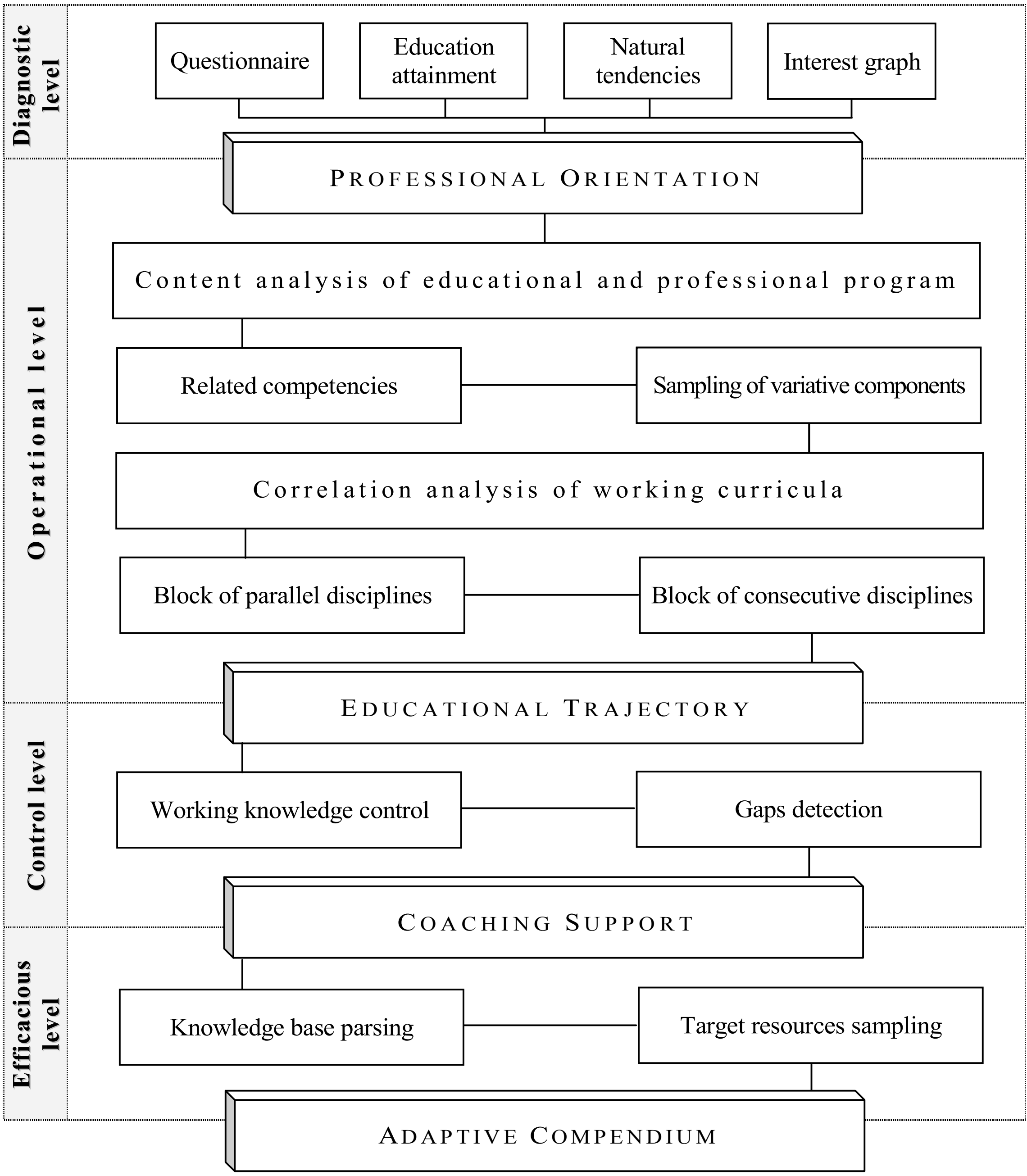

Figure 1: Conceptual model of variable components priority determining in educational trajectory hierarchy

The set of components of these multi-semester blocks finally forms a block of successive disciplines, which together with the mandatory components set of the *RC* forms an annual fragment of the individual educational trajectory of the applicant (3):

$$ET^{Y}=\{RC^{Y} \cup D^{A}\ (ASem,\ SSem)\} \tag{3}$$

The presence of a variable component, especially disciplines of other departments, in a modelled version of the educational trajectory can lead to the formation of academic debt due to lack of the necessary level of knowledge and skills. In order to prevent such a destructive state of affairs, the student should, after the intermediate composition of the individual curriculum, check himself for professional suitability for the chosen professional orientation by passing the control of basic knowledge. Such control will help identify the degree of depth of competence gaps.

Therefore, along with the weight *w* of *vk* related competences, the quantified total value of *rg* academic gaps, which has no relative weight and obtained at the third level of the conceptual model for determining the priority of variable components in the hierarchy of the educational trajectory (Figure 1), is also included in the decision-making criteria. Accordingly, the providential *WSD* weighted sums distribution for individual values of conditional criteria made it possible to build a global preference model as a decision matrix to describe the problem of efficiency analysing and automated choosing the *ET* educational trajectory, which is optimal for applicant's capabilities and inclinations:

	vk_1	vk_2	$\cdots$	vk_n	rg	WSD
w	$w(vk_1)$	$w\ (vk_2)$	$\cdots$	$w\ (vk_n)$		
ET_1	$d_1(vk_1)$	$d_1(vk_2)$	$\cdots$	$d_1(vk_n)$	rg_1	$\varphi(ET_1)$
ET_2	$d_2(vk_1)$	$d_2(vk_2)$	$\cdots$	$d_2(vk_n)$	rg_2	$\varphi(ET_2)$
ET_m	$d_m(vk_1)$	$d_m(vk_2)$	$\cdots$	$d_m(vk_n)$	rg_m	$\varphi(ET_m)$

In the end, the total value for each alternative as a professional orientation option (first column) is calculated from weighted sum of individual values and the correspondence of *d* selected disciplines to attribute (competence). The resulting additive multi-attribute function of weighted feature vector to determine the total utility for the current educational trajectory (4) helps to improve the quality of recommendations:

$$\varphi(ET_i) = \sum_{j=1}^{n} d_i(vk_j)\ w(vk_j) + {}^{1}\!/_{rg_i} \tag{4}$$

At the fourth level of the constructed conceptual model (Figure 1) the tools for the elimination of the revealed gaps are offered. Within the scientific and educational information space of the university with the involvement of confidential cathedral funds and digitized repositories of the academic scientific and technical library is syntactic analysis (parsing) of structural units of the accumulated knowledge base [21].

The purpose of such parsing is the selection of target resources, the content of which covers educational and methodological content that is not owned by the applicant. After the automatic ordering of identified resources in the adaptive compendium, the student can estimate the amount of introductory workload that he needs to work off. In case of a positive decision of the applicant, the layout of the individual curriculum is considered final.

3.2. Designing of intelligent system for determining the optimal variable components

The main difficulty in determining the student's variable part of the educational program is to take into account the structural and logical sequence of study of disciplines of parallel and sequential blocks (3), which determine the content of education in a particular speciality. To solve this problem, an intelligent system was designed, which uses the academic base of educational documentation to solve problems and issue recommendations in the selection of components of the educational trajectory (Figure 2).

In response to the student's request for the accepted professional orientation, the analytical apparatus of the intelligent system performs multivariate content analysis of educational and professional programs and provides a list of selected disciplines of high-level compliance, the relevance criterion of which is the ratio of related subject competencies and interdisciplinary links between them (Figure 3). The provided list strengthens the formal relationship of understanding the normative content of filtered variable components to ensure a holistic approach to understanding professional orientation through the harmonious integration of the research subject area.

In case if a student decides to choose a discipline that is not on the primary list, the analytical system performs a correlation analysis of adequate working curricula and generates a list of variable components in the second iteration. At the same time, the affinity of competencies may be somewhat weakened while maintaining high compliance with the normative content of professional orientation. If necessary, the student can perform modelling of the educational trajectory covering the disciplines of medium- and low-level compliance with professional orientation (Figure 2).

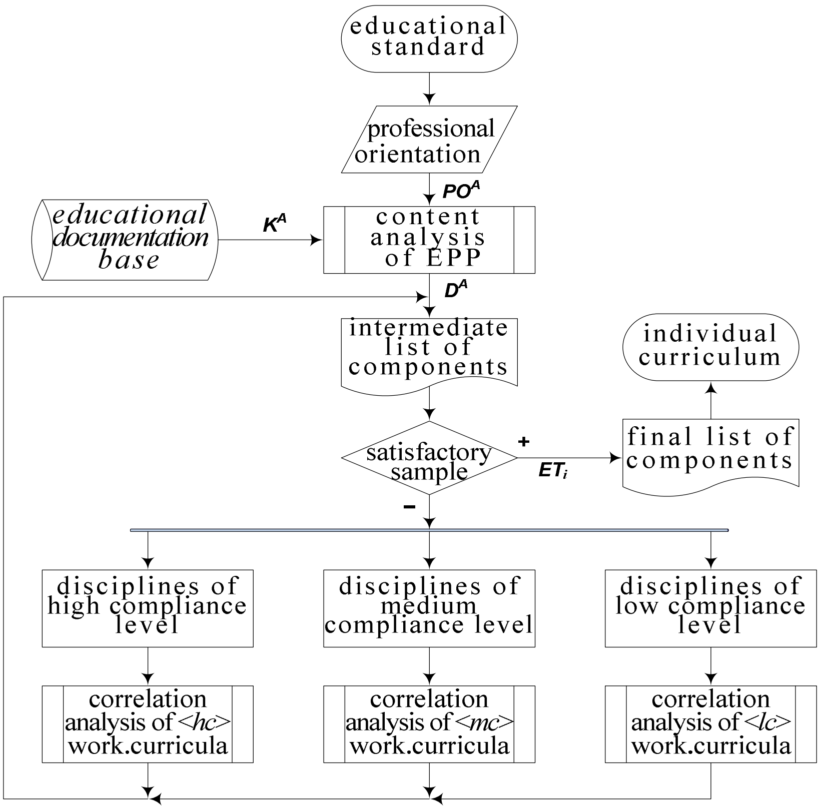

Figure 2: Intelligent selection algorithm of variable components in professional orientation context

Here, the aggregate normative content of the selected disciplines may deviate slightly from the content of professional orientation, but the proposed combination should continue to take into account the structural and logical sequence of formation of cognitive abilities, stable knowledge and professional skills. However, at the same time, the level of $d(vk)$ total disciplines compliance in the constructed global preference model decreases. Obviously, each such iteration will destroy the existing list and make adjustments in the formation of the semester block of parallel disciplines.

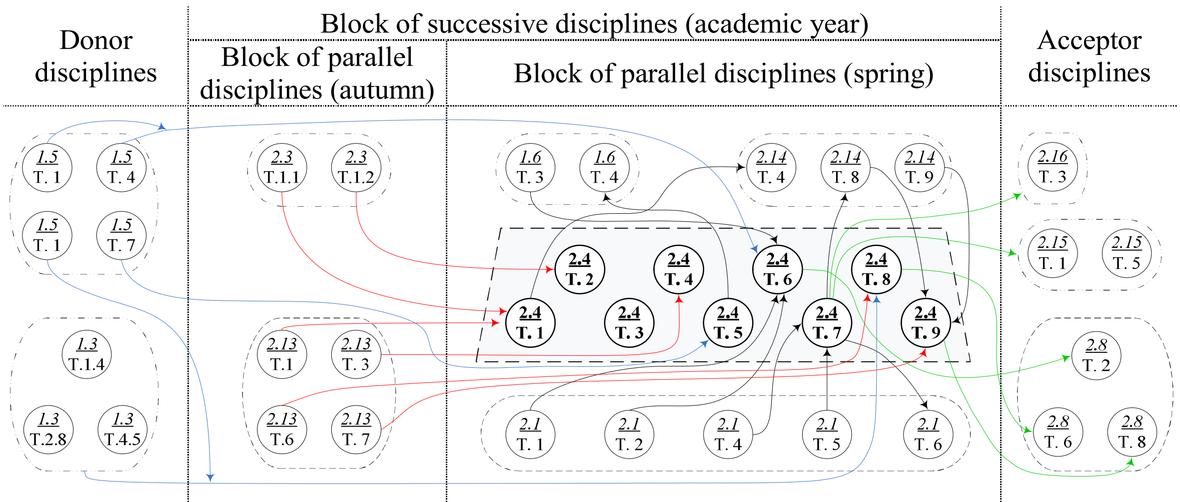

Figure 3: Interdisciplinary links on the example of variable component # 2.4 "Applied Theory of Digital Automata"

The next formation of the block of successive disciplines (Figure 3, red arrow) will take place according to the described mechanism, but with a narrowed list of variable components. This narrowness is due to the specifics of the block of consecutive disciplines of the previous (autumn) semester and their degree of affinity with the selective components of the parallel spring semester.

Next, the optimal educational trajectory is determined based on the weighted feature vector (4). Of course, the student has every right to ignore the proposals of the recommender system and form a variable list to his subjective taste, but there is an increased risk of accumulating academic debt due to lack of necessary competencies

3.3. Generating an adaptive compendium

As noted (Figure 1, levels III-IV), enhanced independent work on gaps will help to acquire missing competencies or update forgotten ones for the chosen educational trajectory (4). Coordinating such work will help adaptive synopsis, composed of resources of the university knowledge base on the materials of topics (Figure 4), of which previously found unsatisfactory performance.

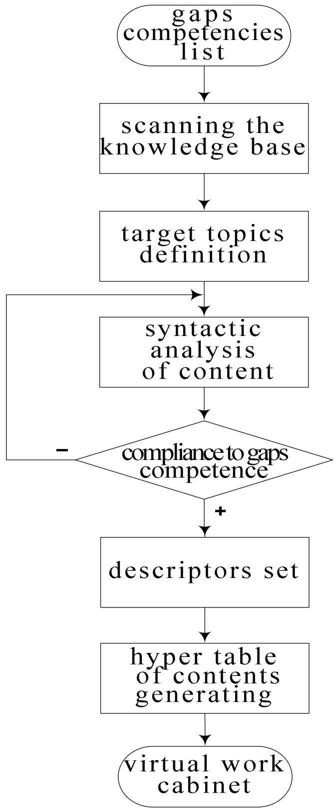

Figure 4: Life cycle of adaptive compendium generation

After passing the control of working knowledge, which determines the basic level of compliance to the mastery of educational materials of the chosen professional orientation, the analytical apparatus of the educational system formalizes gaps in subject competencies. Thus, after scanning the academic knowledge base and identifying the target topics of related disciplines (Figure 3), the syntactic analysis of existing content for compliance with gaps competence. The next step is to compare headings, keywords, and abstracted phrases for each topic, and to evaluate the relevance of the annotations. Weights are formed according to the percentage of matches. Based on the obtained results, the conformity of the selected structural unit of content is assessed. The above algorithm is applied to the next target topic.

After completing the survey of the educational and methodological content target topics of the knowledge base, a set of descriptors accumulates, which is subject to further ordering by relevance, which consists in marking topics in descending order of conformity assessment. To arrange adequate topics, the estimation of the arithmetic mean weighted coefficient of the discipline is used, where the weight coefficient of the variable component will be the inverse of its position relative to the level of correspondence, and the set of parameters for the topic will be the values of conformity assessment according to the updated relational model.

Finally, the hyper table of contents of the adaptive compendium as a coaching support is generated in the personal virtual account of the authorized applicant of engineering education. On the basis of the generated links array, the student gets access to target content of the academic knowledge base [31] from the terminal of any network device [24] and can study at an individual pace according to their own performance peaks.

4. Results and discussion

The purpose of the experiment was to test the projected knowledge management technology based on the intelligent system. A pedagogical experiment was conducted during 2017-2021. It was attended by 132 students majoring in 151 "Automation and Computer-Integrated Technologies". The formative stage of the experiment was attended by 32 people, who were divided into control groups (CG, 16 people) and experimental groups (EG, 16 people). Participation in the study was voluntary. The pilot part of the study was conducted in the first year, as the analysis of student achievement in previous years revealed a contradiction between the need of the labour market for competent professionals able to solve complex professional problems and the insufficient level of professional activity in the chosen professional orientation, developed in an educational institution.

At the ascertaining stage of the experiment, the main problems, factors and tendencies related to the preparation of applicants for professional activity were identified; conceptual bases of increase of professional competence at the expense of improvement of an individual educational trajectory, research hypothesis, criteria and levels are developed. The study hypothesised that the conscious choice of variable disciplines while taking into account the inclinations of applicants to professional orientation will positively affect the formation of individual educational trajectory and increase the level of integrated competence. We have identified the following criteria: the success of students in the disciplines of professional and practical training on the results of exams and tests; participation in student research work; compliance with the subject of scientific research, and later the bachelor's qualification work with the chosen professional orientation. The severity of the criteria was determined at high, medium and low levels.

The introduction of a provision on the choice of variable disciplines made it possible to reconcile the potential of applicants with the appropriate professional orientation. To increase the efficiency of the choice of variable disciplines by applicants and reduce the impact of the unconscious decision, we have developed an intelligent system that automates the generation of the optimal sequence of disciplines most relevant to professional orientation. From the first year, the student could trace the parallel and consistent interdisciplinary relations between disciplines and make an idea of the aspects of educational material in time. This approach reduces the likelihood of losing sight of professional content important to the profession. At the end of each semester, students' academic achievements were monitored according to accepted criteria.

At the formative stage, the experimental group was asked to use the developed intelligent system to build an individual learning trajectory based on professional orientation. Simultaneously with students, systematic work was carried out to motivate independent research in the chosen direction of professional orientation (research projects, participation in conferences at various levels, professional olympiads and international competitions, development of utility models, and work on scientific publications). In the control group, the choice of variable disciplines took place without the external action of the active factor, naturally. To identify the impact of the intelligent system on success, the results of educational achievements in both groups at the beginning and end of the formative stage were compared (Figure 5).

Our analysis of the results of the educational achievements in both groups showed that EG applicants demonstrate higher educational achievements. In particular, in the EG the number of applicants who had low academic achievement at the end of the experiment decreased by 37.5%, and in the CG – by 18.75%. Those who studied at the secondary level partially moved to the higher level. Accordingly, at the end of the experiment at the highest level in the EG group, the number of applicants increased by 12.5%, and in the CG – by 6.25%. In general, the difference in academic achievement between EG and CG by levels was: low – 31.25%; at the average level – 18.75; at a high level – 12.5%.

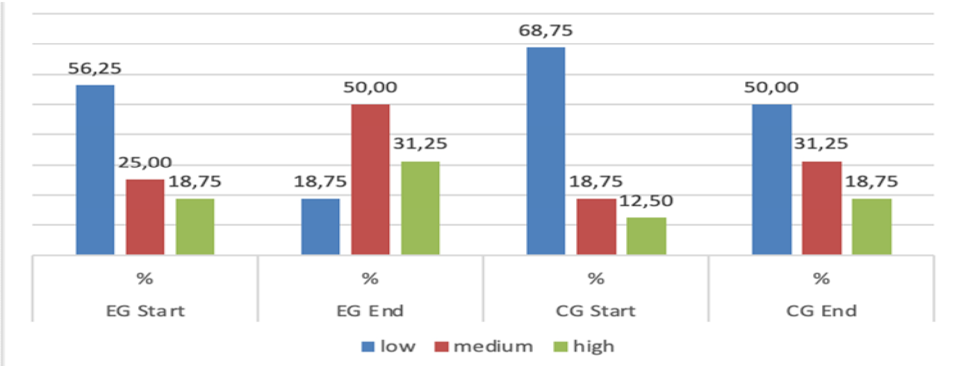

Figure 5: Distribution of students of the experimental and control groups

The results obtained were tested for the difference between the average of the two related samples using a pair of two-sample Student's t-test. Comparison of the tabular and calculated value of the t-test for the significance level $p < 0.01$ makes it possible to draw a statistically reasonable conclusion that in the experimental group learning achievements are higher than in the control group

$$t_{table} = 9.9248 < 11.53 = t_{fact}.$$

Observations of students' learning and creative activity showed that in the experimental group the applicants showed greater motivation, and professional interest, showed higher results in scientific work and tried to solve real professional problems. In particular, the activity of students of both groups in scientific work shows the distribution of the number of scientific publications, presented projects and participation in professional competitions for the 2017-2021 academic years (Table 1).

Table 1

Dynamics of scientific activity of students by the number of scientific works

Academic year	Experimental group, %			Control group, %		
	publications	competitions	projects	publications	competitions	projects
2020/2021*	81,25	0	25	37,5	0	6,25
2019/2020	50	25	6,25	25	18,75	0
2018/2019	37,5	12,5	0	6,25	0	0
2017/2018	31,25	0	0	12,5	0	0

* during this period, professional competitions were cancelled due to the spread of acute respiratory disease COVID-19 caused by coronavirus SARS-CoV-2

Analysis of the data in Table 1 showed that in the first year the applicants did not participate in professional competitions and projects, because at that time they did not have sufficient knowledge and experience. Teachers' attention was paid to involving students in scientific work, acquaintance with scientific methods, work with scientific literature, and writing the first scientific works.

In the following academic years, the activity of students in the experimental group to publications increased significantly compared to the control group, in particular in the experimental group – by 50%, in the control group – by 25%. The most significant difference between the groups was observed in the last year of the study – 44.25%. Starting from the second year, the students of the experimental group showed more activity in competitions and projects. In the last year of study, participation in professional competitions was cancelled due to objective reasons [21, 22, 31].

The subject of bachelor's qualification works in the experimental group had a clear professional orientation for 87.5% of performers, while in the control group only 50%. It was also found that some students in the research found an aspect for which they did not have enough knowledge because the normative and variable disciplines did not provide them. They found a way out of the situation together with the teacher. If the problem was the insufficient level of knowledge in the disciplines studied, applicants for the resources of the university knowledge base automatically formed an adaptive synopsis (Figure 4) to eliminate gaps re-identified at the control (third) level (Figure 1). It is also worth noting that all master's projects topics of graduates 2023, who were participants in the bachelor's experimental group (Table 1), correspond to specialization chosen at formative stage.

Thus, the analysis of the pedagogical experiment results suggests that qualitative changes in the individual educational trajectory of students have significantly increased the level of subject competencies, which in general constitute integral competence due to higher education standard in speciality 151 "Automation and computer-integrated technologies". This proves the effectiveness of the developed knowledge management technology based on the analytical system and the reliability of statistically processed experimental data. Based on the results obtained, we conclude that the initial assumption is correct, the goal is achieved, and the hypothesis is confirmed.

5. Conclusions

As follows, performed research has shown that the transition from traditional to project-based learning strategies be flexibly implemented within the variable components without significantly changing the educational model at the faculty or university level. Adapting the global preference model to educational standard requirements made it possible to simplify complex decisions in determining the dominant segments in the educational trajectory hierarchy and make such decisions more rational. The application of these student-centred approaches to the training of qualified professionals in demand in the labour market helps to clarify and expand the educational services provided by the rational composition of subject competencies and effective knowledge management to achieve programmatic learning outcomes through the best use of knowledge.

The proposed four-level conceptual model of variable components priority determining in educational trajectory hierarchy provides strengthening of subject competencies due to selective components of the educational and professional program in specialities and disciplines offered for other levels of higher education in related specialities. Professional orientation is formalized through normative content of related elective disciplines by concluding the multi-criteria rating to form their total importance. The built-in analytical apparatus supports the content analysis of the educational and professional program for the computerized selection of variable components so that each of them covers the maximum number of related competencies. To achieve the established ratio of constant and variable components, correlation analysis of working curricula was used to ensure the required number of disciplines with the closest interdisciplinary links. At the same time, a sample from a wide range of related disciplines from other departments is provided in such a way that the total number of credits and the form of control do not change. To prevent the emergence of academic debt after the control level of the conceptual model based on the identified missing competencies provided coaching support through co-thematic selection in advance marked target content.

The conducted pedagogical experiment showed that due to the optimal selection of variable disciplines with the help of an intelligent system in EG students demonstrate higher academic achievements, they are faster and at the highest quality level formed subject competencies included in the integrated competence. The difference in academic achievement between EG and CG by levels at the end of the experiment was: at a low level – 31.25%; at the average level – 18.75; at a high level – 12.5%. The most significant difference in publications between the groups was observed in the last year of the study – 44.25%. The clear professional orientation of bachelor's qualification works in EG prevailed by 37.5%. The results confirm the effectiveness of the developed knowledge management technology based on the intelligent system and indicate its potential advantages over the traditional subjective approach to the choice of variable disciplines. This technology provides a full-fledged adaptive toolkit for further training of applicants from other higher education institutions in the academic mobility program.

The expediency of allocating professional orientations from the unified standard of higher education in the speciality helps to increase flexibility in the implementation of subject components to achieve program learning outcomes. The main interested parties there are students, teachers and their future employers. Consequently, the educational process acquires the ability to adapt to students and their way of learning, so that each generation of students achieves the best learning outcomes. Students have a lower dropout rate, a shorter period of adaptation to professional practice and better soft skills. The ultimate goal of such student-centred processes in education is to permanently increase competencies while ensuring trends of sustainable growth and long-term competitiveness through the targeted use of new digital means and teaching methods.

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