Review Article

Research on the Mathematics Space Concept of Junior High School Students in China

ABSTRACT

The space concept is one of the main manifestations of the mathematics core competencies in the compulsory education stage as required by the *Mathematics Curriculum Standards for Compulsory Education (2022 edition)*. In the past two decades, many scholars have studied the space concept, but there is no literature to systematically summarize the research results. Therefore, this paper adopts the literature analysis method to review 47 papers related to the mathematics space concept of junior high school students in China, and obtains the following conclusions: After the promulgation of the *Mathematics Curriculum Standards for Compulsory Education (2022 edition)*, the research on the space concept has increased, but it is mostly theoretical research and less empirical research. The research is divided into six aspects: the connotation and components of the space concept, the division of the space concept's dimensions, the current development status of the space concept of junior high school students, factors influencing the space concept, ways to cultivate the space concept, and curriculum resources development. Studies on the dimensional division, the current development status, and the ways of cultivating the space concept are abundant. The division of dimensions and levels of the space concept provides a research approach to further understanding the development status of junior high school students. The research on the development status suggests that teachers should analyze the weak points in the space concept combined with the specific situation of students. The research on the cultivation ways innovates the design of teachers' teaching activities. But these studies all focus on the period before the promulgation of the new edition standards. There is a lack of research on the connotation and components, the influencing factors, and the development of curriculum resources. Therefore, it is necessary to analyze the research week's points further. The space concept can be interpreted from different perspectives in conjunction with other related disciplinary theories, the influence factors such as students' pre-preparation and teachers' teaching styles can be examined, and a variety of in-school and out-of-school resources and

networked resources can be flexibly applied for curriculum development.

Keywords: Junior high school; Core competencies; Space concept.

1. INTRODUCTION

The space concept has been portrayed and analyzed in three editions of the mathematics curriculum standards for compulsory education (hereinafter referred to as standards), and its importance is growing: in the 2001 edition, the space concept is one of the important learning contents [1]; in the 2011 edition, the space concept becomes one of the ten core concepts [2]; and in the 2022 edition, the space concept turns into one of the main manifestations of the mathematics core competencies in elementary and junior high schools [3]. Research on the space concept has been going on for a long time. Recently, the introduction of core competencies has triggered a wave of research among many educational researchers and front-line teachers. However, there is no literature summarizing the research results before and after the new edition standards. Hence, this paper attempts to make review studies on the space concept of Chinese junior high school students since 2001, to clarify the research status in this field, find out the shortcomings and gaps in the research, and then guide the next research.

The research problem of this paper is what is the research status of the mathematics space concept of junior high school students in China?

Specifically, the problem includes the following three questions:

1. What are the characteristics of the literature on the space concept?
2. What are the research themes in this field?
3. What themes have been adequately studied, what themes have not been studied enough, and are there any gaps?

2. LITERATURE SOURCES

2.1 Source

The literature selected for this paper was obtained from the China National Knowledge Infrastructure (CNKI). CNKI is the largest Chinese database all around the world, which includes academic journals, master's and doctoral theses, conferences, newspapers, patents, and other academic and professional materials, covering a wide range of disciplines such as science and engineering, humanities, and social sciences, medicine, and health, information technology, etc. Therefore, the use of this database can ensure the comprehensiveness and reliability of the literature.

2.2 Data Collection

Using the backward search method and the citation search method, input keywords such as "junior high school", "junior high school mathematics", "the space concept", "mathematics space concept" and "core competencies" to search the literature, and finally, 47 papers were selected, of which 36 are published in academic journals and 11 are master's theses. The time span of the literature is from 2002 to 2022.

2.3 Data Processing

The 47 selected papers were read intensively, and the titles, authors, years, types of studies, research problems, research methods, and research conclusions were recorded, then the record sheets were summarized and organized.

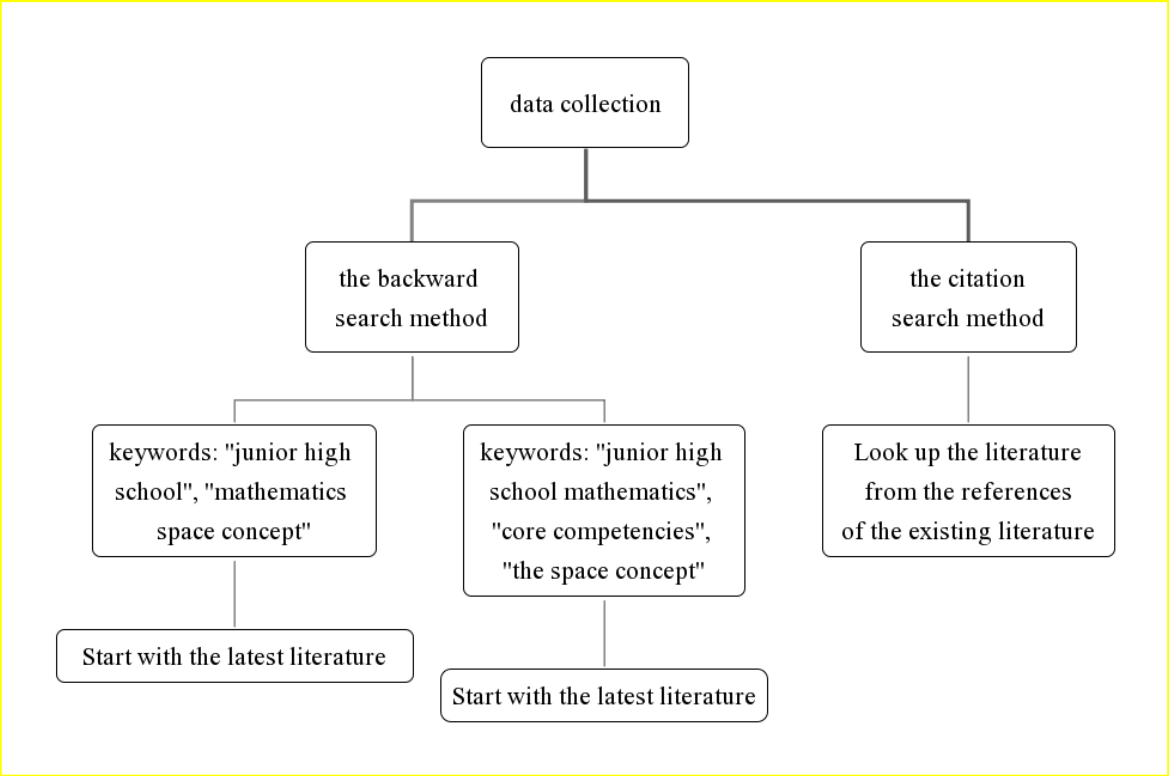

Figure 1 Data collection process

3. RESULTS

3.1 Literature Characteristics

The following literature characteristics are obtained by analyzing the time of publication and the type of studies.

With the update of the standards, the amount of literature has gradually increased. There are 10 papers published after the 2001 standards, 30 papers published after the 2011 standards, and 7 papers published after the 2022 standards, which shows that the research enthusiasm continues to rise after the introduction of the mathematics core competencies.

Theoretical studies are predominant and empirical studies are less. 33 out of 47 papers are of theoretical type. Only a few empirical studies are available, most of which are master's degree theses published from 2016 to 2021, and no studies have come out since the appearance of the new edition standards.

3.2 Research Themes

An overall analysis of the research results reveals the following six main research themes: the connotation and components of the space concept, the division of the space concept's dimensions, the current development status of the space concept of junior high school students, factors influencing the space concept, ways to cultivate the space concept, and curriculum resources development. The research on the division of dimensions, development status, and cultivation ways is very rich, while there are more gaps in the research on the

interpretation of the space concept, exploration of influencing factors, and development of curriculum resources.

3.2.1 The connotation and components of the space concept

Some scholars interpreted the connotation and components of the space concept in the standards.

Sun et al. analyzed the components of the space concept based on the requirements of the standards, including view and construction, intuition and inference, and observation and projection [4]. Wang Linquan believed that the basic components of the space concept included identifying shapes, analyzing shapes, constructing shapes, transforming shapes, and using intuitive geometry to solve problems, moreover, the space concept existed stage characteristics: it was embodied in the operation and perception of figures in elementary school, it was embodied in the formation and development of figures in junior high school, and it was embodied in the connection and construction of figures in high school [5]. Han et al. reinterpreted the meaning of the space concept in combination with the form of expression in standards, and thought that the space concept was first manifested as "imagining", secondly as "making", thirdly as "decomposing", and fourthly as "thinking" [6].

After the promulgation of the 2022 standards, BaoJiansheng and Zhang Jianyue defined the connotation of the space concept from the perspective of mathematics core competencies and pointed out that it was the basis for developing the core competency: intuitive imagination in high school. As for the expressive form, the space concept in junior high school was basically the same as that in elementary school, including forming a representation of objects described according to figures, perceiving and expressing the spatial orientation and position of objects, perceiving and describing the motion and change of figures [7].

3.2.2 The space concept dimensions division

The vast majority of the empirical research used tests to explore the current development status of the space concept among junior high school students, but the division of dimensions and levels in the test papers still differed.

Scholars generally divided the space concept into 4-6 dimensions, the view dimension and the motion and change of figures dimension were common dimensions [8-21]. Some studies added the position relationship of objects dimension [11,13,18,19,20], some studies added the projection dimension [12,13,16,19], some scholars added the drawing dimension [11,17,19], and a few scholars added the decomposition of complex figures dimension or the intuitive inference dimension [11,17,18,19]. Yan Miao [9] and ZouJiaye [10] further divided two dimensions of map recognition ability and space imagination ability, and Wang Wenli added the transformation between two and three dimensions and the transformation between dynamic and static [15]. Thus, it can be seen that despite the differences in the types of dimensions, they all contain the main manifestations of the space concept required in the standards.

A few scholars also classified the levels of the space concept. Huang Jingshu and He Xiaoya divided the development of the space concept into these three levels: intuitive imagination level, intuitive imagination and simple analysis level, and intuitive imagination and complex analysis level [14]. Wang Yunqing [12] and Huang Quanbo [21] similarly divided it into three levels, which are direct observation, simple imagination, and manipulation level, abstraction and simple analysis level, and intuitive thinking and complex analysis level. Zhang

Dongmeidivided it into three levels, which are the intuitive recognition and image perception level, intuitive inference and simple analysis level, and abstraction and complex analysis level in order [17]. It can be found that most of the studies are very similar in their classification of levels, which basically follow the logical sequence of intuitive-simple-complex.
In general, the division of dimensions and levels of the space concept provides a research approach to understanding the development status of junior high school students space concept,which can well judge what level of development the studentsare at, in which dimensions they perform well, and in which dimensions they fall short.

3.2.3 Current development status of the space concept of junior high school students

Numerous studies showed that junior high school students had some degree of space concept competency, but there were different manifestations in different dimensions.
Yan Miao believed that junior high school students map recognition ability was poor [9]. Yu Xiaohui considered that view, drawing, and intuitive inference abilities were weak, and juniors' ability to decompose complex figures was significantly weaker than that of seniors [11]. Shi Jian and GuJiling found that students' performance in projection and the figures' motion and change was better than that in view and orientation of objects [13]. Through investigation, Wang Wenli obtained that junior high school students' view, drawing, and dimensional transformation abilities developed better and faster [15]. Zhang Dongmei believed that junior high school students performed best in the dimension of figures' motion and change, and the dimension of folding and unfolding of figures, and worst in the dimension of inference [17]. Chen et al. explored that students were able to gradually improve their ability to analyze complex figures, but the ability of figures' motion and change needed to be cultivated [18]. Zhao Zhixiong believed that the dimension of view and drawing, which examines students' observation ability, and the dimension of inference, which examines students' analysis ability, performed poorly [19]. ZouJiaye thought that students were unable to synthetically analyze complex figures and their dynamic transformations [10].
It can be seen that the results obtained are not entirely consistent due to the different divisions of the dimensions, but a part of scholars agree that junior high school students have poor reasoning ability about figures, so it is necessary to analyze the weak points in teaching with the specific situation of students and focus on the cultivation of students reasoning and analysis ability.

3.2.4 The space concept influencing factors

The factors affecting the development of the space concept of junior high school students were mainly gender, age, and school category.
Shi Jian [13] and Zhang Dongmei [17] both found that there was a significant difference in terms of school category, but not in terms of gender, and that there was a significant positive correlation between their competency and mathematics achievement. Huang Jingshu and He Xiaoya's findings showed that there was a significant difference between the space concept level of students in key schools and non-key schools, however, there was no significant difference in male and female students, and it was the same situation between the first and second-grade students [14]. Wang Wenli also discovered that there was no significant difference in the space concept by gender [15].

3.2.5 The space concept cultivation ways

Research in the area of cultivation waysfocused on classroom instruction and exercise design. Some scholars used a lesson in the area of "Graphing and Geometry" as an entry point to discuss what teaching strategies or teaching methods should be used to develop students' space concepts. Wu Sanyu believed that to better develop the space concept, classroom transformation was needed. Taking the lesson "Three Views" as an example, it should be changed from the teacher's presentation to the students' presentation and shifted from the teacher'sinstruction to students' experimentation [22]. In the lesson "Three Dimensional Figures and Planar Figures", Wang Wei designed puzzles, origami, and models to develop the space concept [23]. ShenYiqun and Wang Xiaofeng illustrated the important role of mathematical experiments in cultivating students' spatial imagination and developing their space concept by taking the teaching of "Movement of Figures" as an example [51]. XueXingying explored the role of interactive courseware in developing the space concept by using the lesson "Expanding and Folding the Square" as an example. The interactive courseware's animation demonstration, hands-on operation, and the same screen display function could effectively promote the development of the space concept [24]. Sun Kai believed that in the teaching of "Rich Graphic World", students should first experience the abstraction of objects to geometric models, and then experience the abstraction of geometric models to geometric figures, so as to develop the space concept [52]. Zhang Lin pointed out that in the teaching of "Congruent Triangles", it was necessary to design diversified origami activities to accumulate students' hands-on experience, deepen students' understanding of congruent triangles in complex shapes, and develop their space concept [25]. In Qin Hongliu's view, the concept teaching of "Congruent Triangles" should follow the teaching process of observing geometric figures - manipulating the motion of figures - constructing congruent triangles [26]. Liu Xiaohong analyzed the lesson "Comparing the Lengths of Line Segments" and found that implementing the cultivation requirements of the space concept requires teachers to flexibly use the textbook, the Geometer's Sketchpad, and the curriculum resources in life [27]. Fan Zhenhui took the lesson "Describing Geometry from Three Views" as an example to elaborate the teaching process of the space concept, and pointed out that to develop students' space concept, it was necessary to make reasonable use of realistic situations and students' experience, build a platform for operation and thinking, and organize and summarize the experience in time [53].

Some scholars analyzed the embodiment and application of the space concept in mathematical problems. By analyzing the sample problems, Huang Yumei [28] and Liu Zhifeng [29] found the key points that reflected the space concept competency in the problems and gave the problem-solving ideas and process, which provide enlightenment for the development. QianDechun and Zhou Lian analyzed the reasons for students' lack of space concept competency in a multiple-choice problem of "View" and proposed strategies to deal with it [30].

In other studies, based on theoretical guidance and own experience, the scholars put forward teaching suggestions on the development of junior high school students space concept focusing on the following aspects: 1. Cultivate students' hands-on skills, encourage students to perform practical operations, and experience the shape, size, and position relationships of space objects or geometric figures. 2. In connection with students' life experiences, more life materials are used to design teaching activities, which is helpful for students to develop the space concept faster. 3. Teachers should skillfully use modern information technology and teaching tools to enable students to have full visual perception. 4. pay attention to students'

gender differences and individual differences, and strengthen classification guidance and training [31-49, 54,55].
Some studies propose the cultivation strategies of the space concept for a specific lesson or a problem, while some studies outline cultivation methods from the perspective of theoretical analysis, which gives teachers not only detailed teaching guidance but also the space to freely innovate their teaching activities in the right direction.

3.2.6 The space concept curriculum resources development

A few scholars carried out curriculum resource development and design of the space concept in junior high school. They actively explored innovative teaching activities that could develop the space concept and verified the effectiveness of teaching activities by conducting teaching experiments. Yang Minyi integrated Geogebra into mathematics teaching, built a teaching strategy model, and conducted controlled experiments. She found that When teaching geometry in a Geogebra environment, students' space concept test scores are obviously better than teaching in a conventional environment and their space concept level is higher. Thus, Geogebra-based geometry teaching could effectively develop the space concept, and each dimension's ability was greatly improved [20]. Chang Linghuan designed a framework for teaching activities based on micro-lecture and conducted experiments. Subsequently, the space concept level of the students in the experimental and control classes was tested separately, and it was found that the students' space concept improved significantly after the micro-lecture teaching. The experimental results showed that micro-lecture teaching contributed to developing students' space concept, and the micro-lecture with their characteristics could effectively solve the dilemmas in the development, such as students' poor hands-on skills and lack of life experience [50]. ZouJiaye developed an origami extended class, which focused on five links: recognizing shapes, memorizing steps, restoring steps, studying the mathematical value of the work, and completing the paper folding independently, and after the course, the space concept of most students was improved to some extent compared to before the extended class [10].
It can be seen that after developing relevant curriculum resources and training students space concept, the test scores were significantly better than before the training. The space concepts sub-dimensions such as the view dimension, the position relationship of objects' dimensions, and the ability to decompose complex figures' dimensions were greatly improved.

4. DISCUSSION

Through the analysis and summarization of 47 papers, the study revealsthat the research on the junior high school students mathematics space concept is relatively abundant in the past two decades in China. The heat is continuously increasing, but the research types are single, most of them are theoretical studies done by front-line teachers. In addition, there is a lack of empirical studies, and no one has done empirical studies after the new standards.
The current research results mainly focus on the following six aspects: the connotation and components of the space concept, the division of the space concept's dimensions, the current development status of the space concept of junior high school students, factors influencing the space concept, ways to cultivate the space concept, and curriculum resources development. Among them, the division of the space concept's dimensions, the current development status, and the cultivation ways are the focus, and before the new edition standards, they have been

very well researched, but subsequent studies have been inadequate. The research on the connotation and components of the space concept, the influencing factors, and the development of curriculum resources are relatively less, and there is still a large space left.

For the study of the connotation and components of the space concept, scholars mostly focus on the content of the standards for in-depth interpretation, as the edition of the standards varies, so do the scholars' interpretations, which can broadly contain three components of abstracting objects into figures, perceiving the orientation of objects, and describing the motion of figures. However, the research perspective is limited and lacks interdisciplinary and multi-faceted analysis.

For the study of the division of the space concept's dimensions, scholars generally believe that the space concept can be divided into 4-6 dimensions, the view dimension and the motion and change of figures dimension are the most frequent dimensions, in addition, there are studies adding the position relationship of objects, projection, drawing, decomposition of complex figures, intuitive inference, map recognition ability, space imagination ability, the transformation between two and three dimensions, the transformation between dynamic and static, and other dimensions. The division of space concept's level is more uniform, divided into three levels: direct observation, simple analysis, and complex analysis. However, no scholars have yet studied the division of dimensions and levels of the space concept core competency in the new edition standards.

For the investigation on the current development status of the space concept of junior high school students, scholars believe that junior high school students have a certain level of the space concept, and different dimensions present different development. However, no research in this area has been conducted after the 2022 edition standards. Whether the space concept has been improved after the concept of core competencies in compulsory education has been proposed deserves further study, as whether students' weaknesses have been improved after the implementation of the new standards, and what new problems have emerged need to be further explored.

For the study of the factors influencing the space concept, scholars find that the gender and age factors do not produce significant differences, the school category factor produces significant differences, and the level of the space concept is positively correlated with students' mathematics achievement. However, the types of factors studied are relatively limited, and many other factors possibly affect the development of the space concept of junior high schools students, such as students' reasons, teachers' reasons, and school's reasons, which need to continue to explore the relevant factors in actual teaching.

Many scholars have discussed how to cultivate and develop junior high school students' space concepts from theoretical and discursive perspectives, and the main teaching strategies are students' hands-on operations, teachers' animated displays, and finding living materials. However, there is a lack of research that empirically verifies which teaching strategies can effectively promote the development of the space concept, and there is no reflection of how the cultivation ways differ from that used in the implementation of the old edition standards.

Research on the curriculum and teaching resources development has been explored by scholars applying resources such as Geogebra, micro-lecture, and origami activities, but the research in this area is not sufficient, not only the development procedures are not mature enough, but also the resources are rather limited. The research can be continued in the future using new-style mathematical software or mathematical tools.

5. CONCLUSION

By compiling and analyzing the literature, the following conclusions were drawn.

1. After the promulgation of the 2022 edition standards, research on the space concept has increased, but it is mostly theoretical research and less empirical research.
2. The research is divided into six main areas: the connotation and components of the space concept, the division of the space concept's dimensions, the current development status of the space concept of junior high school students, factors influencing the space concept, ways to cultivate the space concept, and curriculum resources development.
3. There are abundant studies on the division of the dimensions, the current development status of the space concept, and the ways to cultivate it. The division of dimensions and levels provides a research approach to understanding the development status of junior high school students space concept.The research on the development status suggests that teachers should analyze the weak points in teaching according to the specific situation of students, and focus on the cultivation of students reasoning and analysis abilities. The research on cultivation ways not only gives teachers detailed teaching guidance but also gives them free space to innovate teaching activities in the right direction. Nevertheless, these studies all focus on the period before the implementation of the new edition standards, and no scholars have conducted a dimensional analysis of the space concept and investigated the current status of the space concept development among junior high school students after the implementation. In addition, the proposed ways to cultivate students' space concepts are still in the theoretical stage, and further empirical studies are needed to verify their effectiveness.
4. There is a lack of research on the connotation and components of the space concept, influencing factors, and curriculum resource development. At present, there are few interpretations of the connotation and components, and no scholars have applied interdisciplinary theories to analyze the space concept. The only relevant influencing factors scholars have studied are gender, age, and school type, and there is a lack of research on the influence of other possible factors on space concept development. The types of curriculum resources developed are too few, and the design concept is not up-to-date.

Therefore, further analysis of the research gaps is necessary. Here are five points that can be improved. 1. Interpret the space concept from different perspectives in conjunction with theories of other related disciplines to enrich its connotation of it. 2. Conduct research on the space concept development of junior high school students after the implementation of the new edition standards, analyze the changes that occurred before and after the implementation, identify new problems, and then improve teaching. 3. Increase empirical research on cultivation ways and implement theoretical teaching methods into practice. 4. Enrich research on influencing factors and examine the influence of factors such as students' pre-preparation and teachers' teaching methods on developing students' space concepts. 5. Flexibly apply a variety of in-school and out-of-school resources and networked resources for curriculum development.

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