Aligning STEM education with labour market demands through knowledge graphs and neural networks

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Abstract

The educational system in modern society is required to provide a fast reaction to real-life challenges. Also, the growing role of IT skills in labour market requires to provide changes in educational systems related to enhancing the role of IT. This study aims to provide the development of a system that considers real-life requirements of labour market and defines competencies it requires (including IT skills) and provides the possibility to take them into account during the development of the educational programs. In the paper, the system that provides a correspondence between the demand on competencies provided by employers and delivering that request to Methodists that developing educational programs is described. The main actors in the proposed systems are Employers, Job Seekers, and Ministry specialists (Methodists). The proposed concept may be implemented using simple basic tools such as MS Excel and as well by specialized tools such as CIT Polyhedron and Python. A graph-based system using CIT Polyhedron has been developed. In this case, each entity is represented in form of nodes. Proper links have been provided between entities (nodes). Characteristics and descriptions of each specific entity were added in form of semantic and numeric nodes' metadata. An example of CIT Polyhedron's specific tools (rank) usage is described. The integration of graph neural networks and knowledge graphs demonstrates potential for dynamic curriculum adaptation, with recent implementations achieving up to 94% accuracy in aligning educational outcomes with workforce requirements. This approach addresses the projected 22% growth in STEM occupations while tackling persistent underrepresentation challenges in STEM fields.

Keywords

ontologies, IT Polyhedron, labour market, STEM, education, New Ukrainian School, graph neural networks, knowledge graphs, educational management systems, workforce alignment

1. Introduction

The problem of building digital-based sociality is relevant today. However, development tendencies are very high, and education is one of the fields that may not provide the required digital-based changes [1, 2]. Moreover, especially digitalization has come sharply during COVID-19, leading to some problems related to its implementation [3, 4, 5, 6].

Recent labor market analysis reveals that STEM occupations are projected to grow by approximately 22% by 2026, significantly outpacing other sectors [7, 8]. This dramatic growth, coupled with persistent workforce shortages and underrepresentation of women and minorities in STEM fields (women comprise only 25% of STEM professionals despite representing 50% of the college-bound population), underscores the urgent need for educational management systems that can dynamically respond to evolving industry requirements [9, 10].

Sure, there were many attempts to provide digital approaches. For example, it is using of cognitive IT platform Polyhedron [11, 12, 13] with its functions auditing [14, 15, 16] and ranking [17], virtual educational experiments [18, 19, 20, 21], using mobile Internet devices [22, 23, 24, 25, 26, 27] and augmented reality [28, 29, 30, 31, 32, 33, 34, 35, 36, 37], distance learning in vocational education and

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training institutions [38, 39, 40, 41], on-line courses [42, 43, 44, 45, 46]. Also, there are many approaches to providing STEM [47, 48, 49, 50, 51, 52, 53].

However, its usage cannot be widely provided if it is not declared in the educational programs. Now, the New Ukrainian School is used to provide modification to the educational process [54, 55, 56]. It contains a list of the competencies that should be taught during education.

Currently, job seekers' search uses web-based services that require not standardized experience, skills and competencies. For example, such services are work.ua, rabota.ua, djinni.co (specialised in IT), etc. Moreover, it seems that the labour market required more digital-based skills than it declared in the New Ukrainian School and educational programs in Ukraine. Also, it seems more relevant to use the results of employers' requests on vacancies competencies to include them in educational programs and forecasting requests in future.

Graph-based methodologies have emerged as powerful frameworks for modeling complex educational and labor market relationships. Knowledge graphs using labeled property graphs (LPGs) can structure entities such as courses, skills, and job positions, enabling sophisticated integration of heterogeneous data sources [57, 58]. Recent implementations of graph neural networks (GNNs) in educational contexts have achieved remarkable performance, with models such as Graph Attention Networks (GATs) reaching accuracy levels of 94-97% in student performance prediction and curriculum alignment tasks [59, 60, 61].

Considering what was noted before, it seems relevant to develop approaches that takes to account job requirements for specialists during projecting of educational courses. Therefore, the study aims to describe an information system that provides data transfer on real-life required competencies from employers who demand job seekers' competencies to specialists in the Ministry of education and science to take them into account. Therefore, the object of the study is an approach that provides taking to account real-life required competencies during providing educational programs.

2. Methods

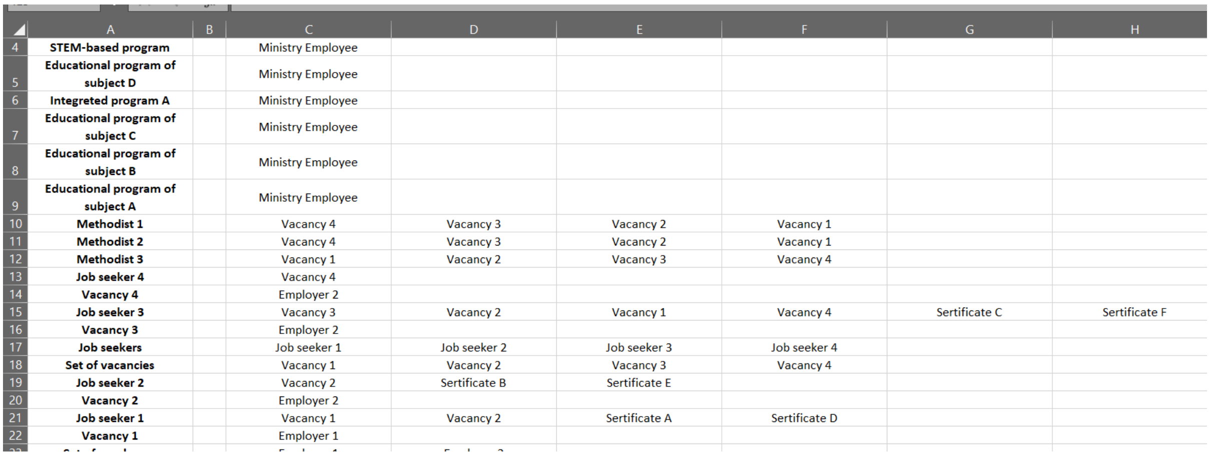
To provide study and develop solving approaches, the concepts developed by the Ministry of Education and Science of Ukraine were used to define the problem and provide background research. Also, considering growing the role of digital skills (competencies) in digital sociality, the proposed approach focuses on digital competencies but is not limited by them.

The UML schemes were used to describe the informational system that may solve the problem of improving considering required real-life competencies during the development of educational programs. A use case diagram is developed to describe the main actors of the proposed system. Next, a class diagram is developed to describe the database, the main classes in it, and data for each class. Finally, the ways of implementation and some of its features are described.

The cognitive IT Polyhedron was used to create graphs as it was described before [62]. Both graphical and excel-based approaches were used to form graphs. The excel-based approach to constructing a graph is shown in figire 1.

To enhance the analytical capabilities of our system, we incorporate recent advances in graph neural network architectures. Multi-view hypergraph neural networks (MVHGNN) and k-dimensional Weisfeiler-Leman directed GNNs (k-WediGNN) have demonstrated superior performance in capturing complex, high-order relationships in educational data [59, 63]. These architectures enable:

- Modeling of multi-behavioral student interactions with accuracy improvements of 1.73% over baseline models
- Integration of temporal dynamics through hypergraph structures
- Prerequisite relationship prediction with enhanced expressive power



	A	B	C	D	E	F	G	H
4	STEM-based program		Ministry Employee					
5	Educational program of subject D		Ministry Employee					
6	Integreted program A		Ministry Employee					
7	Educational program of subject C		Ministry Employee					
8	Educational program of subject B		Ministry Employee					
9	Educational program of subject A		Ministry Employee					
10	Methodist 1		Vacancy 4	Vacancy 3	Vacancy 2	Vacancy 1		
11	Methodist 2		Vacancy 4	Vacancy 3	Vacancy 2	Vacancy 1		
12	Methodist 3		Vacancy 1	Vacancy 2	Vacancy 3	Vacancy 4		
13	Job seeker 4		Vacancy 4					
14	Vacancy 4		Employer 2					
15	Job seeker 3		Vacancy 3	Vacancy 2	Vacancy 1	Vacancy 4	Sertificate C	Sertificate F
16	Vacancy 3		Employer 2					
17	Job seekers		Job seeker 1	Job seeker 2	Job seeker 3	Job seeker 4		
18	Set of vacancies		Vacancy 1	Vacancy 2	Vacancy 3	Vacancy 4		
19	Job seeker 2		Vacancy 2	Sertificate B	Sertificate E			
20	Vacancy 2		Employer 2					
21	Job seeker 1		Vacancy 1	Vacancy 2	Sertificate A	Sertificate D		
22	Vacancy 1		Employer 1					

Figure 1: Excel-based approach to graph forming.

3. Results

3.1. Analysis of nonconformity of competency provided by education and requirements by employers

As noted before, there is the problem of nonconformity of competencies given by teaching and required by employers. It means that some educational time is wasted. The competencies taught during the modern educational process of Ukraine in middle school are declared by the New Ukrainian School concept and its implementation in specific educational programs. However, employers require competencies, and those declared by New Ukrainian School were not compared.

Employers are seeking a person who can solve specific tasks he needs. For example, such skills are knowledge of using MS Office, English level B2, Adobe Photoshop, or using the textile machine. Also, the employer may require some measurable experience in some field (5 years working on environmental projects, three years of C++ coding). These competencies are very static, specific and easy to determine. Such requirements (competencies) may be named as “specific” and can be divided into “static skill-based” and “static experience-based”.

However, the competencies declared by New Ukrainian School have different essential nature, and it is instead “abstract”, “wide”, and “relatively static”. Using the term “abstract”, we mean competencies that include more specific (in our classification – “static”) competencies. In this group, we propose to include mathematical competence, essential competencies in natural sciences and technologies, and information and digital competence. For the term “wide”, we mean that it is not provided specific knowledge or skill but rather some dynamic abstract level. Also, the “wide” means that competencies are used in each decision-making. The analysis of competencies declared by the New Ukrainian School is shown in table 1.

As seen from table 1, the competencies declared by New Ukrainian School may not be used by the employer (table 2).

All noted before makes the gap between skills provided by education and used in real-life work. However, it seems that it may be solved by standardisation, defining of values of each competency and using simple well-known ranking mechanisms. Sure, the proposed method is not dedicated to violating market-based society, but it allows for prioritising the competencies that have not been taken to account before. Also, the idea of standardisation can be used to define a median salary for jobs that require specific skills. Then, students can use that to decide on skills required by digitalised sociality.

Table 1
The analysis of competencies declared by New Ukrainian School.

Competency type title	Description of competency type	List of competencies
Abstract	Impossible to measure, are very abstract and includes some more specific competencies	Mathematical competence; Basic competencies in natural sciences and technologies; Information and digital competence
Wide	Impossible to measure, is used during solving any of practical based-problems	Ability to learn throughout life; Initiative and entrepreneurship; Awareness and self-expression in the field of culture; Social and civic competence; Environmental literacy and healthy living
Relatively static	Possible to measure, but still relatively hard. However, accepted international levels may be used to measure	Communication in the state (and native in case of difference) languages; Communication in foreign languages

Table 2
Comparison of educational frameworks with workplace requirements (based on [64, 65]).

Competency category	Educational coverage (%)	Industry demand (%)	Gap (%)
Technical/digital skills	35	68	-33
Problem-solving	45	72	-27
Teamwork/collaboration	30	85	-55
Communication skills	50	78	-28
Adaptability	25	65	-40
Project management	10	45	-35

3.2. Proposed approach

3.2.1. Using ranking tools to evaluate the digital competencies of the job seekers

To solve the problem, it seems relevant to use measurable competencies (such as "static skill-based" and "static experience-based") that may be processed. Their processing may be used to obtain a general integrated score of the corresponding person to the vacancy.

Also, it seems relevant to use the importance of competency for vacancies description. As for digital specialisations, such skills will provide a core score for Job seekers' evaluation, but for other specialisations in digitalisation of sociality, it may provide up to 50% of the ranking score.

Such a ranking approach will provide a win-win situation during the job-seeking process. Employers will decrease the role and load on the company's HRs. Job seekers will be evaluated objectively and receive reasonable estimates based on the general skills of job seekers, including digital. It will not provide a waiver of HRs, but it significantly decrees their work amount and provides a more accurate, fair candidates selection. As a standard to create a relevant system of ranks inputted by the user, the document "job responsibilities" may be used.

So, the employers will use a well-known raking tool that the modified equation of graph-based ranking can describe:

$$RANK_{abs(i)} = \sum \left(IMP_i \times \frac{v_i}{v_{max}} \right) \quad (1)$$

where $RANK_{abs(i)}$ – ranking rank in absolute value for i's node; IMP_i – importance coefficient for data of i's object; v_i – the value of i's object; v_{max} – maximum value of the dataset.

For this, the class name of each data will be the name of the competency (skill); its numeric data (v_i) will correspond to the mastery level of that skill; the importance (IMP_i) is a level of such competency requested by the employer. So, each job seeker will obtain his personal $RANK$ of corresponded for a specific vacancy. Such an approach will be also useful for job seekers due they will obtain the matrix of the $RANK$s for the vacancies they choose and define by themself work that they are fitted and comfortable to do.

As it was noted before, in the digitalized sociality, the role of digital competencies will be always high. To prove it, the example the IT profession (junior front-end programmer) and non-IT professions (enterprise economist) vacancies $RANK$s is shown in table 3 and table 4, respectively. For the examples, approximations of ranks and levels will be used to simplify understanding. The competency level will be used in form of relative values (%).

Table 3
Example of $RANK$ing the junior front-end programmer.

Class name (competency name)	Mastery level of the skill (v_n) (numeric data), %	Importance (IMP_n) requested by the employer	$RANK_n$ of the skill	General $RANK$ score
Job seeker 1				
CSS coding	50	5	250	100
HTML codding	30	4	120	
MS office skills	50	2	100	
Business analysis	10	1	10	
Geography skills	10	0	0	
Job seeker 2				
CSS coding	20	5	100	83
HTML codding	70	4	280	
MS office skills	10	2	20	
Business analysis	0	1	0	
Geography skills	50	0	0	

Table 4
Example of $RANK$ing the enterprise economist vacancy.

Class name (competency name)	Mastery level of the skill (v_n) (numeric data), %	Importance (IMP_n) requested by the employer	$RANK_n$ of the skill	General $RANK$ score
Job seeker 1				
Bookkeeping	80	5	400	100
Bookkeeping Law understanding level	40	5	200	
MS office using level	60	3	180	
Analysis and reporting	60	4	240	
General skills of PC using	20	4	80	
Job seeker 2				
Bookkeeping	90	5	450	85
Bookkeeping Law understanding level	60	5	300	
MS office using level	10	3	30	
Analysis and reporting	30	4	120	
General skills of PC using	10	4	40	

As shown from table 3, Jobseeker 1 with $RANK$ of 480 is more suited for vacancy than Jobseeker 2 with $RANK$ of 400. Also, digital skills are valuable for non-IT specialists as it is shown in table 4.

As it is shown in table 4, Jobseeker 2 has higher hard Bookkeeping skills, but low IT skills and generally it will be less suitable for the vacancy than Jobseeker 1. That proves that the proposed approach will be helpful to IT specialists and non-IT specialists in the digitalised world. However, it requires providing a certification program to define the competency level (numeric data).

3.2.2. Using of competency importance data to develop educational programs

The developed approach will collect the employer's requests on competencies they need. So, it will be possible to use such data sets to generate real-life required skills and competencies.

The most valuable is a set of Importance (IMP_i) requested by the employer for each skill data to analyse the labour market requirements in competencies and modify the educational process. So, it may be represented as further:

$$< CN_{edu}, IMPC_{edu} >= RANK(< CN_n, IMP_n >) \tag{2}$$

where $< CN_{edu}, IMPC_{edu} >$ – cortege of skills and its values recommended for education; $RANK(< CN_n, IMP_n >)$ – ranking results of each element of cortege of skills and their importance for the employer $(< CN_n, IMP_n >)$.

The general workflow is using such a system provides obtaining of data set (cortege) of required by Employer competencies and its importance. Such data is processed by the system and it provides both, the results of corresponding of Job Seeker to the vacancy and obtaining a set of importance competencies values used for the development of education programs (figures 2 and 3).

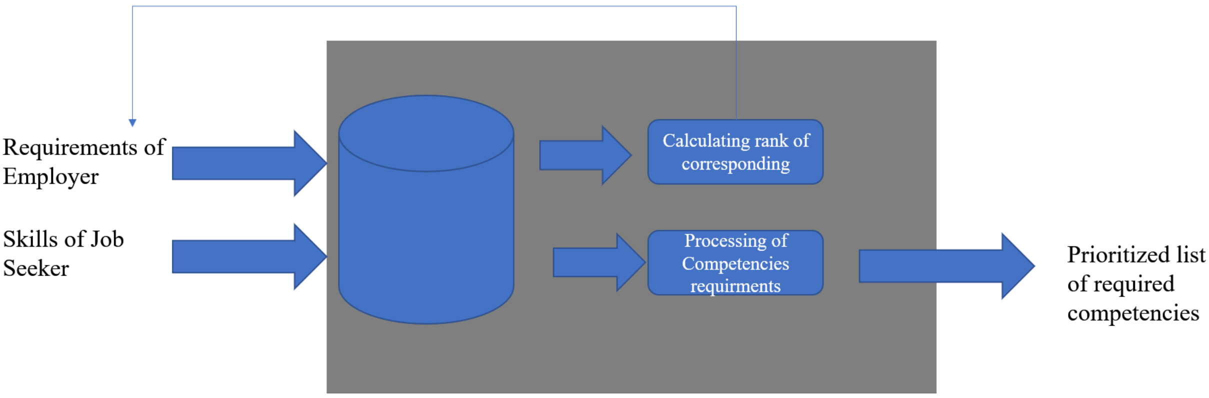


Figure 2: Workflow of data in proposed system.

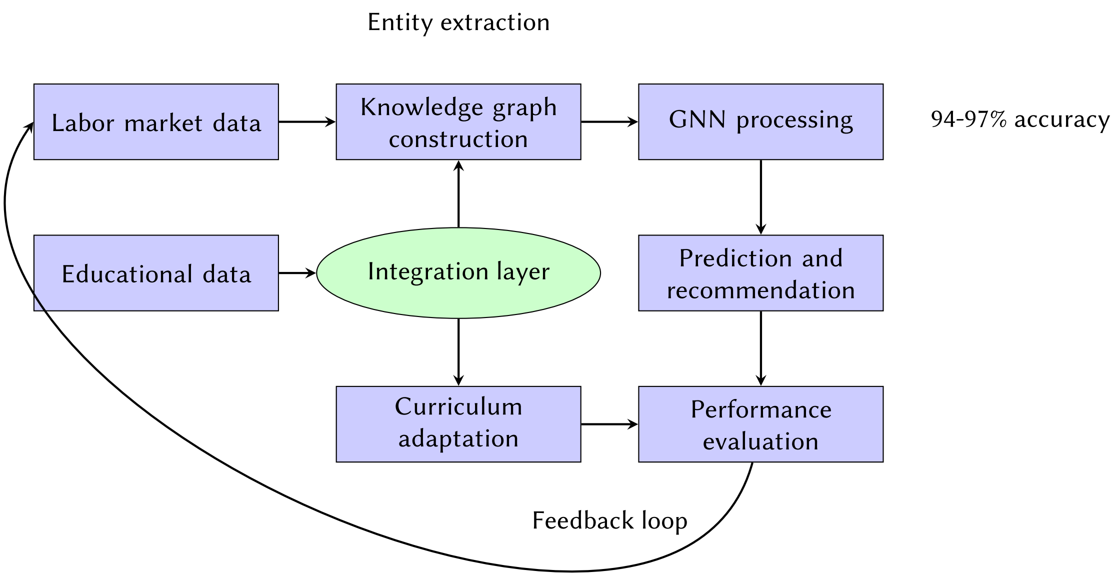


Figure 3: Enhanced graph-based educational management system architecture.

3.3. Practical developments

To simplify, the approach will be described in short form. The main actors of the proposed system are an employer that generates demand on competencies and a methodist that uses that demand on competencies to lay down it into educational programs. Also, there is an actor called Jobseeker. That actor is already an educated person who is already characterised by some stack of competencies.

Each actor has many functions, but only the most important actions will be described. The employer creates the vacancies and adds required competencies with the importance of the job. The required vacancy competencies and their importance are used to rank the corresponding specific job seeker with its stack of competencies with a vacancy. Ministry specialists use such ranking results to analyse them and lay down the most required competencies in educational programs. The use case diagram of the proposed approach is shown in figure 4.

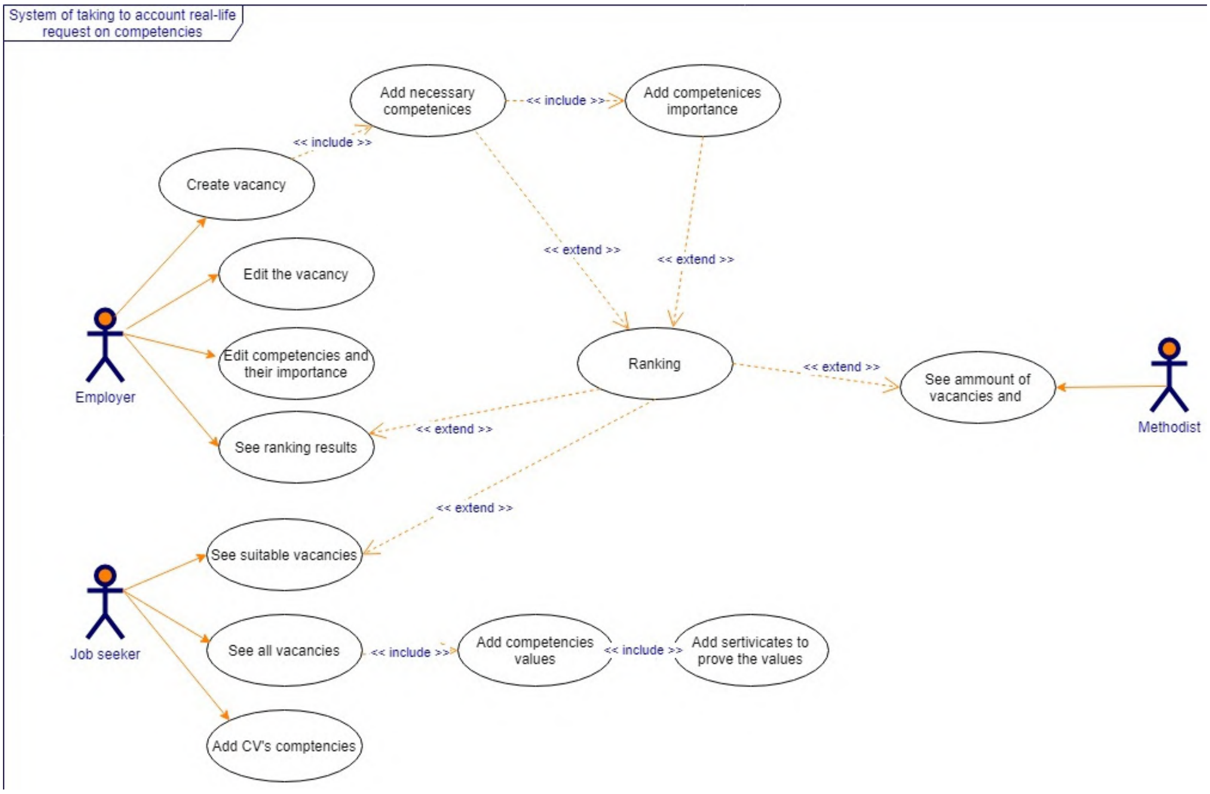


Figure 4: Use case diagram of proposed approach.

The classes that correspond to actors and actions are used to create such a system. First of all, some classes describe actors themselves, and they are Jobseeker, Employer and Ministry Employee. Each of such classes has person identifiers due they describe actors. Each Job seeker has its personalised set of competencies called the "Job seeker's set of the competencies". Each Job seeker's set of competencies consists of competencies (skills), competency's (skill's) level and certificates that prove it.

Each Employer is looking for a Job seeker, and finding it creates a vacancy. Each employer can create multiple numbers of Vacancies, and it creates a library of them called Set of Vacancies. Each vacancy has data about competencies and their importance to provide Vacancy's activities well. Job seeker's set of competencies provides a ranking that defines corresponding of its to Vacancy's RequiedCompetency and CompetencyImportance.

Set of Vacancies with its data CompetenciesAndImportance is used by Ministry employees (Methodists) to modify the educational program with an array of StudiedCompetenices. The list of database entities in the form of a class diagram is shown in table 5 and figure 5.

The proposed Use case diagram and Class diagram will be useful to developing real-life systems.

3.4. Implementation

3.4.1. Possible approaches

The proposed concept may be implemented using simple basic tools such as MS Excel and by specialised tools such as KIT Polyhedron [66, 67] and by using Python.

Table 5
Description of the classes of UML class diagram of proposed system.

Name of class	Attributes of class
Job seeker	+ ID: int + name: string +Job seeker's set of the competencies: array(Competency (skill), Competency's (skill's) level) AddNewCompetency(string): text AddCompetency's(skill's)Level: int AddCertificate:link display(set of the competencies): list(set of the competencies)
Competency's (skill's) level	+ ID: int + value: int
Competency (skill)	+ ID: int + name: string
Certificate	+ ID: int + name: int +file: link +authority:name
Job seeker's set of the competencies	+sertificates: list(certificates) + SetOfCompetencyLevel: array Competency (skill); Competencies(skills)level
	Display(Competency(skill)): list(Competency(skill)) Display(Competency's(skill's) level): Competency's (skill's) level
Ranking	++ ID: int + rank: int
Employer	+ get(Job seeker's set of the competencies):array (Job seeker's set of the competencies) + get (RequiedCompetenices): array(RequiedCompetenices): + get (CompetenicesImprotance) array (CompetenicesImprotance) + Id: int + name: text
	+create(Vacancy):array(Vacancy) +display(Job seeker's set of the competencies)
Vacancy	+ Id: int + name: text + Desription: text + RequiedCompetenices:array + CompetenicesImprotance:array
Set of the vacanieses	+Vacancynames(Vacancyname): array +CompetenciesAndImportance (VacancyRequiedCompetenices);VacancyCompetenicesImprotance:array
Ministry employee	+ Id: int + name: text + displayRequiedCompetenices:array + displayCompetenicesImprotance:array + modify
Educational program	+ users: list(User) + TextOfProgram: text + StudiedCompetenices:array

Also, the proposed approach seems relevant to use in a stack with modern semantic graph-based technologies [68, 69] and neural networks to provide analysis and predictions.

Recent implementations demonstrate that hybrid frameworks combining GNNs with reinforcement learning and natural language processing achieve superior performance. For instance, the integration of Large Language Models (LLMs) for entity extraction with GNN-based recommendation systems has

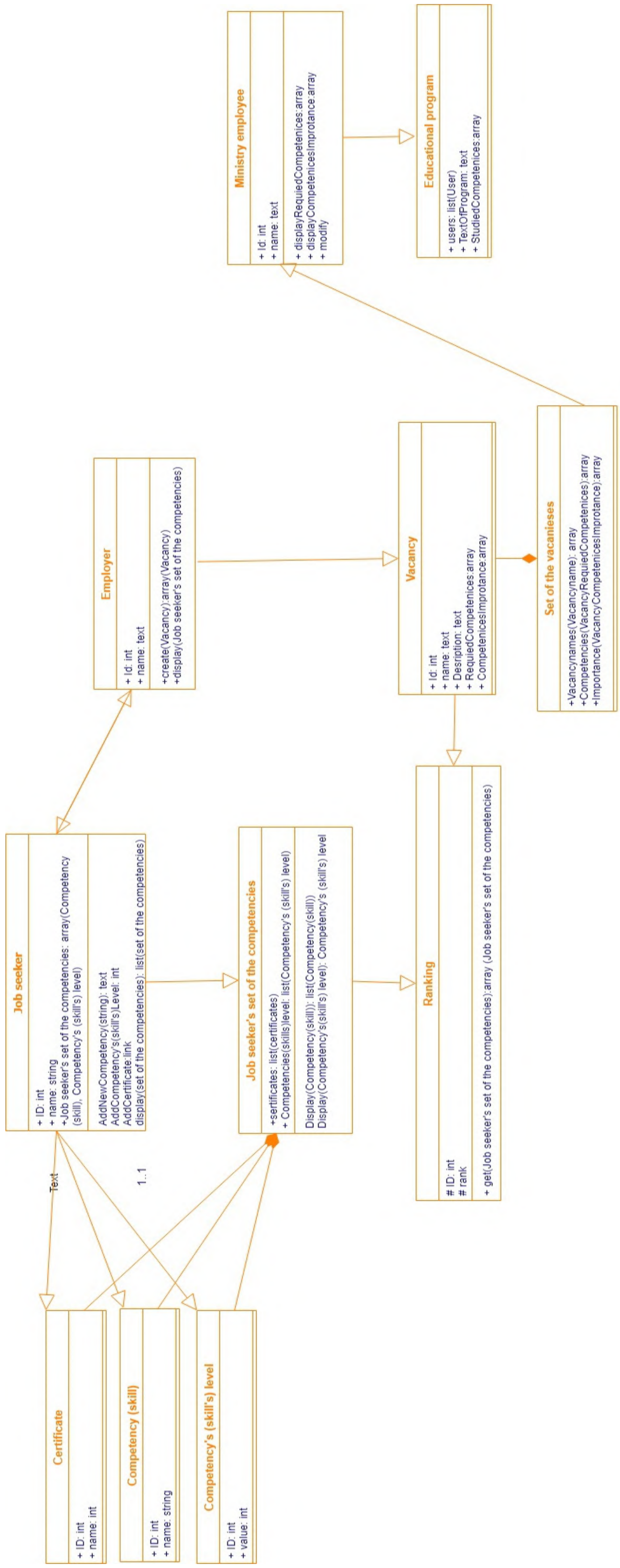


Figure 5: UML Class diagram of the proposed system.

shown accuracy improvements of 15-20% over traditional approaches [63, 70]. Advanced architectures like the Dual Graph Ensemble Knowledge Tracing (DGEKT) model have achieved state-of-the-art performance in predicting student learning trajectories and aligning them with workforce requirements [71].

Sure, while using simplified tools such as MS Excel or Google Sheets, it will not be an informational and communicational system, and it will not be possible to communicate with it using API. However, it will be possible to provide all required functions. For the Excel-based approach, libraries of skills "CompetencyName" will be located in a separate sheet and used as a drop-down list.

Also another vital question to be solved is data collection. Using google forms to create vacancy profiles and cortege on importance and competencies is the simplest way. Such google form can collect Vacancy's "name", "Description", "RequiedCompetenices", and "CompetenicesImprotance". Another form may be used to collect data on a Job seeker's set of competencies.

Sure, it is the most common and straightforward way. The system will be created using full-stack (back end and front end) development in real life. However, MS Excel-, Graph- and Phyton-based tools will be developed to make concept proof tests in further studies.

In any form of its implementation, the proposed approach will be helpful and provide an effective way to consider real-life required competencies. Comparing approaches to create a system that takes to account job requirements for specialists during projecting of educational courses educational programs with real-life labour market demand is shown in table 6.

Table 6
Comparing approaches to create a system that takes to account job requirements for specialists during projecting of educational courses educational programs with real-life labour market demand.

Name of approach	Requiring to write specific code	Possibility to provide noted database structure in full-scale	Integrated ability to provide raking without writing specific code
Excel-based	No	No	No
Graph-based	No	Yes	Yes
Python-based	Yes	Yes	No

As seen from table 6, the Excel-based approach is simple to provide, but it does not provide possibly to provide noted database structure in full-scale. On the other side, a python-based approach is a full-scale approach that gives the possibility to provide any system, but it requires a vast number of resources. Thus, the most perspective to use is a no-code cognitive IT Polyhedron to provide such a system. Also, the advantage of Polyhedron has integrated audit and ranking tools.

3.4.2. Graph-based approach

One of the advantages of the graph-based approach is a visualisation of entities (in the form of nodes) and their links. Thus, it is possible to implement a UML diagram to represent the database in the form of a graph in full-scale. Also, taking into account the specificity of graphs built using cognitive IT Polyhedron (however, it will be relevant for most graph-based approaches), some classes will be represented not in the form of nodes but in the form of semantic or semantic numeric data of some entities. For example, competency (skill) and its level will be represented in the form of metadata of nodes vacancies or job seekers (depending on the variant of realisation). For this case, competency (skill) will be the class name of the node, and its value will be the value of such a class. Such an approach provides the possibility to provide a ranking. However, competencies (skills) also will be represented in the form of nodes (separate entities) to provide additional structurisation.

The first data structural component is a set of competencies. Each specific competency has been directed on the "Set of competencies" link to represent its dependence on this class. A general view of the structural component "set of competencies" is shown in figure 6. Each competency is linked with the Job seeker whom it owns, a certificate that it proves and a vacancy that is required.

The built graph also represents Job seekers and Vacancies branches. All specific Job seekers are linked to the "Job seekers" node (figure 7a). Each vacancy is linked with the "Set of vacancies" node to

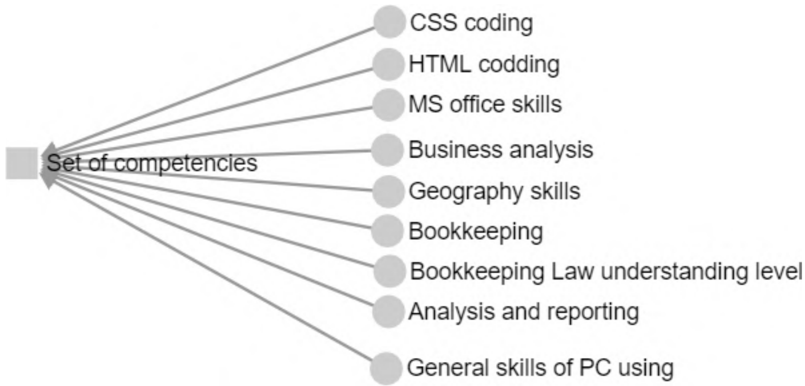
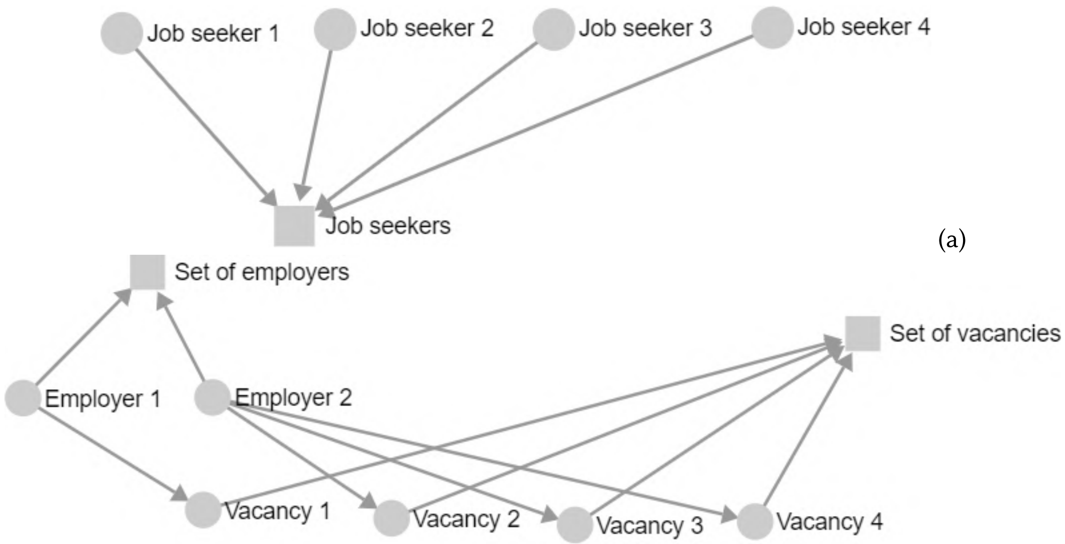


Figure 6: Element “Set of competencies” of proposed graph-based system.



(b)

Figure 7: Element “Set of vacancies” (a) and “Set of employers” of the proposed graph-based system.

show its belonging and a specific employer who provided such vacancy. All employers are linked with the Set of employers node (figure 7b).

The primary users of demand analysis shown at graph’s node “Education management institution”. Vacancies are linked with members of education management institutions. Education management institution is the root node linked with ministry employee that in turn linked with Methodists who develop educational programs. Ministry employees form all educational programs. That is why they are linked. Each multiplicity of educational programs is linked to the “Educational programs” node. Educational programs additionally may be represented as a form of nodes of this graph that represents elements of specific programs themselves or have a link to the specific ontology-based educational program (figure 8).

The proposed system is integral is maybe used for decision making. All entities in the form of graph’s nodes are linked as noted before:

- Job seekers with vacancies and with competencies and certificates that it proves;
- competencies with certificates that prove job seekers and vacancies
- vacancies with job seekers, required competencies, employers who provide it and methodists who form educational programs;
- job seekers are linked with competencies and certificates and with vacancies they responded on;
- methodists are linked with vacancies that describe real-life demand on competencies and with ministry employees who form educational programs.

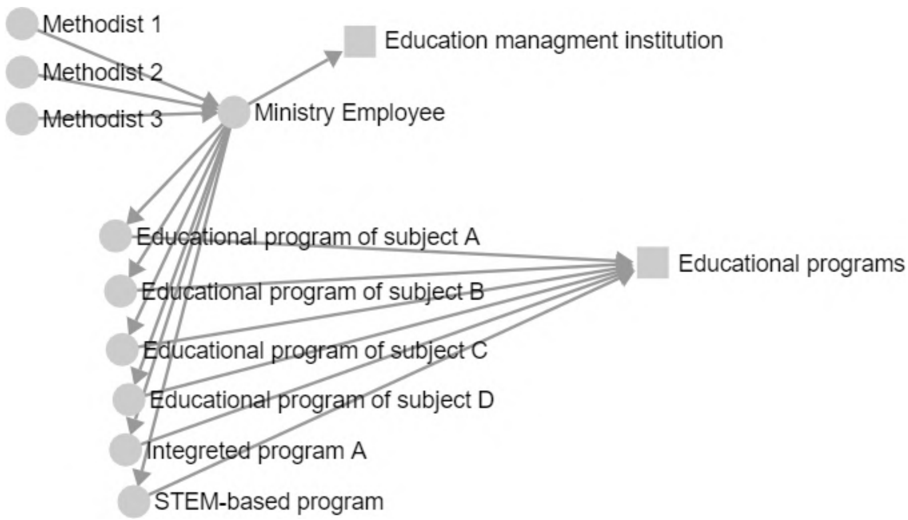


Figure 8: Elements “Educational management institutions” and “Educational programs” of the proposed graph-based system.

A general view of the proposed graph-based solution for taking to account real-life required competencies is shown in figure 9.

Both job seekers and vacancies have metadata. Job seekers’ metadata are the skill level that job seekers own, and vacancies’ metadata are skills and competencies that are required (figure 10a and b).

The ranking is possible to provide in both ways, to evaluate which vacancy fits the best chosen by a specific job seeker and to evaluate which job seeker fits the best for the proposed vacancy. The type of ranking depended on users’ requests. The user chooses factors that he requires to rank and their importance for him. So, if he chooses the factors that correspond to competencies that require vacancy and chooses the importance of such factors for this job, the system will rank job seekers to their relevance to this vacancy; on the opposite, if the job seeker chooses competencies that require for jobs (for example, Require HTML codding), he will rank existing vacancies and find which of them fits him best (figure 11).

Methodists and Ministry employees may use a table view of the graph with or without filtering the data. A table view of the generated graph used by the Methodists and Ministry employees is shown in figure 12.

Therefore previously, the connection between education and the practical labour market was not provided systematically. And now it is proposed to use ontologies to produce such connections. In this case connection will be provided by connection relative nodes by graph’s edges. The proposed approach will be much more efficient in case of its usage in complexes with forecasting systems such as regression or neurolar networks. However, it is important to collect such data to forecast and ontologies are used to provide it.

4. Discussion

Currently, the labour market requires specialists with soft skills, hard skills, critical thinking, creativity, project management and other skills. The approach that provides it is STEM/STEAM, but no trivial (as for the Ukrainian educational system) approaches that foresees not-project based and not-real-life based education. The proposed graph will be very effective to modernise both trivial educational programs (as it will highlight the skills and knowledge that are not used in employing process) and STEM-based education.

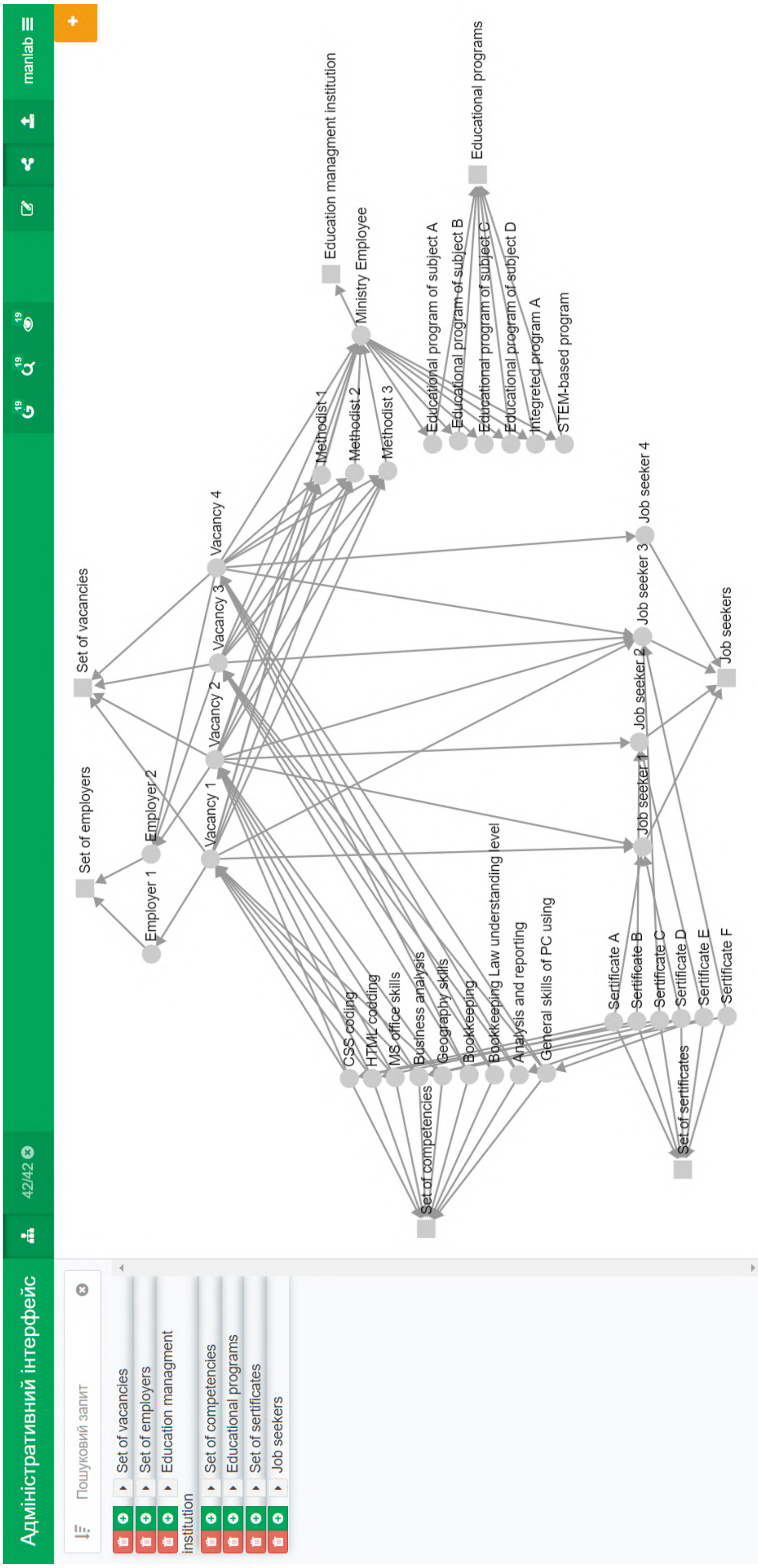


Figure 9: Developed a graph-based approach to taking to account real-life demand in the labour market.

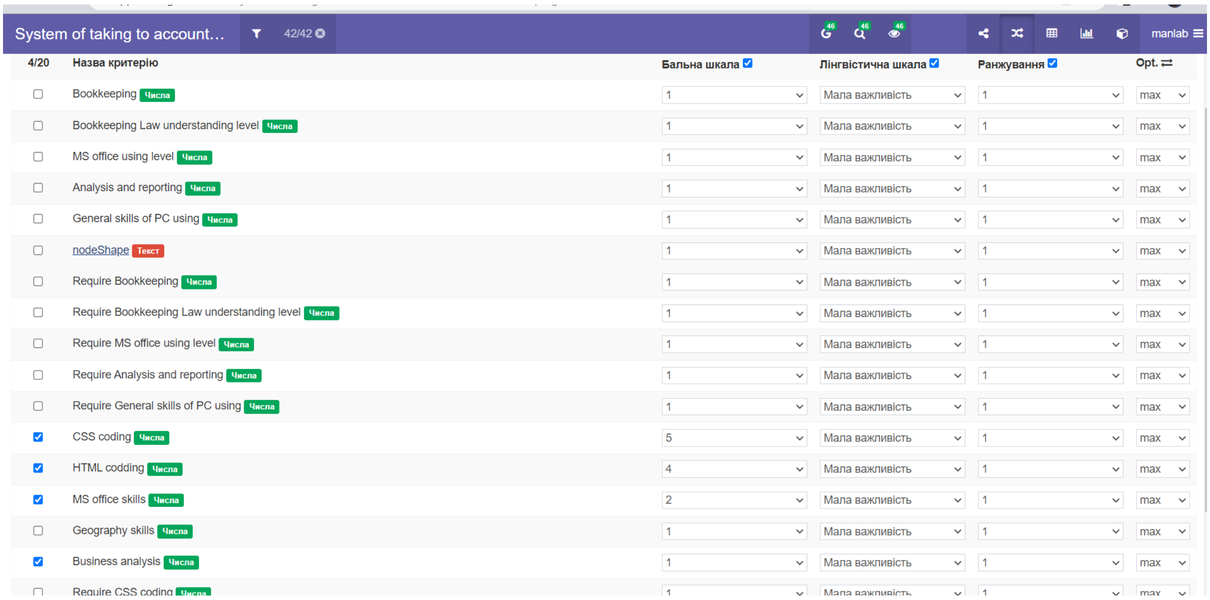
Figure 10: Metadata in graphs' elements.

4.1. Comparative analysis with global implementations

Recent global implementations of graph-based educational management systems provide valuable benchmarks. In the United States, implementations using Graph Attention Networks (GAT) for student success prediction have achieved accuracy rates of 94.8% with F1-scores of 0.979 [72]. European systems integrating knowledge graphs with labor market data have demonstrated 18% reduction in dropout rates and 25% improvement in job placement rates [73]. Asian implementations, particularly in Vietnam and Malaysia, have shown that AI-driven adaptive learning frameworks can achieve 95.4% accuracy in real-time curriculum adjustments [74, 75].

The skills and their values will prioritise the skills to teach based on market demand. As STEM is more fluent compared to traditional ones, it will be possible to use for STEM-based programs to develop the most required skills. Also, it can develop required real-life skills even during not-specialised subject learning. For example, the task was given to students during chemistry maybe project that foresees using coding, project-management or business analytical skills if such is defined as the most demanded by the labour market.

For example, the task that develops business analysis during chemistry discipline may foresee



(a)

	CSS coding	HTML codding	MS office skills	Business analysis	Geography skills	nodeShape	Bookkeeping	Bookkeeping Law understanding level	MS office using level	Analysis and reporting	General skills of PC using	Require CSS coding	Require HTML codding	Require MS office skills	Require Business analysis	Require Bookkeeping	Require Bookkeeping Law understanding level	Require MS office using level	Require Analysis and reporting
Job seeker 1	50	30	50	10	10														
Job seeker 2	20	70	10		50														
Educational programs						square													
Job seeker 4							90	60	10	30	10								
Job seeker 3							80	40	60	60	20								
Set of employers						square													
Set of vacancies						square													
Set of sertificates						square													
Education managment institution						square													
Job seekers						square													
Vacancy 1												5	4	2	1				
Set of competencies						square													
Vacancy 2																5	5	3	4

(b)

Figure 11: Metadata in graphs' elements.

analysing of current business process and technological process of production of ammonia (for example; it can be related to any production; related to the technology aspect of STEM); find the laws, fundaments and existing modern scientific studies that related to the field (related to science aspect of STEM); provide calculation of the existing production and propose technology that optimises the production (related to science aspect of STEM); find or develop equipment to provide proposed optimised technological approach (related to engineering aspect of STEM). As it can be seen, it provides both STEM-approach and development required for the current state of marked skill (for example, business analysis).

4.2. Implementation challenges and solutions

While the proposed system shows significant promise, several implementation challenges must be addressed. Policy and infrastructure barriers vary globally, with the Global North focusing on competitiveness and skills shortages while the Global South faces resource constraints and equity issues [76, 77]. Successful implementation requires:

- Investment in digital infrastructure and teacher professional development programs
- Context-specific adaptation of graph-based models to local educational systems
- Establishment of ethical guidelines for AI-driven decision-making in education
- Development of standardized competency assessment frameworks

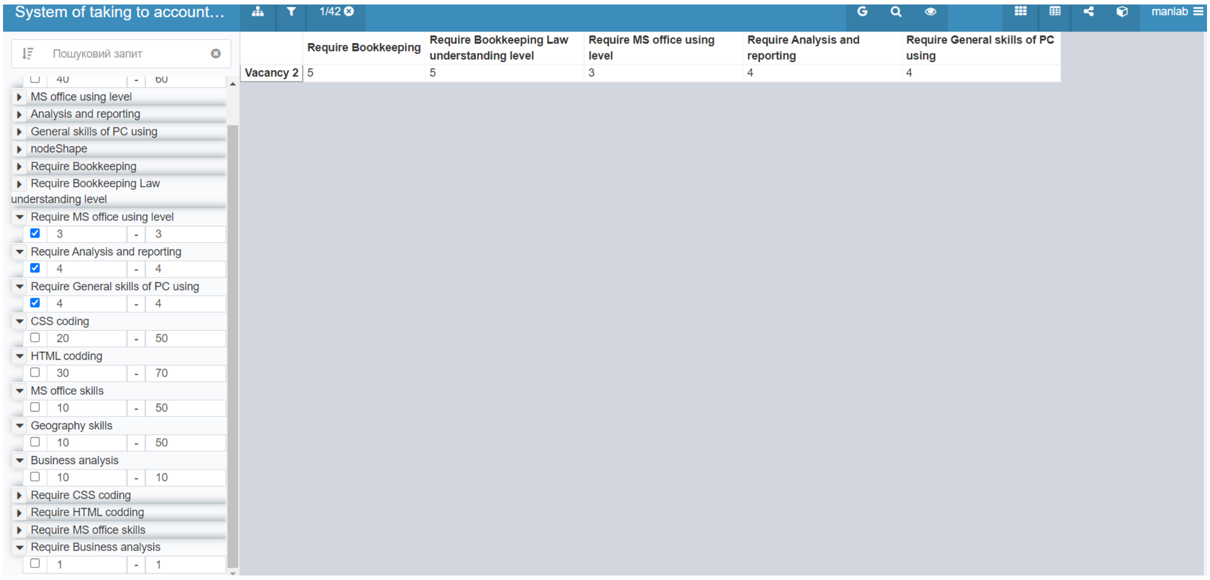


Figure 12: Table view of the generated graph to use by the Methodists and Ministry employees.

- Creation of feedback mechanisms to continuously update the system based on labor market changes

5. Conclusion

It is shown that some competencies that are required in real life are not prioritised in educational programs. The study describes an information system that provides data transfer on real-life required competencies from employers to specialists in the Ministry of education and science and Methodists consider them.

The main actors in the proposed systems are Employer, Job Seeker and Ministry specialist (Methodist). The main classes in proposed systems are Jobseeker Competency's (skill's), level Competency, (skill) Certificate, Job seeker's set of the competencies, Ranking Employer Vacancy, Set of the vacancies, Ministry employee, educational program. Each of these classes has the data that describes it.

The proposed concept may be implemented as well using simple basic tools such as MS Excel and as well by specialised tools such as KIT Polyhedron and as by using Phyton. In further studies, MS Excel-, Graph- and Phyton-based tools to make concept proof test.

It is shown that the graph-based approach is characterised by advantages, and it was chosen to build the system's prototype. It represents the graph's root nodes are a Set of competencies, Job seekers, a Set of Vacancies, a Set of employers, educational management institutions and educational programs. It is proven that the most perspective approach during which such a system can be used is STEM because a high level of flexibility characterises it.

The integration of advanced graph neural networks and knowledge graphs in educational management systems represents a transformative opportunity for STEM education. Future research should focus on:

1. Developing automated integration frameworks for heterogeneous, multi-modal data sources
2. Conducting longitudinal studies in diverse socio-economic contexts to assess scalability
3. Exploring hybrid models combining graph analytics with real-time adaptive feedback
4. Establishing international standards for competency-based educational management
5. Creating collaborative platforms for cross-border knowledge sharing and system interoperability

The successful implementation of graph-based educational management systems could significantly impact global STEM workforce development, potentially addressing the projected 22% growth in STEM occupations while promoting diversity and inclusion. As educational institutions worldwide grapple with rapidly evolving workforce requirements, the proposed approach offers a scalable, data-driven solution for aligning educational outcomes with labor market needs.

Declaration on Generative AI

The authors have not employed any generative AI tools.

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