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RESEARCH ARTICLE

Software methods for curriculum processing, analysis and visualization

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Abstract
Objectives. The purpose of this study is to identify methods and approaches to developing a software package which can automate the processing, analysis, and visualization of curricula in educational programs.
Methods. We provide an overview of relevant scholarly literature and research results. The software package applies regular expressions for data processing, comparative analysis, and descriptive statistics to identify differences. It also uses a graph-based model for visualization.
Results. We designed the architecture of a software package for preprocessing, analyzing, and visualizing curricula following the SOLID[1] principles of object-oriented programming. We implemented the package in C++, in order to calculate curriculum characteristics and build a graph representation. This formed the basis of our proposed visualization method. We demonstrate the functionality of the package through a comparative analysis of curricula, identification of distinctive features, and detection of design shortcomings.
Conclusions. Our software package helps identify specific features, reveal possible weaknesses, and support the comparative analysis of different curricula. Using it improves the quality of educational process management, addresses gaps in educational data analysis, and contributes to the creation of a university digital ecosystem. The results of our study are useful for faculty members designing and developing curricula, as well as administrative and managerial staff (including those in academic affairs) and other higher education stakeholders.

Keywords: curriculum, educational program, method, software, graph model, competency-based approach, interdisciplinary links

[1] S is the single responsibility principle; O is an open-closed principle; L is the Liskov substitution principle; I is the interface segregation principle; D is the dependence inversion principle.

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НАУЧНАЯ СТАТЬЯ

Программные методы обработки, анализа и визуализации учебных планов

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Резюме
Цели. Цель работы – поиск методов и подходов разработки программного комплекса для обработки, анализа и визуализации данных учебных планов образовательных программ в автоматизированном режиме.
Методы. Проведен теоретический анализ научных работ и результатов в области исследования. В программном комплексе используются следующие методы: для обработки данных – регулярные выражения, для анализа посредством выявления различий – метод сравнительного анализа и методы описательной математической статистики, для визуализации результатов – графовая модель представления данных.
Результаты. Разработана архитектура программного комплекса для обработки (с предобработкой), анализа и визуализации учебных планов с использованием принципов объектно-ориентированного программирования SOLID[2]. Программная реализация на языке программирования C++ использована для подсчета характеристик учебных планов и создания графового представления, на основе которого предложен собственный способ визуализации учебных планов. Продемонстрированы возможности программного комплекса: проведен сравнительный анализ учебных планов, выявлены их особенности, обнаружены недочеты при их проектировании.
Выводы. Использование программного комплекса обработки, анализа и визуализации учебных планов может помочь выявить особенности учебного плана, указать на возможные недоработки и слабые места, провести сравнительный анализ разных учебных планов. Его применение позволит повысить качество управления образовательным процессом, заполнить пробелы в области анализа образовательных данных и будет способствовать созданию цифровой экосистемы вуза. Результаты работы могут быть полезны преподавателям, проектирующим и разрабатывающим учебные планы, представителям административно-управленческого персонала, в т.ч. работникам учебно-организационных отделов, а также другим участникам образовательного процесса вуза.

Ключевые слова: учебный план, образовательная программа, методы, программная обработка, графовая модель, компетентностный подход, междисциплинарные связи

[2] S (single responsibility principle) – принцип единственной ответственности; O (open-closed principle) – принцип открытости-закрытости; L (Liskov substitution principle) – принцип подстановки Барбары Лисков; I (interface segregation principle) – принцип разделения интерфейса; D (dependence inversion principle) – принцип инверсии зависимостей. [S is the single responsibility principle; O is an open-closed principle; L is the Liskov substitution principle; I is the interface segregation principle; D is the dependence inversion principle.]

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INTRODUCTION

At the present time, the management of the educational process at universities is based on the use of a large amount of diverse data about students and their learning process, as well as information about educational programs (EPs), and teaching staff who provide their implementation, inter alia. At the same time, the available data is used only partially, as a rule, to provide administrative support for the educational process. For example, a higher education institution has data on the competencies which need to be developed as a result of completing a specific EP and statistics on the employment of graduates who have completed this program. However, the interrelationships between such data are not always analyzed in order to make changes to the EP or the educational process to ensure better results.

There are many such examples, all related to the fact that education management is currently based on the classical approach to educational analytics [1]. However, data collection, processing, and analysis technologies are rapidly evolving. This in turn is leading to the development of new approaches [2]. New software tools are needed for the successful implementation of such approaches in everyday practice. They must enable real-time access to the data on the educational process needed for analysis and adjustments. A large number of works are devoted to the creation and description of the features of information systems (IS) which use these tools and the creation of intelligent systems based on them (see, for example, [3–6]).

One of the main objects of analyzing the educational process is the EP which can be viewed as a plan for achieving the stated educational outcomes. In particular, the EP describes the features of the learning process and presents a set of competencies to be developed in the learner upon completion of the course. Therefore, the demand for the EP largely depends on how well it meets the expectations of its main consumers [7]: students; student representatives; faculty; administrative and management staff; external experts; including representatives of potential employers, etc. The quality of EPs plays a significant role in the reputation of a higher education institution.

A key component of the EP is its curriculum, describing the scheme for its implementation. The curriculum contains information about competencies, achievement indicators, and educational units (EUs). These also include disciplines, practices, state final examination, their sequence, and workload. The curriculum is a valuable source of information for managing the educational process. Analysis allows for the implementation of the EP to be assessed and its characteristic features identified.

Most research studies devoted to the processing of curriculum demonstrate a manual processing method, i.e., without the use of software tools for process automation. This work demonstrates the development and application of software methods for processing (including preprocessing), analysis, and visualization of the curriculum. Their implementation is presented in the developed software. This package enables the curriculum to be converted into a single format, their characteristics to be identified, a comparative analysis performed. It also allows them to be presented in a graph model for subsequent visualization.

The current task of the study is to assess the effectiveness of the formation of the competencies stated in the EP. This can be resolved by analyzing the interrelationships between the planned learning outcomes and a wide range of learning indicators, such as the percentage of students transferring to other programs. This article takes a step towards automating the processes of analyzing the curriculum structure and calculating their characteristics which can subsequently be linked to the quality of competence development.

1. RESEARCH METHODS

We analyzed a number of studies in order to create a software tool which identifies the optimum non-obvious features of the curriculum which corresponds to modern approaches to intelligent data analysis [8], and which can be integrated into the digital ecosystem of a university. They can be classified into five thematic areas (from general to specific):

1) Digital transformation: the impact of digital transformation in universities at different levels of data management.
2) Intelligent data-driven decision-making systems: challenges and opportunities for IS as a whole, as a modern approach to synthesizing new data and identifying patterns in existing data.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	-	-	-	Form of control							Credits		Total academic hours							Course 1		Course 2		Course 3		Course 4	
2																				S1	S2	S3	S4	S5	S6	S7	S8
3	To count at plan	Index	Name	Exam	Test	Evaluated test	CP	CW	RCW	Other	Expert	Fact	Expert	According to plan	Control work	Class-room	IW	Control	Practical training	Credits	Credits	Credits	Credits	Credits	Credits	Credits	Credits
4	**Block 1. Disciplines (modules)**										213	213	7996	7996	3748	3748	3348	900		27.5	28.5	28	28	28.5	28.5	30	14
5	**Required part**										139	139	5332	5332	2722	2722	2034	576		27.5	28.5	24	22	15.5	7.5	14	
6	+	B1.O.01	Philosophy	4							4	4	144	144	54	54	54	36					4				
7	+	B1.O.02	History		12						4	4	144	144	72	72	72			2	2						
8	+	B1.O.02.01	History of Russia		1						2	2	72	72	36	36	36			2							
9	+	B1.O.02.02	Universal history		2						2	2	72	72	36	36	36				2						
10	+	B1.O.03	Foreign language	4	123						9	9	324	324	144	144	144	36		2	2	2	3				
11	**The part formed by participants in educational relations**										74	74	2664	2664	1026	1026	1314	324				4	6	13	21	16	14
12	+	B1.V.01	Optimization methods	6	5						9	9	324	324	108	108	180	36						3	6		
13	+	B1.V.02	Number theory	5							4	4	144	144	72	72	36	36						4			
14	+	B1.V.03	Integral transformations	7							5	5	180	180	72	72	72	36								5	
15	+	B1.V.04	Theoretical mechanics	3							4	4	144	144	36	36	72	36				4					

Title | Schedule | PlanSummary | Plan | Competencies | Competencies (2) | Competencies (3) | Competencies (4) | Course 1 | Course 2 | Course 3 | Course 4 | Practices | ...

Fig. 1. A fragment of a *Microsoft Excel* table exported from the Plans IS.
CP—course project, CW—course work, RCW—remote course work , IW—independent work, S1–S8—semesters 1–8

Table 1. Formats for completing curricula, differences are indicated by underlining

No.	Curricula	Data from the page "Competencies (2)" The "Competencies being developed" column
1	01.04.02.07 "Applied Computing in Science and Engineering" (reference version)	UC-1, UC-2, UC-3, UC-4, UC-6, GPC-1, GPC-3, GPC-4
2	09.04.01.06 "Microprocessor Systems" (incorrect option)	ID-1UC-6, ID-2UC-6, ID-3UC-6, ID-1GPC-1, ID-2GPC-1, ID-3GPC-1, ID-1GPC-3
3	10.03.01.31 "Computer System Security" (dual indicators)	UC-1, GPC-7, GPC-8, GPC-1.1, GPC-1.3, GPC-1.4
4	09.03.03.32 "Applied Informatics in Social Communications" (indicators are specified instead of competencies)	UC-1.1, UC-1.2, UC-1.3, GPC-1.1, GPC-1.2, GPC-1.3, GPC-4.1, GPC-4.2, GPC-4.3

Note: UC are universal competencies, GPC are general professional competencies, ID are identifiers.

3) EP assessment: assessment of their quality and potential for improvement.
4) Competency component: methods for assessing the competency component of the EP.
5) Curriculum data analysis: capabilities for analyzing the curriculum data to obtain a general understanding of the EP design.

Our research has led to the development of automated methods and approaches for creating the *SPA-SFU2*[3] software complex (from System-Plans-Analyze of Siberian Federal University). The source data for *SPA-SFU2* is the data from the Plans IS, developed by the MMIS[4] Laboratory. This IS is widely used among Russian universities for the purposes of working with the curriculum. Although it meets their needs, a level of redundancy was found (Fig. 1) when comparing the research objectives and the Plans IS database. Figure 1 shows a fragment of the input data for *SPA-SFU2*, where the colors indicate: red—empty curriculum fields; yellow—duplicate fields; green—fields with data relevant to the study. Note that column "C" lists the names of EUs—disciplines, practices, and state final examination (SFE)—to which credit units (CU) are assigned and which are the main structural elements of the curriculum.

The data formats vary significantly, since higher education institutions work with the curricula of a broad range of federal state higher education standards created over different years and by different designers. All comply with federal legislation and local regulatory documents, but their diversity complicates the development of software methods for preprocessing of the curriculum. For this reason, algorithms have been developed to bring them to a single standard in order to eliminate differences. These differences are expressed in the deviation of the format for filling in curriculum data from the most common among the curricula used in the study (Table 1, the standard data format is indicated in row 1). Examples of differences include: different data

[3] https://github.com/ekhalturin-ki15/SPA-SFU2. Accessed September 28, 2025. (In Russ.).

[4] https://www.mmis.ru. Accessed September 28, 2025. (In Russ.).

entry format; the use of different names for EUs and their corresponding competencies; a different method of indicating EU indicators (Table 1, nonstandard format is underlined); and others. When designing software methods, eliminating differences was the most labor-intensive task, since it required predicting situations which could potentially arise when working with all possible curricula.

An example of a discrepancy detected in the format of the research curricula: Table 1 shows that curriculum 09.04.01.06 "Microprocessor Systems" includes a list of indicators rather than competencies (row 2), complicating the programmatic analysis of data. In order to resolve this problem, we suggest using a backup regular expression which can extract the indicator, including from a different curriculum format. If this difference in the format of form filling is ignored, a situation will arise where a group of competencies with the name "ID-1UC" is defined instead of "UC" (universal competency). This will subsequently introduce an error in the calculations of the percentage distribution by groups of labor intensity competencies.

Another example is the discrepancy arising in the curriculum 10.03.01.31 "Computer System Security" (line 3). It contains competencies identical in appearance to the indicators of competency achievement (a situation of duplicate indicators). There are curricula which list not competencies, but a list of indicators to be formed, as presented in the curriculum 09.03.03.32 "Applied Informatics in Social Communications" (line 4). This requires additional analysis of the situation by the *SPA-SFU2* user, in order to determine what exactly is presented in the EU: competencies or indicators of their achievement.

From the point of view of software processing methods, some of the curricula data is statistical noise. For example, the list of competencies formed by the EU "Defense of the final qualification work" includes all possible curriculum competencies, negatively affecting the objectivity of the graph model obtained. The most common outliers are EUs related to practices and the state final examination, since they have a complete list of competencies formed by the entire set of EUs. They are much more labor-intensive (measured in CU) than other EUs. The presence of outliers reduces the clarity of the aggregated data obtained. For example, the metric "number of connectivity components" will be equal to one, which is not informative.

As a result, after eliminating the differences, *SPA-SFU2* operates only with the data on the curriculum necessary and sufficient for comprehensive analysis. This can be found in *Excel* tables on pages:

1) on the "Title" page, general information about the curriculum is specified;
2) the "Competencies (2)" page contains a complete EUs list;
3) on the "Competencies" page, indicators of competency achievement are compared. In addition, the nesting of EUs by modules is determined;
4) on the "PlanSummary" page shown in Fig. 1, the number of CUs allocated to the study of the course unit for each semester of study is determined, and it is also clarified whether the course unit is compulsory for completion.

The above data enables ambiguities in the data (differences in the names of identical entities and different formats for filling in the data) to be eliminated, and the final data in various categories to be determined:

1) integral characteristics for each individual semester of the curriculum, for all semesters of the curriculum, for the entire curriculum as a whole;
2) characteristics that determine the strength of interdisciplinary links;
3) data on graph models of the curriculum;
4) percentage distribution of the labor intensity of competence formation and indicators of their achievement.

The final result of *SPA-SFU2* can be used for such purposes as: pairwise comparison of the curricula, in order to identify the most successful moments (the order of EU, defined for EU formed competencies, distribution of load on EU); identifying a typical curriculum for different universities for the same EP; as well as determining specific situations which arise in the event of a large deviation from the average value of some of the curriculum characteristics. These can include, for example, situations where a large percentage of the total workload is allocated to the formation of general professional competencies. This can lead to a reduction in the workload on other competencies, since their total number is strictly regulated in the Federal State Educational Standards of Higher Education.[5]

An analysis was conducted of 49 curricula at the Institute of Space and Information Technologies of Siberian Federal University. The analysis of the curricula does not differ in terms of education levels (for bachelors, specialists, and master students), fields of study, and university affiliation, since their source is the Plans IS. This enables the study to be scaled up and replicated in any institution which uses the Plans IS to work with the curricula.

Let us note its key features of *SPA-SFU2,* in order to understand the effectiveness in resolving the task of the curriculum data analysis. The software package was developed in C++ using a minimum number of

[5] https://www.fgosvo.ru. Accessed September 28, 2025. (In Russ.).

1	Parameter name	Parameter value
2	Curricula data catalogs	plans\grad
3	Result output catalogs	result\grad
4	Divide credits by number of competencies	yes
5	Divide credits of the competence by number of competencies	yes
6	Undirected graph	yes
7	Use multi-level indicators	no
8	Max. length of discipline names	15
9	Regular expression for indicator splitting	(\w{1,}).{0,}-(.{1,})\.(.{0,})
10	Regular expression for indicator splitting (Additional)	\w{1,}.{0,}-(\d{1,})(\w{1,}).{0,}-(.{1,})
11	Regular expression for competence splitting	(\w{1,})\W{0,}-(.{1,})
12	How many semesters are there in one course	2
13	Number of quartiles	4
14	There are a lot of competencies if their number is greater than X =	6
15	Truncation of the mean for quartiles	0.05
16	Create an edge if its weight is greater than X =	0.001
17	L – Credits of the left vertex R – Credits of the right vertex A – total number of credits N – total number of disciplines K – power of intersection by competencies D – power of intersection by disciplines Supported operators +, −, *, /, ^ (degree), mod, abs, sin, cos, log	One can use any formulas, for example: 1) From SPA-SFU version No. 1: ((L + R) / (2 * A)) * K 2) Average: ((L + R) / 2) * K 3) Geometric mean: ((L * R) ^ (1 / 2)) * K
18	The weight of the graph edge where the vertex is a discipline	(5 * (L + R) / (A)) * K
19	The weight of the graph edge, where the vertex is competence	(5 * (L + R) / (A)) * D

Fig. 2. Fragment of the application configuration file

third-party libraries (only the OpenXLSX[6] library is used to work with *Excel* tables), enabling the entire data set of 10 curricula to be processed in less than a second (one curriculum has more than 2000 cells to analyze, and together with the data calculated by *SPA-SFU2* upon completion of the program, there are more than 10000 cells).

The study uses graph representations of the curriculum as a standard approach in the curriculum analysis, used in many studies [9, 10]. Graph representation allows metrics to be obtained for determining hypotheses regarding the correctness of the curriculum structure. *SPA-SFU2* calculates curriculum data about the corresponding graph model. There are many ways in which the curriculum can be represented as a graph, but in this study, four main ones were selected. In each of these methods, the edges between the vertices are calculated using the formula specified in the configuration file (Fig. 2, line 18). The formula used takes into account the number of matching competencies (the more matches, the greater the weight of the edge) and the labor intensity measured in CU.

Let us list the methods for constructing a graph model of the curriculum:

1) A standard graph model where a set of vertices corresponds to EUs. The edges between vertices indicate interdisciplinary connections at the intersection of the list of competencies being formed. The weight of a vertex corresponds to the labor intensity of the EU (how much CU is allocated for successful learning). The weight of an edge corresponds to the number of overlapping competencies (this model is described in more detail in [11]).
2) An extended graph model where a set of vertices corresponds to EUs graded by semester. One EU may belong to several vertices, if studied over several semesters. In [12], a similar graph representation is used to analyze the curricula.
3) A reverse graph model where a set of vertices corresponds to competencies. For this model, an additional formula is provided in the program configuration file (Fig. 2, line 19). A similar model is used in [13].

This study uses mathematical statistics. Measures of central tendency are determined on the basis of curriculum data, and the quartile distribution is thus calculated. Data on graph models is stored as an adjacency list which enables the best asymptotic performance of algorithms. For example, the calculation of the global clustering coefficient (the purpose of which is specified in [14]) has an asymptotic value of $O(|V| \times |E|)$, in which $|V|$ is the number of vertices and $|E|$ is the number of edges. Figure 3 presents a description of this algorithm. The use of binary search is made possible by storing vertex numbers in the adjacency list in ascending order.

[6] https://github.com/troldal/OpenXLSX. Accessed September 28, 2025.

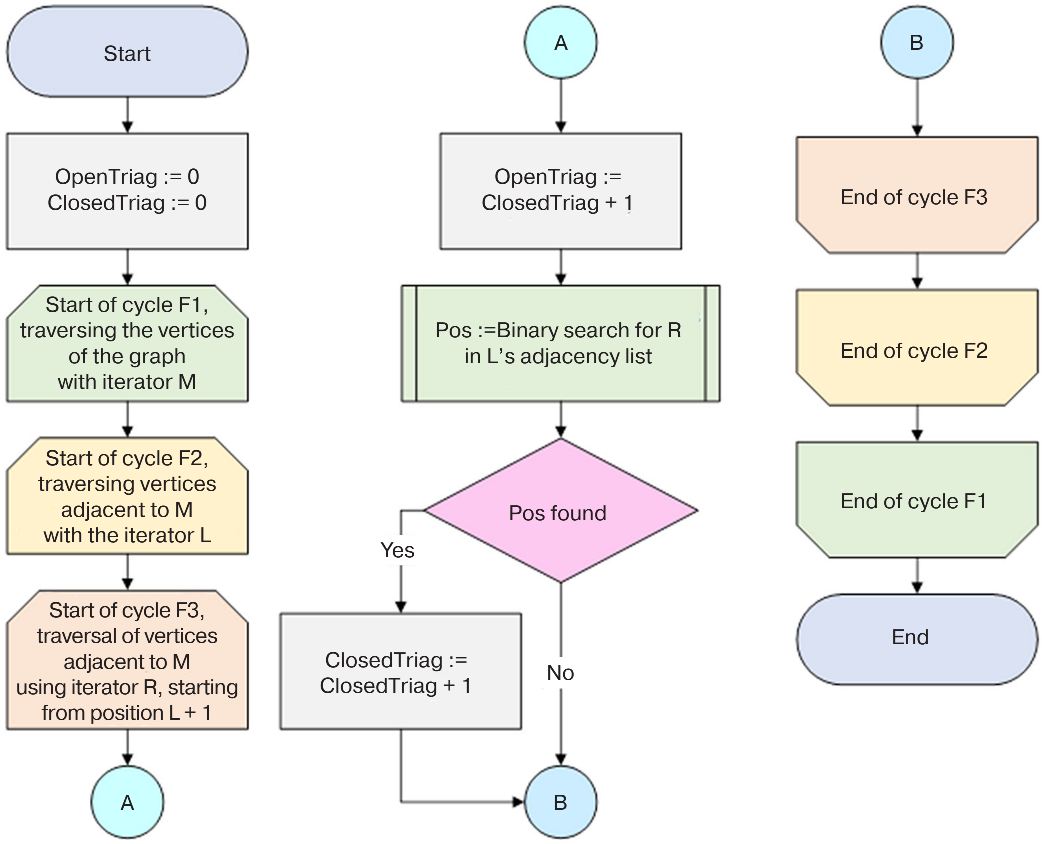

Fig. 3. Flowchart of the algorithm for calculating the global clustering coefficient of a graph

The OpenTriag variable is used to count and store the number of "open triangles," i.e., states in which only two of the three possible connections are formed for three points. The variable ClosedTriag has a similar purpose, but only for the state when all three connections are formed for three points. The clustering coefficient is equal to the ratio of ClosedTriag to OpenTriag. As you can see, its value does not exceed one.

2. RESULTS

The *SPA-SFU2* software package is presented as a console application which accepts *Excel* tables from the Plans IS as input and, upon completion, creates catalogs with *Excel* and cvs tables. The choice of the *Excel* format for the curricula is due to its clarity for the user, as well as the ease of editing and restructuring for other educational analytics tasks. For example, the user can specify EU teachers instead of competencies, in order to determine the distribution of the final workload. *SPA-SFU2* was developed using a modular architecture which enables new functionality to be added to the software complex without changing the existing one. For example, this allows for a curriculum processing module, including the xml format, to be added if necessary.

The program is controlled by configuring its parameters in the configuration file (Fig. 2, the left column lists the parameter names, and the right column lists their values). Several independent curricula samples can be specified (Fig. 2, line 2, the specified curriculum data directory contains several subdirectories with *Excel* tables). These include how to perform calculations (Fig. 2, lines 4–7), regular expressions for obtaining data from *Excel* table cells (Fig. 2, lines 9–11), threshold values (Fig. 2, lines 12–16), and formulas used for calculations (Fig. 2, lines 17–19).

Figure 4 shows an entity-relationship diagram in Martin's notation [15], corresponding to the database of the developed software (S). For convenience, the prefix before the field name indicates its data type. For example, the string data type of the sName field from the DTCurricula table stores the name of the curriculum. The colors of the tables, like their prefixes in the name, indicate their purpose: DT denotes a data storage table; R denotes a linking table; and Matrix denotes a two-dimensional data array storage table.

The architecture of the software complex is based on SOLID[7] design principles [16]. The RGlobal

[7] S is the single responsibility principle; O is the open-closed principle; L is thet Liskov substitution principle; I is the interface segregation principle; D is the dependence inversion principle.

Fig. 4. Entity-relationship diagram for the application database

table (item 1 in Fig. 4) combines various methods: a) data input from DTSolve (item 2 in Fig. 4) which enables software parameters to be entered not only through the configuration file; b) aggregation from DTAdapter (item 3 in Fig. 4) which allows you to use your own methods for building a graph model of the curriculum; c) output from DTOutData (item 4 in Fig. 4) which allows you to vary the ways of displaying data, for example, to export it directly to business analytics systems, and not only to tabular files. The main table of the software is DTCurricula (item 5 in Fig. 4) which stores the input data on the curriculum. All other tables store data calculated using the software.

In order to calculate the clustering coefficient described in the research methods, an adjacency list is used, in order to improve the final asymptotics of the algorithm to the minimum possible. This is designated in the diagram as MatrixAdjacencyList (item 6 in Fig. 4). Thanks to the graph clustering coefficient, conclusions can be drawn about how strongly the EUs are interconnected.

Table 2 shows how the graph characteristics of two curricula with the maximum (curriculum 09.03.02.30) and minimum (curriclulum 09.03.03.33) clustering coefficients differ across the entire sample of bachelor's degree curricula. The characteristic is highlighted in

Table 2. Metrics of a graph model of two bachelor's curricula

Curriculum designation	09.03.02.30	09.03.03.33	Curriculum designation	09.03.02.30	09.03.03.33
Clustering coefficient	**0.92**	**0.43**	Graph density	0.14	0.12
Maximum number of CUs in EU	10 CU	15 CU	Minimum number of CUs in EU	2 CU	2 CU
Graph diameter by weight	1.01	1.36	Graph diameter by vertices	5 vertices	4 vertices
Number of linkage components	10	3	Pairs of unconnected vertices	895 pairs	89 pairs
Weight of the maximum skeleton tree	10.86	16.34	Weight of the minimum skeleton tree	7.21	8.04

bold, and this graph model is designated as "standard" in the methods section of this study. Figure 5 demonstrates a possible option for their visualization using the *Gephi*[8] software package.

Figure 5 shows the graph model of the curriculum 09.03.02.39 on the left, and curriculum 09.03.03.33 on the right. Each node represents a course unit, the name of which is given in abbreviated form. The larger the node, the greater its weight, expressed in terms of the CU allocated to the EU. The nodes are arranged from bottom to top according to the semester in which they are taught. The higher the node, the higher the semester number. For example, "Business Processes in the Media Industry," abbreviated as "BizMedia," is taught in the 8th semester of the bachelor's program. EUs taught in the same semester are highlighted in one color e.g. all red nodes are taught in semester 1. The edges between the nodes indicate interdisciplinary connections and are calculated using the formula shown in Fig. 2 in line 18. The user can change the formula to any desired one. The more teaching hours are allocated to the study of a course unit and the more competencies the education units have in common, the greater the weight of the edge between them. If there are no matching competencies, the weight is zero and there is no edge.

Table 2 shows that the calculated summary characteristics are sufficient to make preliminary conclusions. For example: in the curriculum 09.03.02.30 "Information Systems and Technologies" there are a large number of connectivity components (areas in which there is a path between any two vertices). The higher the value, the more heterogeneous the EUs are in terms of their list of competencies. Table 2 also shows other graph characteristics which can help determine the quality of a curriculum during its expert evaluation [17]. The diameter of the graph indicates the dispersion of competencies. The density of the graph and the weight of the skeleton tree indicate the total strength of interdisciplinary connections [11], while the number of unconnected disciplines indicates the dispersion of disciplines in terms of the competencies formed.

[8] https://gephi.org. Accessed September 28, 2025.

A high clustering coefficient indicates that most EUs corresponds to an identical list of competencies. This suggests that the authors of the curriculum did not pay sufficient attention to establishing the correspondence of EUs to the list of competencies they were developing. They may have copied the same data into different cells. In the curriculum 09.03.03.33 "Applied Informatics: Digital Economy," on the contrary, each EU has its own unique list of competencies.

In addition to graphical representation, *SPA-SFU2* calculates data on the number of EUs depending on their type (compulsory, elective, optional) and category (humanities, technical, and natural sciences), as well as how many CU are allocated to their study. The data obtained clearly indicates the specifics of the curriculum depending on the predominance of a certain type of discipline. For example, there may be different ratios of humanities EUs in different curricula in related fields of study, which demonstrates their specificity.

Other data calculated by *SPA-SFU2* includes the percentage distributions of CU allocated to the formation of competency groups (the Federal State Educational Standards for Higher Education[9] define three competency groups: universal, general professional, and professional). They can be used to understand which group of competencies is given priority, as well as how specialized the training program is.

Measures of central tendency are calculated, in order to identify deviations in the curriculum from their average value across the entire curriculum sample for each metric. For each curriculum parameter, *SPA-SFU2* calculates the maximum and minimum values, mode, median, and mean. This enables the most distinctive curriculum to be identified against the background of the others. Table 3 shows the metrics of the graph model of the 2021 bachelor's degree curriculum at the beginning of training, taking into account only the first year of study. As can be seen, only two curricula have elective courses in the first year of study.

[9] https://www.fgosvo.ru/news/view/5720. Accessed September 28, 2025. (In Russ.).

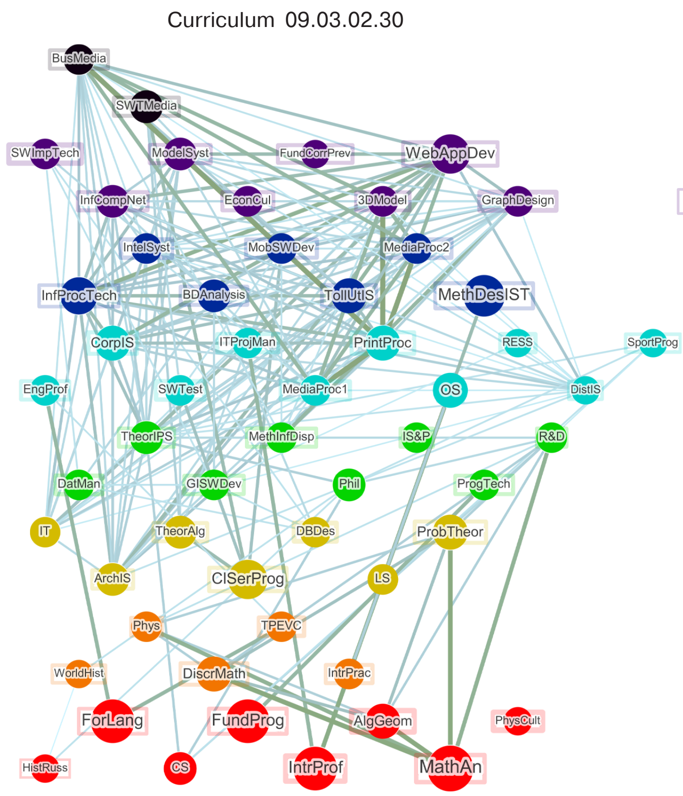

Fig. 5. Visualization of the graph model of the curriculum for all semesters of study.

IntrPrac—Introductory practice;
R&D—Research and development;
IT—Information technologies;
ArchIS—Architecture of IS;
TheorAlg—Theory of algorithms;
DatMan—Data management;
TheorIPS—Theory of information processes and systems;
ClSerProg—Client-server programming;
DBDes—Database design;
EngProf—English for professional purposes;
InfProcTech—Information processing technologies;
CorpIS—Corporate IS;
IntelSyst—Intelligent systems and technologies;
SWImpTech—Software implementation technologies;
SWTest—Software testing and quality control;
GISWDev—Geoinformation systems software development;
ITProjMan—Information technology project management;
BDAnalysis—Big data analysis;
MobSWDev—Mobile software development;
MethInfDisp—Methods and facilities of information display;
InfCompNet—Information and computing networks;
ModelSyst—Process and systems modeling;
TollUtIS—IS tools and utilities;
EconCul—Economic culture and financial competence;
FundCorrPrev—Fundamentals of corruption prevention;
3DModel—3D modeling and animation;
WebAppDev—Web application development;
BusMedia—Business processes in the media industry;
MediaProc1—Media content processing, part 1;
MediaProc2—Media content processing, part 2;
PrintProc—Printing process;
SWTMedia—Media industry software tools;
GraphDesign—Graphic design of the interface;
Phil—Philosophy;
HistRuss—History of Russia;
WorldHist—World history;
ForLang—Foreign language;
LS—Life safety;
Phys—Physics;
CS—Computer science;
FundProg—Fundamentals of programming;
IntrProf—Introduction to professional activity;
AlgGeom—Algebra and geometry;
MathAn—Mathematical analysis;
DiscrMath—Discrete mathematics;
ProbTheor—Probability theory and mathematical statistics;
TPEVC—Theory and practice of effective verbal communication;
ProgTech—Programming technologies;
MethDesIST—Methods and tools for designing ISs and technologies;
OS—Operational systems;
PhysCult—Physical culture and sport;
RESS—Remote Earth sensing systems;
DistIS—Distributed ISs;
SportProg—Sports programming;
EntEcon—Enterprise economics;
DigEcon—Digital economy;
DigBusMod—Digital business models;
BusProcMod—Business process modeling;
DigCont—Digital control;
DigMarkAnalTech—Digital market analysis technologies;
DigEntArch—Digital enterprise architecture;
DynModProdProc—Dynamic modeling of production processes;
DigProd—Digital production;
BusFL—Business foreign language;
DistDBBlockchain—Distributed databases and blockchain technologies;
PractModelOptimBP—Practicum: modeling and optimization of business processes;
DigAssetMan—Digital asset management;
CyberSecur—Cybersecurity;
WebProgDes—Web programming and computer design;
PracDigProdDev—Practicum: digital product development;
BusApp—Business applications;
NetTechInternetThing—Network technologies and the Internet of Things;
TrainingEffComm—Training course: effective communication;
ITSysMonitor—IT systems for monitoring socioeconomic development;
CompSysNetTelecom—Computing systems, networks, and telecommunications;
SysAnalysis—System analysis;
Prog—Programming;
IS&Tech—Information systems and technologies;
AdvMath—Advanced mathematics;
EffComm—Effective communication;
IS&P—Information security and protection;
Law—Law;
ISDes—IS design;
FundProjMan—Fundamentals of project management;
DB—Databases;
MacrEcon—Macroeconomics;
Econometr—Econometrics;
SWDevTech—Software development technology

Table 3. A software-generated table of aggregated data from the 1st year undergraduate curricula

Designation	Quantity of your choice	Maximum rib weight	Minimum rib weight	Graph diameter	Clustering coefficient	1st quartile	2nd quartile	3rd quartile	4th quartile	Unconnected vertices
01.03.04.30	0	0.371	*0.087*	0.371	1.000	9	9	5	1	67
09.03.01.30	0	0.341	0.091	0.614	0.805	3	6	7	7	55
09.03.02.30	0	0.338	0.090	0.338	1.000	2	3	3	0	70
09.03.03.32	0	0.461	0.092	0.461	0.000	3	2	0	2	71
09.03.03.31	0	0.459	0.092	0.459	0.000	3	2	0	2	71
09.03.03.33	0	0.446	0.089	0.692	0.333	4	2	4	7	61
09.03.03.35	0	0.439	0.088	0.439	0.000	3	2	0	2	71
09.03.04.30	0	0.369	0.099	0.591	0.800	2	4	1	5	66
10.03.01.31	0	0.376	0.111	0.376	1.000	*1*	4	2	1	70
15.03.04.32	27	0.766	0.106	0.468	0.917	10	4	13	12	*39*
27.03.03.30	11	0.670	0.089	0.580	0.882	3	3	4	8	60
27.03.04.30	*3*	*0.332*	0.088	*0.331*	1.000	2	4	4	0	68
Median	11	0.439	0.091	0.461	0.882	3	4	4	2	68
Mode	0	–	0.089	–	1.000	3	3	2	2	71
Truncated mean	13.667	0.447	0.094	0.477	0.645	3	3	3	3	64

It can also be noted that for the curriculum 09.03.03.31 "Internet technologies and mobile applications" has a global clustering coefficient of zero (Table 3, column 6 "Clustering coefficient"). This means that no three EUs form the same competence in the first year of study. Columns 8–11 show the quartile distribution of the minimum distances between all pairs of vertices. In fact, all study curricula distances (10 bachelor's curricula) are combined into a single array. They are sorted, and each value is assigned to one of the four quartiles. The first quartile includes pairs of vertices between which there is a relatively small distance in the graph model. The fourth quartile includes pairs of vertices between which there is a relatively large distance. The situation where there is no route between vertices belongs to the "Unconnected vertices" group.

As can be seen in Table 3, minimum and maximum values are determined for each calculated measure, as well as other central trend measures. The percentage of truncation of the mean value is specified in the program configuration file (Fig. 2, line 15). If a dash is indicated in a cell, it means that the value is not informative (for example, if all values are the same or all values are different, the mode value is not indicated). Unique maximum values are highlighted with underlining, minimum values are highlighted in italics. Also, the number of decimal places for all values has been reduced for greater clarity. Table 3 also shows that curriculum 15.03.04.32 "Automation of Technological Processes and Production" (gray row) stands out from the rest, as its metrics most often contain the minimum and maximum values relative to all the bachelor's degree curricula which have been analyzed. Thus, this curriculum does indeed have its own characteristics. For example, it is the only curriculum which teaches "Chemistry" and "Ecology" curricula within all areas of the institute's training in the field of information technology.

A log file is generated (Fig. 6), in order to assist *SPA-SFU2* users in identifying controversial issues in the curriculum filling format. It indicates the elements of curriculum processing and the shortcomings which may arise in the process. For example, by analyzing the errors generated by the log file, curriculum 27.03.04 "Management in Technical Systems" GPC-7 was found to have been formed only on the basis of practices (number 1). These were excluded from the analysis, since the entire set of the curriculum competencies is defined as formed for them.

3. DISCUSSION

Assessing the quality of EPs (for more details on quality, see [18]) in the context of the effectiveness of achieving educational outcomes is a complex, multifaceted task which attracts the attention of both academic researchers and developers of commercial

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Competencies (2) [line 61]: In the curriculum
R:/grad_sfu/2703040030_op-21.plm.plx.xlsx No competencies are specified for the elective discipline with the index B2.E.
- The R:/grad_sfu/2703040030_op-21.plm.plx.xlsx curriculum has been processed with errors.

- No course with the index GPC-7 was found in the R:/grad_sfu/2703040030_op-21.plm.plx.xlsx curriculum ①
```

Fig. 6. Fragment of a log file generated by the application

educational platforms [19]. For example, difficulties may be associated with the ambiguity of EP assessment criteria, in particular, the high variability in the percentage distribution of the labor intensity of forming different groups of competencies at different stages of training.

As an initial stage of EP quality assessment, we propose that the task of studying the curriculum be considered from the point of view of analyzing the composition and structure of the EP. At the same time, traditional methods of curricula evaluating (expert assessments, tabular comparisons) are not as effective as software methods. This is due to the following factors: subjectivity of opinions [20]; the impossibility of analyzing a large number of curricula within a limited time frame; as well as errors in performing the analysis, inter alia. In this regard, the development of software tools to support the analysis of the curriculum, as the first step in assessing the quality of the EP, is a matter of urgency.

We recommended using the software methods presented in this work. They can be expressed in the following actions, for making decisions on curriculum modernization and applying the experience gained in creating new curricula and EPs:

1) preprocessing: converting data into a uniform format for ease of further use and expansion of processing capabilities;
2) processing: extraction from the entire set of data obtained from the *Excel* table Plans IS of the data necessary for further analysis of the characteristics of interest to the researcher;
3) analysis: calculation of aggregated data based on data obtained during processing, e.g., data that clearly indicates the characteristics of the curriculum;
4) visualization: displaying data obtained during analysis in a form that is convenient for the researcher to use for quick and accurate decision-making based on that data [21].

Let us consider the problems of implementing such software tools, related to refining the characteristics of the curricula, calibrating them based on expert opinion, and determining their relationship with other characteristics of the EP training. This includes such factors as student retention, and graduate employment rates, among others.

The software methods proposed in this work are useful for solving the above-described problems and contribute to the development of automated tools for data-driven decision-making.

CONCLUSIONS

The study proposes software methods for processing, analyzing, and visualization of the curricula, implemented in the *SPA-SFU2* software package. The package helps curricula to be compared with minimal effort. It helps their characteristics to be determined based on numerical indicators, and the reasons for significant deviations of these indicators from the average value to be established. *SPA-SFU2* clearly indicates problem areas in the curriculum for decision-making on their correction. It helps to identify possible shortcomings in the curriculum, understand the resulting competence component, and determine the implicit patterns in the data contained therein.

Visualization of the curriculum using *SPA-SFU2* enables a faster and more accurate understanding of the internal structure of the curriculum and its characteristic differences. *SPA-SFU2* can be useful when demonstrating the characteristics of the curriculum to applicants, students, and teachers. For example, it can be used to demonstrate the percentage distribution into competency groups or to visualize the interrelationships of the EU through graph representation.

SPA-SFU2 can be used to create new curricula which optimize the planned educational process, the formation of which is based on a comparative analysis with the other educational curricula in related areas of training, thus ensuring their uniqueness and effectiveness.

The *SPA-SFU2* software package for curricula analyzing is a necessary link for developing a comprehensive educational analytics IS and can serve as an element of the university's digital ecosystem.

At the present time, the *SPA-SFU2* software package presented in this study is not fully automated. It requires expert opinion to make decisions based on the characteristics it obtains. This problem could be addressed by incorporating artificial intelligence modeling approaches into *SPA-SFU2*. This could be achieved by using neural networks or simulating artificial intelligence by accumulating behavioral scenarios in predefined situations.

In the future, the following tasks in this specified order need to be addressed, in order to fully automate the processing, analysis and visualization of the curricula, as well as to better cover their useful characteristics:

1) to obtain and compare information external to the EP (for example, data on student performance, survey results, and information on graduate employment) with the characteristics of the curricula obtained and calculated by *SPA-SFU2*;
2) to introduce the complex digital solutions based on the principles of artificial intelligence and big data processing;
3) to find other ways to visualize the curriculum characteristics, in order to demonstrate their features not presented in the study.

Authors' contributions

E.A. Khalturin—methodology, original draft preparation, review and editing, presenting software methods.

A.A. Kytmanov—supervision, conceptualization writing, research problem, original draft preparation and editing.

Yu.V. Vaynshteyn—discussion, editing.

T.V. Zykova—formal analysis, practical application.

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