# Constructing and Analyzing Knowledge Graphs in the Field of Number and Algebra in Junior High School Mathematics

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**Abstract.** Mathematics is an essential subject in junior high school for cultivating students' logical thinking and problem-solving skills. Number and algebra are challenging areas and overarching concepts within this subject. Combining them with knowledge graphs offers a more three-dimensional and intuitive way to present these concepts, which can facilitate learning. However, there is a scarcity of knowledge graph construction, especially concerning the concepts and content of number and algebra in junior high school mathematics. This study involves organizing knowledge points and methods related to number and algebra in junior high school mathematics to obtain entity and relationship data. Subsequently, the Neo4j graph database system is employed to import and retrieve data, ultimately constructing a knowledge graph, with an analysis of its effectiveness.

**Keywords:** Number and algebra, Concepts, Knowledge Graphs, Neo4j

## 1 Introduction

Numbers and algebra are crucial concepts and content in middle school mathematics, serving as foundational knowledge in the discipline. Learning about numbers and algebra allows students to grasp fundamental mathematical concepts and methods, fostering logical thinking skills and problem-solving abilities. However, both teaching and learning mathematics and algebra are often challenging for teachers and students alike. The concepts are numerous, intricate, and challenging to comprehend, leading to lower scores in examinations. Addressing the pressing issue of how to enhance the learning and understanding of numbers and algebra becomes imperative.

Currently, with the continuous development of intelligent information services, knowledge graphs have entered the mainstream. Knowledge graphs describe


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concepts, entities, and their relationships in the objective world in a structured manner. They transform information from the internet into a form that closely aligns with human cognitive structures, offering improved capabilities for organizing, managing, and understanding vast amounts of online information [1]. Knowledge graphs find extensive applications in intelligent search, smart question-answering systems, personalized recommendations, and are increasingly influencing the field of education and teaching. Their specific graphical representation forms are more in line with human cognitive structures, facilitating both teacher instruction and student learning.This study integrates the field of numbers and algebra in middle school mathematics with knowledge graphs, combining traditional subject teaching with artificial intelligence technology. The aim is to utilize digital technology to better present the concepts and relationships between numbers and algebra, facilitating teacher instruction. Additionally, the study seeks to gain insights into students' mastery of knowledge, enabling a more precise understanding of students' dynamic learning progress. It also aims to promote student learning, laying the groundwork for personalized learning recommendations in the future, while concurrently advancing the development of educational informatization.

## 2 Research Background and Significance

Proposed by the 20th National Congress of the Communist Party of China: "We must adhere to the principle that technology is the primary productive force, talent is the primary resource, and innovation is the primary driving force. We should vigorously implement the strategies for revitalizing science and education, strengthening the nation with talent, and driving development through innovation. We need to explore new fields and avenues of development, continually shaping new dynamics and advantages."President Xi Jinping pointed out in his congratulatory letter to the International Artificial Intelligence and Education Conference: "Artificial intelligence is a crucial driver leading the new wave of technological revolution and industrial transformation. It is profoundly changing people's ways of production, life, and learning, propelling human society into the era of intelligent collaboration, interdisciplinary integration, and collaborative creation and sharing. Grasping the global trends in artificial intelligence development, identifying breakthroughs and key directions, and nurturing a large number of high-end talent with innovation capabilities and a spirit of cooperation is an important mission for education."Today, with the proliferation of computers and the development of artificial intelligence, the field of education is beginning to be influenced by digital technologies and tools. Emerging technologies like artificial intelligence, big data, online courses, e-textbooks, and learning management systems provide the foundation for educational digitization. However, traditional education systems face various challenges, including how to effectively leverage technology, implement personalized education, and transform the role of teachers. These challenges have ignited the drive to use technology and artificial intelligence to improve education, making it more tailored to individual students, efficient, and conducive to deep learning.

Knowledge graphs are a product of the development of artificial intelligence to a certain stage. Combining knowledge graphs with subject-specific education forms an educational knowledge graph. As a visualization of knowledge, educational knowledge graphs process vast and unstructured data, structuring it into organized knowledge systems. In the field of education, they continuously explore new development possibilities [2]. By offering personalized learning through educational knowledge graphs, analyzing students' learning behaviors and abilities, and providing individualized learning paths and resources based on their unique needs, this approach helps improve student performance and allows each student to fully realize their potential. Integrating knowledge graphs with the field of mathematics transforms traditional teaching methods and promotes educational reform. Mathematics is a vital subject at the junior high school level, serving as the foundational discipline for natural sciences and a key subject for developing students' logical thinking and problem-solving abilities. In the teaching of mathematics, numbers and algebra are important domains. Algebraic concepts run throughout the entire learning process in mathematics.

However, these concepts often pose significant challenges for students, including difficulties in understanding symbols, grasping abstract concepts, and linking various mathematical ideas. In the realm of teaching, teachers face issues related to varying student learning levels, difficulty assessing student progress, and a lack of teaching resources. This research combines knowledge graphs with the teaching of mathematics, aiming to address the aforementioned issues and better assist teachers in teaching and students in mastering relevant knowledge.

# 3 Research Status

## 3.1 Domestic Research Status

Research on subject knowledge graphs in China began as early as the early 21st century. Initially, subject knowledge graphs were primarily used as a visual analytical tool to provide a clearer and more intuitive representation of research findings. Scholars such as Lian Tonghui conducted visual analyses of tourism literature indexed by the Chinese Social Sciences Citation Index (CSSCI) between 2000 and 2010, creating knowledge graphs that depicted key terms, authors, publishing institutions, cited authors, cited literature, and cited journals in the field of tourism [3]. As computer hardware and software continued to advance and with the further development of artificial intelligence and education, subject knowledge graphs evolved beyond being solely visual tools. They became an integral part of smart education, involving the construction, innovation, and application of subject knowledge graphs and influencing deep learning. Qi Guilin and others introduced key technologies for constructing knowledge graphs, including entity relationship recognition, knowledge fusion, entity linking, and knowledge reasoning [4]. Knowledge graphs also found applications in various interdisciplinary fields such as sports, medicine, economics, geography, and special education, facilitating the analysis of disciplinary development trends. According to Hu Fanghuai, knowledge graphs have wide-ranging applications in fields like semantic search, intelligent question answering,knowledge engineering, data mining, and digital libraries [5]. Zhong Liang believes that knowledge graphs, through techniques like content analysis and natural language processing, can effectively display the structural relationships among disciplinary knowledge and various knowledge points using relevant visualization tools, aligning with learners' cognitive habits [6].

### 3.2 Abroad Research Status

Abroad, research on knowledge graphs is more in-depth and includes not only general knowledge graphs but also domain-specific knowledge graphs, particularly in the field of education. Knowledge graphs promote teaching, improve the learning and cognitive processes of students, and offer personalized learning experiences. Initial research involved analyzing the effects of knowledge graphs, as seen in a meta-analysis by Schroeder et al. A moderate effect size ($g+ = 0.58$) was found to confirm the beneficial effects of knowledge graphs on learning [7]. Mayer argues that all cognitive processes related to integrating new information into existing prior knowledge structures can be described as meaningful learning [8]. Learners, according to Bada and Olusegun, are considered active individuals who build new knowledge on the foundation of previously acquired knowledge. Since its development, knowledge graphs have been tested in many learning environments to determine their relative advantages compared to similar teaching methods [9]. Troussas and colleagues proposed a new approach to use knowledge graphs for recommending suitable educational content to learners. In their approach, the knowledge graph incorporates learners, educational entities, and their relationships, creating an interconnected framework to drive personalized e-learning content recommendations [10].

## 4 Knowledge Graph Construction

### 4.1 Entity Extraction

Entity extraction is an important task in knowledge graph construction. It aims to identify and extract information from text that represents real-world entities such as people, places, times, and more. These extracted entities are used as nodes in constructing a knowledge graph. In the context of building subject-specific knowledge graphs, it is common to select key concepts and knowledge points from the subject matter as entities. In this study, the researchers focused on the Chinese ninth-grade mathematics curriculum, particularly the topics related to numbers and algebra, using the content provided in the People's Education Press (PEP) textbook for reference. Since the content for this specific subject matter is relatively limited, the researchers employed a manual extraction method to identify and extract entities related to numbers and algebra. The process is illustrated in Figure 1 of the research paper. To extract entities, the researchers followed a top-down approach, starting with the identification of the target entities based on the teaching objectives of the ninth-grade mathematics curriculum. These target entities included concept entities and method entities, and the extraction process proceeded from larger concepts to smaller knowledge points within the subject matter. In summary, this research focused on extracting entities related to the topic of numbers and algebra from the ninth-grade mathematics curriculum, using a manual extraction method guided by the curriculum objectives and the structure of the content in the chosen textbook. The extracted entities would be used to construct a knowledge graph specific to this subject.

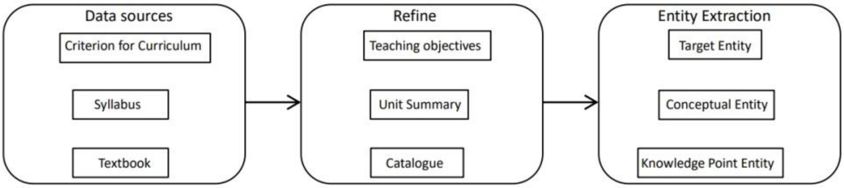



**Fig. 1.** Extract model diagram

The detailed knowledge was sourced from various materials such as textbook tables of contents, teaching objectives, unit summaries, subject taxonomy, and teacher's lesson plans. The extracted knowledge points were organized into roughly 4-5 levels of hierarchy. Once the knowledge points were identified, they were tokenized into subwords to form the subcomponents of the entire subject area. The final extracted entities include target entities, method entities, knowledge point entities, and concept entities. After extracting these entities, they were further organized and refined through a screening process.

## 4.2 Relation Extraction

Relation extraction and entity extraction are fundamental steps in building a knowledge graph. Relationships between knowledge can be categorized into common knowledge relationships and domain-specific relationships. Common relationships include sequential relationships (predecessor and successor), hierarchical relationships (belonging to, containing), and associative relationships (causal, related, similar). In the field of mathematics, there are specific relationships such as "related methods." In middle school mathematics textbooks, statements like "The vertex is the lowest or highest point of a parabola" represent inclusion relationships. Statements like "Given the quadratic function y = -x2 + 4x with a value of 3, find the value of the independent variable x, which can be viewed as solving a quadratic equation -x2 + 4x= 3 (i.e., x2 - 4x + 3 = 0)" demonstrate a related relationship or related method between quadratic functions and quadratic equations. After conducting research in the field of mathematics and algebra, these relationships can be categorized into two classes: common relationships and special relationships, totaling six types, as illustrated in Figure 2.

| Relationship Classification | Name of Relationships | Relationship Description | Example triples |
|---|---|---|---|
| Common Relations | Contain | The content of Point B in Point A. | <Number and Algebra,inclusions,Quadratic Functions> |
| | Precursor | Point A is the foundation of Point B. | < Univariate quadratic equation, precursor, Solving a quadratic equation of one variable > |
| | Correlation | Point A is related to Point B. | < Formula method, correlation, root finding formula > |
| | Cause and Effect Relationship | Point A is the cause of the change in Point B. | < Discriminant of roots, causal relationship, $\triangle>0$ two unequal real roots > |
| Special Relations | Related Properties | The property of Point A is related to the property of Point B. | < Quadratic function, related properties, parabola > |
| | Related Method | Point A is the solution to Point B. | < Quadratic function, correlation method, point tracing method > |

**Fig. 2.** Relationship classification chart

The determination of relationships between knowledge is primarily based on multiple comparisons of how entities are described and defined in curriculum standards, syllabi, and textbooks. Subsequently, it requires iteration, improvement, and validation through real-world teaching by frontline teachers.

### 4.3 Graph Construction

The construction of the knowledge graph is mainly done using the Neo4j platform, which is a popular and widely used Graph Database Management System designed specifically for storing and processing graph data, where data is represented in the form of nodes and relationships. Graph databases are an extension of relational databases, designed to efficiently manage and query data with complex relationships. They provide a more concrete and visual representation of the relationships between knowledge points in the domain of mathematics and algebra, facilitating effective tracking of student knowledge and accurate knowledge point review recommendations in the future.

In this study, the construction of the graph is based on the acquired knowledge entity triple data. The following are the five steps:

1. Add Extract knowledge entities and entity relationships (as detailed in the previous text);

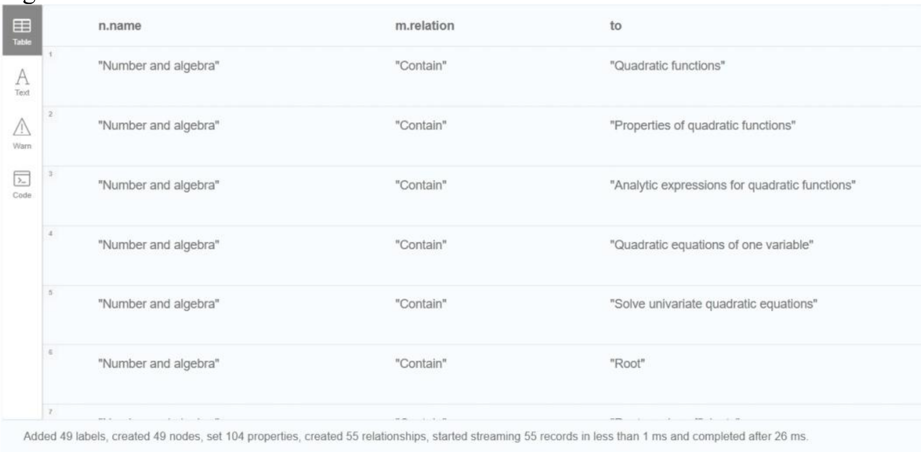
2. Generate a file containing the obtained entity and relationship data. Following the common knowledge graph triple format, place knowledge entity 1 and knowledge

entity 2 in the first and second columns of the table, respectively. The entity relationship is written in the third column.

3. Place the data files in the import folder of the Neo4j program for easy data import into Neo4j;

4. Access the Neo4j platform and load and read data code;

5. In Neo4j, input code commands to generate the knowledge graph, as shown in Figure 3.



| | n.name | m.relation | to |
|---|---|---|---|
| 1 | "Number and algebra" | "Contain" | "Quadratic functions" |
| 2 | "Number and algebra" | "Contain" | "Properties of quadratic functions" |
| 3 | "Number and algebra" | "Contain" | "Analytic expressions for quadratic functions" |
| 4 | "Number and algebra" | "Contain" | "Quadratic equations of one variable" |
| 5 | "Number and algebra" | "Contain" | "Solve univariate quadratic equations" |
| 6 | "Number and algebra" | "Contain" | "Root" |

Added 49 labels, created 49 nodes, set 104 properties, created 55 relationships, started streaming 55 records in less than 1 ms and completed after 26 ms.

**Fig. 3.** Graph generation result table (a part of the whole)

## 5 Conclusions

Through manual research and organization of the field of middle school mathematics, a data document was obtained. The Neo4j visualization graph database was utilized for importing and reading, ultimately generating the graph as shown in Figure 4. The purple nodes correspond to the initial entity nodes in the data, while the orange nodes correspond to the entities pointed to in the data. The relationships between two nodes correspond to the relationship columns in the data. The final graph is generated with one knowledge point entity node pointing to another knowledge point entity node, with the corresponding relationship between the two entities. This study presents the knowledge points in the field of middle school mathematics, specifically in the area of numbers and algebra, in the form of a knowledge graph. It addresses the issues of isolation, conceptual ambiguity, and difficulty in understanding and linking concepts that teachers and students encounter in their daily teaching and learning. By presenting the knowledge points in the field of numbers and algebra in a visual and clear graph, teachers can better design their instruction, accurately grasp the key and difficult points. Additionally, through the knowledge graph, teachers can better understand the dynamic learning progress of students and tailor their teaching to individual needs. It can help students more easily understand and remember abstract mathematical concepts.

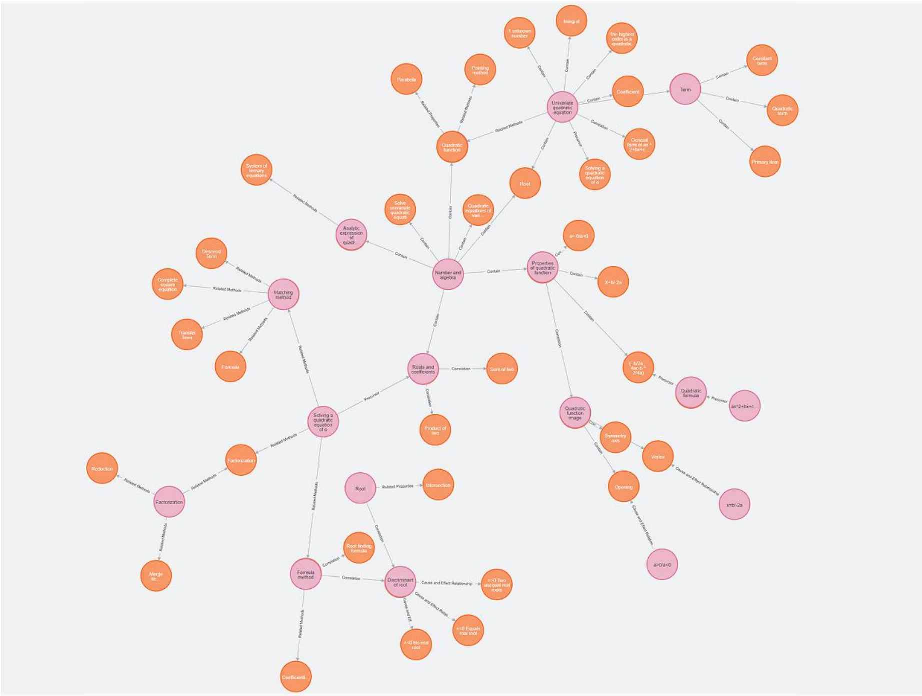



**Fig. 4.** Knowledge graph of numbers and algebra (a part of the whole)

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