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Classification and Analysis of the Application of Knowledge Graphs in Education

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Abstract. *A classification of the use of knowledge graphs in the educational field is presented and analyzes the methods used is carried out. The lack of systematization of the use of knowledge graphs in education, adapted to the individual needs and interests of various stakeholders, has necessitated the analysis and classification of the use of knowledge graphs in education, taking into account the key participants in the educational process. The purpose of the article is to classify the use of knowledge graphs by key participants in the educational field and analyze the methods used to construct and manipulate knowledge graphs. The research methodology is based on review, analysis, classification of scientific articles and projects. As a result of the analysis, several conclusions were obtained. The most common application of knowledge graphs is their use as an educational environment for students, serving as a tool for learning specific subject areas. Teachers perceive knowledge graphs as a means of organizing and structuring educational materials, and education managers consider them valuable for constructing individual learning trajectories and as auxiliary tools for decision making. Various authors have proposed a variety of approaches to working with knowledge graphs, using a variety of techniques such as machine learning, natural language processing algorithms, ontology creation, expert assistance, and the use of a wide range of models. The general trend is that methods for working with knowledge graphs often combine different approaches and technologies to achieve maximum efficiency in solving specific problems. The possibility of further application of the results is to identify the least covered group of stakeholders and develop for them a model of a recommendation system based on knowledge graphs, using modern and relevant methods for processing them.*

Keywords: *knowledge graph, ontology, machine learning models, natural language processing, semantic web, educational technologies, personalized learning, adaptive learning, educational trajectory, intelligent tutoring system, curriculum design, concept mapping, entity extraction, entities linking, knowledge representation.*

Introduction

Knowledge graphs (KGs), representing structural relationships between entities, are becoming an increasingly popular research direction in the fields of cognition and human-level intelligence. The heightened attention to KGs over the past decade has led to the formation of the IEEE P2807 working group and the publication of the first KG standard in January 2023.

However, the lack of systematization of the use of KGs in the educational process depending on the needs and interests of various stakeholders has necessitated the analysis and classification of the use of KGs in education from the point of view of the main participants in the educational process, including consideration of the methods used to solve various specific problems.

Previous literature reviews on KGs have mostly focused on technical aspects, their embeddings, and general applications of KGs. Some research studies provide an extensive review of this area from the perspective of labor market assessment using data analysis methods. Another review emphasizes the potential of KGs in various domains, such as healthcare, education, information technology, science and engineering, finance, sociology, and politics.

The purpose of this article is to review, systematize, and classify the use of KGs in education from the point of view of key participants in the educational process, as well as to identify general trends and approaches in the methods of building and manipulating KGs.

Methods

Educational stakeholders are a diverse group of people whose roles and interactions shape the educational environment. In our work, the main participants considered are students, teachers, and managers.

Let us turn our attention to the most numerous groups of KGs, whose primary consumers are students. In the first category of works [1, 2], there are projects enhancing efficiency in distance learning. In the article by Badawy et al. [1], a tool for searching and viewing educational resources is presented. It is capable of extracting key topics from textual educational resources, linking resources with references, and creating interactive dynamic KGs to enhance efficiency in distance learning. Using this tool, a KG, consisting of resources (books), topics, and chapters was built. This KG can be applied in an e-learning system as a means of interactive learning of educational resources. Constructed by Nair et al. [2] and others, the automated question-answering system allows students to learn and serves as an interactive method to enhance efficiency in remote learning. By using a KG and a forum for answering questions, the system helps students understand educational concepts. The paper explores the specifics of knowledge entity extraction, evaluation and analysis of information points, construction of KGs from unstructured text, and entity integration.

The following paper by Chi et al. [3] presents the design of a scientific publication management model for scientific metadata integration based on KGs and data analysis technology. Based on this model, an interdisciplinary trans-regional multifunctional scientific resource search and analysis platform was built, aiming to improve the efficiency of scientific search and encourage the use of scientific resources in entrepreneurship.

The next category of works [4, 5] deals with personalized learning. The work of Rizun, M. [4] considers KGs as a technology that simplifies and improves didactic processes of knowledge management in universities to individualize learning and and provides course selection by students. It also gives an extended analysis of the phenomenon of KGs. The author sees the main objective of further research as the construction of a KG to individualize university education through the application of some information technology to represent the graph as an application or web page. Sun et al. [5] and others in their paper propose a new method for creating personalized KGs based on a convolutional graph network. The convolutional neural network of the graph is used for each learner based on the difficulty of the exercises, which can provide more accurate personalized services.

The next group of works [6-10] considers KGs as a student-centered learning environment in a subject area. Subject-matter KGs play an important role in intelligent education by facilitating the linking of learning materials. They are used for an intelligent question-answering system and a personalized learning material recommendation service. In the article by Telnov and Korovin [6], authors discuss technologies of knowledge representation, reasoning models, and methods of cognitive hypothesis generation based on ontologies, as well as means of semantic annotation of full-text network content and representation of information objects in graph databases equipped with logical inference tools. The potential audience is mainly students and teachers. The emphasis is placed on the application of problem-oriented KGs as an educational technology in the training of specialists in nuclear physics and nuclear power engineering. In the article by Zhao et al. [7], KGs are applied to intelligent learning in middle school by automatically solving mathematical exercises based on logical reasoning. Agrawal, G. [8], in his work, uses KGs to create an interactive and student-centered learning environment for learning cybersecurity. In the paper by Su and Zhang [9], a method for the automatic construction of a subject KG for computer science and physics is proposed. The subject KG is constructed from big educational data using an initial bootstrapping strategy to gradually expand the knowledge points and the links between them. Qin et al. [10] use the database discipline as an example to construct and visualize an educational KG and create a knowledge map, which is conducive to building an intelligent learning system for the database discipline.

Another category of application of KGs to the student segment is described in the article by Meissner and Thor [11], who create an algebra subject area KG used for the process of creating exams, e-assessment items, and material recommendations.

The next category of work [12] and [13] focuses on the application of KGs to help instructors build instructional structures for subject areas. The paper by Chen et al. [12] proposes a system called KnowEdu that automatically constructs a KG for a subject area or course of study. Using heterogeneous data (curriculum standards and teaching guides) in different formats (text, audio, and video) from the education domain, this system first extracts subject or course concepts and then identifies educational relationships among the concepts. Specifically, it uses a neural sequence labeling algorithm for pedagogical data to extract educational concepts and employs probabilistic association rule analysis for learning assessment data to identify educationally relevant relationships. According to the author, the identified relationships can help teachers develop appropriate pedagogical strategies. Ke and Lin [13], in their work, build a learning structure based on a KG that, to some extent, assists teachers in developing topics within a single discipline in an interdisciplinary context focused on STEAM (science, technology, engineering, arts, and mathematics) curriculum.

In the group of works [14], and [15], the main users are managers who solve the problem of building an educational trajectory. Yu et al. [14] aim to create a visualization method for all courses based on Google Knowledge Graph. By analyzing the properties of courses and their prerequisites, he extracts the relationship between prerequisites and current courses to build a KG of the curriculum system. Based on this KG, the relationship between courses can be clearly analyzed and information can be extracted, which can help to match the course schema and quickly retrieve course information when needed. Aliyu et al. [15], in their paper, present an automated resource allocation approach based on KGs to solve the problem of manual course allocation at the beginning of each semester or academic year by the departments of higher education institutions. They develop a KG so that a course allocation schedule can be automatically generated.

Let us build a classification of the application of KGs in education from the point of view of the participants in the educational process, having previously summarized the considered sources in Table 1.

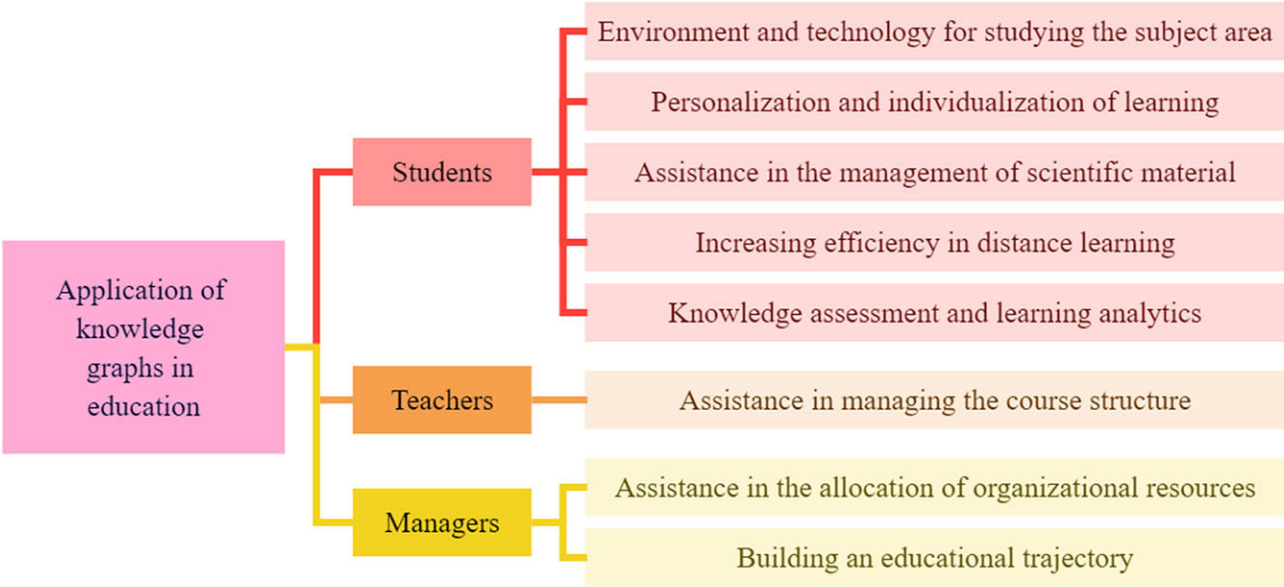
Table 1 summarizes the authors of the reviewed articles and indicates the participants in the educational process who are the users of the developed KGs. Finally, the third column provides a brief characterization of the use of KGs. As can be seen from the table, KGs are most often used by students as a medium for studying the subject area, by teachers as an aid in structuring the teaching material, by managers in building the educational trajectory, and as an auxiliary tool in decision-making by all participants in the educational process.

Let us build a classification scheme (Figure) for the application of KGs in education from the point of view of educational process participants on the basis of the prepared table.

The diagram illustrates the broad application of KGs in education, with the most diverse

Table 1 – Distribution of the application of KGs in education by target audience and application category

Author	The target audience	Application category
Badawy et al. [1]	Students	Increasing efficiency in distance learning
Nair et al. [2]	Students	Increasing efficiency in distance learning
Chi et al. [3]	Students	Assistance in managing scientific material
Rizun, M. [4]	Students	Individualization and personalization of training
Sun et al. [5]	Students	Individualization and personalization of training
Telnov and Korovin [6]	Students	Educational technology for the subject area
T Zhao et al. [7]	Students	Domain learning environment
Agrawal, G. [8]	Students	Domain learning environment
Su and Zhang [9]	Students	Domain learning environment
Qin et al. [10]	Students	Domain learning environment
Meissner and Thor [11]	Students	Knowledge assessment and learning analytics
Chen et al. [12]	Teachers	The structure of educational concepts and pedagogical strategy for studying the subject area
Ke and Lin [13]	Teachers	Help in building the structure of the subject area in an interdisciplinary context
Yu et al. [14]	Manager	Building an educational trajectory
Aliyu et al. [15]	Manager	Assistance in allocating organizational resources



Classification of the use of KGs in education by stakeholders and application categories

use observed among the student population. KGs serve to facilitate knowledge representation and organization, personalized learning, and the its analysis. With their structured and organized approach to knowledge representation, KGs enhance students' ability to comprehend and connect concepts. Researchers have utilized KGs to illustrate different domains, such as natural sciences, mathematics, and languages, like Telnov and Korovin [6], in exploring physics. Personalized learning is a pedagogical approach centered on the student's individual requirements and interests. KGs can customize the learning experience by providing tailored educational resources based on the students' preferences. Sun et al. [5] offer personalized services to students based on the difficulty of their exercises. Learning analytics employs data analysis to glean insights into learner performance and behavior. KGs can be utilized for learning analytics by gathering and examining performance data to identify areas where students may require extra support or where instructional materials can be enhanced. For instance, Meissner and Thor [11] developed a system for assessing students based on KGs that utilize learning analytics to offer personalized feedback via recommendations for learning materials.

To analyze articles through the utilization of KG methods, we will condense the primary techniques employed into a single table.

Table 2 reveals a range of techniques for working with KGs, including machine learning, natural language processing algorithms, ontology creation, and model utilization. TextRank and BM-25 are among the ranking methods [1] employed to assess the significance and relationships between graph elements. Ontologies [6], [8] are often used to formalize knowledge and represent it in a structured format. Ontologies make it easier to understand and interact with data. Some authors [4] have utilized different methods, highlighting the application of standard schemas and ontologies like Schema.org. This suggests a push for uniform knowledge representation standards. In certain cases [6], [7], and [8], expert knowledge is applied to create KGs and ontologies. Expert knowledge aids in determining the structure of graphs and highlighting crucial concepts and relationships. Many studies, including [2], [8], [9] and [10], utilize machine learning techniques such as support vector machines, k-nearest neighbor's algorithm, naive Bayesian models, logistic regression, BERT, LSTM, and others. Some authors utilize techniques, including those described in [14] and [15], for extracting entities from text and structured data to enrich the KG automatically with new information. Thus, the general trend is that KG techniques often combine different approaches and technologies to maximize their effectiveness in solving specific problems.

Results

An analysis and classification of the application of KGs in education have been conducted in this research paper. The authors hope that this work will substantially contribute to the systematization and comprehension of applying this tool in the educational process.

Analysis of existing literature reviews revealed that most of them focused on technical

Table 2 – Methods and techniques for working with KGs in education

Author	Techniques and techniques for working with KGs
Badawy et al. [1]	Wikipedia miner, TextRank, function ranking BM-25
Nair et al. [2]	Uses the bidirectional encoder representations from transformers (BERT) language model to generate responses, and long and short-term memory (LSTM) networks for Hindi translation.
Chi et al. [3]	Support vector method, k-nearest neighbor, naive Bayesian model, logistic regression
Rizun, M. [4]	Entity and relationship dictionaries from Schema.org5
Sun et al. [5]	Word2Vec model, NEO4J for KG construction, graph convolution neural network (GCN) for node classification
Telnov and Korovin [6]	Ontologies in Protege and domain experts
T Zhao et al. [7]	Crowdsourcing and domain experts
Agrawal, G. [8]	Bottom-up approach with machine learning and domain experts for ontology building, custom entity matcher
Su and Zhang [9]	BERT-BiLSTM-CRF (conditional random field) model for constructing KGs
Qin et al. [10]	Beginning-inside-outside (BIO) labeling method for named entity recognition, BiLSTM-CRF for object recognition, Word2Vec for training textual data associated with the database
Meissner and Thor [11]	Manual and automated methods: Manual modeling by experts and T-Mitocar respectively for graph creation, EAs.LiT, Fachlandkarten-Tool and DBpedia Spotlight accordingly for expansion
Chen et al. [12]	Gated recurrent block networks for concept extraction, analysis of probabilistic association rules to identify relationships
Ke and Lin [13]	The high-order singular value decomposition with orthogonal iteration (HO-SVD-OI) for the tensor decomposition algorithm, the high-dimensional orthogonal iteration mechanism to calculate the matches between STEAM learning resources
Yu et al. [14]	Extracting entities from structured tables
Aliyu et al. [15]	Extracting entities from structured tables

aspects, embeddings, or general applications of KGs. However, this article changes this focus by providing a detailed review of the methods and applications of KGs in education. The classification given in this article differs from that presented in the reviews in that it provides specific examples of KG applications in education with a target audience and a specific application category, allowing for a clearer understanding of the context of KG use. In contrast to the review articles, our classification describes in more detail the specific tasks and methods used within each project. These differences make our classification more specific and focused on practical applications of KGs in education, while the reviewed survey articles provide a general overview of the topic.

Notably, the article culminates in the development of a classification of KG applications in education based on the target audience and application category. Table 1 provides a clear and structured depiction of how various authors view the effective incorporation of KGs in the educational process. Particular attention is given to students, teachers, and administrators to enhance understanding of how the tool can be modified to satisfy the distinct requirements of participants in an educational environment. One interesting observation is that the majority of KG applications in education aim to enhance the efficiency of remote learning, personalize and individualize the learning experience, and establish an optimal learning environment for specific subjects. The range of applications is diverse: from knowledge assessment and learning analytics to the construction of educational trajectories and the allocation of organizational resources.

The results presented in Table 2 reveal the diversity of methodologies and techniques for applying KGs in education. Analysis of the presented data allows us to identify several key trends and common approaches that influence the effectiveness of using KGs in educational processes. An important trend is the desire to unify knowledge representation standards. Authors such as Rizun, M. [4], Sun et al. [5], Telnov and Korovin [6], and Agrawal, G. [8] note the use of ontologies, including standard schemas such as Schema.org. This demonstrates the need for a common standard to facilitate better sharing and understanding of data in an educational context. Many researchers, including Nair et al. [2], Chi et al. [3], Yuan Sun [5], Agrawal, G. [8], Su and Zhang [9], Qin et al. [10], and Chen et al. [12], have successfully integrated machine learning techniques to improve the efficiency of educational processes. The use of models such as Word2vec, BERT, and graph convolution neural networks (GCNs) emphasizes the importance of applying advanced technologies to tailor education to the needs of each learner. Expert knowledge, as presented in Telnov and Korovin [6], T Zhao et al. [7], Meissner and Thor [11], plays an essential role in the construction of problem-oriented KGs. This approach highlights the importance of including human factors in the creation of educational technologies, especially in the context of specialized fields such as nuclear physics and mathematics. Entity extraction methods presented, for example, in [14] and [15], demonstrate the active use of structured data for automatic enrichment of KGs. This approach facilitates updating the graph with new information, making it more relevant and up-to-date.

Conclusion

This research paper examines and categorizes the utilization of KGs in education from the standpoint of the key participants in the educational process while exploring a wide range of methods and techniques. Our findings illustrate the diverse approaches to implementing KGs in the context of education, supplying valuable insights for researchers, developers of education technologies, and educational institutions.

The authors' desire to establish a standard knowledge representation in educational settings is one of the key findings of our analysis. Despite differences in methodologies, many authors stress the importance of using commonly accepted schemas and ontologies to achieve uniformity and enhance data interoperability.

The integration of machine learning techniques into the learning process, as presented by several authors, indicates a shift towards more personalized and efficient methods of learning. This confirms the relevance of implementing advanced technologies in education and underlines the necessity of consistently updating methods and approaches.

Expert knowledge plays a significant role in creating problem-oriented KGs, which can greatly enhance the effectiveness of educational technologies, particularly in specialized fields. Thus, it is crucial for educational institutions to collaborate with experts for successful project implementation.

Despite the variety of methods used, evaluating the effectiveness of different approaches when dealing with KGs in education remains an open question. The potential for applying the findings further involves pinpointing the stakeholder group that has received the least attention and creating a tailored recommendation system model for them, which leverages knowledge graphs and employs contemporary and pertinent processing techniques.

Overall, our analysis highlights that KGs are becoming an increasingly important tool for modernizing and improving educational processes. With their innovative methods and diverse application, KGs enable more effective knowledge generation and transfer, hence providing unique opportunities for students and educational institutions.

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Білім графтарың білім беруде қолданылуын жіктеу және талдау

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Аңдатпа. *Зерттеу білім беру саласында білім графтарың қолданудың классификациясын ұсынады және қолданылатын әдістерді талдайды. Білім беруде әр түрлі мүдделі тараптардың жеке қажеттіліктері мен мүдделеріне бейімделген білім графтарың пайдалануды жүйелеудің жоқтығы білім беру үдерісінің негізгі қатысушыларын есепке ала отырып, білім беруде білім графтарың пайдалануды талдау және жіктеу қажеттілігін туғызды. Мақаланың мақсаты – білім беру саласындағы негізгі қатысушылардың білім графтарың пайдалануын жіктеу және білім графтарың құру және өңдеу үшін қолданылатын әдістерді* *талдау. Зерттеу әдістемесі ғылыми мақалалар мен жобаларды шолуға, талдауға, жіктеуге негізделген. Талдау нәтижесінде бірнеше қорытындылар алынды. Білім графтарың қолданудың ең кең тараған түрі оларды белгілі бір пәндік салаларды меңгеру құралы ретінде қызмет ететін студенттерге білім беру ортасы ретінде пайдалану болып табылады. Мұғалімдер білім графтарды оқу материалдарын ұйымдастыру және құрылымдау құралы ретінде қабылдайды, ал білім беру менеджерлері оларды оқытудың жеке траекторияларын құру үшін құнды және шешім қабылдаудың көмекші құралы ретінде қарастырады. Әртүрлі авторлар машиналық оқыту, табиғи тілді өңдеу алгоритмдері, онтологияны құру, сарапшылардың көмегі және кең ауқымды үлгілерді пайдалану сияқты әртүрлі әдістерді пайдалана отырып, білім графтарымен жұмыс істеудің әртүрлі тәсілдерін ұсынды. Жалпы тенденция білім графтарымен жұмыс істеу әдістері көбінесе нақты есептерді шешуде максималды тиімділікке жету үшін әртүрлі тәсілдер мен технологияларды біріктіреді. Нәтижелерді одан әрі қолдану мүмкіндігі мүдделі тараптардың ең аз қамтылған тобын анықтау және оларды өңдеудің заманауи және сәйкес әдістерін пайдалана отырып, білім графтарына негізделген ұсыныстар жүйесінің үлгісін әзірлеу болып табылады.*

Кілт сөздер: *білім графтар, онтология, машиналық оқыту үлгілері, табиғи тілді өңдеу, семантикалық желі, білім беру технологиялары, жекелендірілген оқыту, бейімді оқыту, білім беру траекториясы, интеллектуалды оқыту жүйесі, оқу бағдарламасын әзірлеу, тұжырымдамалық карта, нысанды шығару, нысандарды байланыстыру, білімнің көрінісі.*

Классификация и анализ применения графов знаний в образовании

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Аннотация. *Представлена классификация применения графов знаний в образовательной сфере и проведен анализ используемых методов. Отсутствие систематизации использования графов знаний в образовании, адаптированных к индивидуальным потребностям и интересам различных заинтересованных сторон, обусловило необходимость анализа и классификации применения графов знаний в образовании с учетом ключевых участников образовательного процесса. Цель статьи – провести классификацию применения графов знаний по ключевым участникам в образовательной сфере и проанализировать методы, использованные для построения и манипуляции графами знаний. Методология проведения исследования основывается на обзоре, анализе, классификации научных статей и проектов. В результате анализа получено несколько выводов. Наиболее распространенным применением графов знаний является их использование в качестве образовательной среды для учащихся, выступающей в качестве инструмента для изучения конкретных предметных областей. Преподаватели воспринимают графы знаний как средство организации и структурирования учебных материалов, а менеджеры образования считают их ценными для построения индивидуальных траекторий обучения и как вспомогательные инструменты при принятии решений. Различные авторы предлагают разнообразные подходы к работе с графами знаний, используя множество методов, такие как машинное обучение, алгоритмы обработки естественного языка, создание онтологий, помощь экспертов и использование широкого спектра моделей. Общая тенденция заключается в том, что методы работы с графами знаний часто сочетают в себе различные подходы и технологии для достижения максимальной эффективности при решении конкретных задач. Возможностью дальнейшего применения результатов является выявление наименее охваченной группы стейкхолдеров и разработка для них модели рекомендательной системы на основе графов знаний с использованием современных и актуальных методов их обработки.*

Ключевые слова: *граф знаний, онтология, модели машинного обучения, обработка естественного языка, семантическая сеть, образовательные технологии, персонализированное обучение, адаптивное обучение, образовательная траектория, интеллектуальная система обучения, разработка учебной программы, концептуальная карта, извлечение сущности, связывание сущностей, представление знаний.*

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