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How Prepared are China's Preservice Mathematics Teachers? An Insight into their Cognition of Space Concept Literacy

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

At present, the research on space concept literacy in junior high school is a hot topic in the field of education in China. Many scholars have conducted research from different directions, but there is still a gap in the current research on preservice mathematics teachers' cognitive degree of space concept literacy. Therefore, this study used a semi-structured interview method to investigate 10 undergraduates and 10 graduates in a normal university in China to obtain their understanding of the contents related to space concept literacy. The results show that: 1. The cognitive breadth of space concept literacy is high, and most preservice mathematics teachers can cognize all the contents. 2. The cognitive clarity is relatively high. Most preservice teachers have a clear understanding of the cognitive contents, but the cognition of the value is relatively vague. 3. The cognitive accuracy is not high, and only a few preservice teachers can accurately master all the contents, among which the connotation is better, while the cultivation goals and value are worse. 4. The common implementation focus is the following three aspects: preparation of space concept

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literacy, cultivation of space concept literacy, and intensification of space concept literacy. 5. The cognition of the implementation focus is rational. However, preservice teachers have little understanding of content structuring and overall unit instructional design as suggested by the *Standards*, and lack the ability to capture emerging technologies such as AR technology.

Keywords: Space concept literacy; preservice teachers; cognitive degree; junior high schools.

1. INTRODUCTION

The *Mathematics Curriculum Standards for Compulsory Education (2022 Edition)* (Hereinafter referred to as the *Standards*) states that space concept literacy is one of the main manifestations of mathematics core literacy in compulsory education, which mainly refers to the cognition of shape, size, and positional relationship of objects or graphs [1]. It contributes to students' understanding of space and graphs, is closely linked to the development of geometric intuition and reasoning skills, and is the foundation for the development of intuitive imaginative literacy at senior high school level [2]. So its educational value has attracted the attention of many scholars. However, existing studies show that some dimensions of space concept literacy of students do not develop well, and students' space concept level is constrained by teachers' mastery and implementation of space concept literacy [3]. How to develop students' literacy through improving teachers' literacy urgently needs to be addressed. But at present, there is a lack of research on teachers, especially on preservice mathematics teachers' cognition. Thus this paper attempts to address this issue.

2. LITERATURE REVIEW

2.1 Research Status

A number of scholars have studied space concept literacy in junior high school in the past two decades, and by combing through the literature, it is found that the main research themes are as follows: dimensional division, current development status of junior high school students, influencing factors, cultivating ways and curriculum resources development.

2.1.1 Dimensional division

Scholars generally categorized space concept literacy into 4-6 dimensions, with the view dimension and the graphs' motion and change dimension being common dimensions [4-17]. Some studies added the objects' position relation dimension [5,7,13-15]. A small number of studies added the projection dimension [5,7,11], the graphing dimension [5,12,14], the decomposing complex graphs dimension [12,13], or the intuitive reasoning dimension [5,14]. Yan Miao and Zou Jiaye further extracted two dimensions: the ability of cognizing graphs and the ability of spatial imagination [4,16]. Wang Wenli added the dimensions of the two-dimensional and three-dimensional conversion, and the dynamic and static conversion [9].

2.1.2 Current development status of junior high school students

Numerous studies have shown that junior high school students have a certain degree of space concept literacy, but different dimensions have different performances. Yu Xiaohui considered that students' view, graphing, and intuitive reasoning skills were weak [5]. Shi Jian and Gu Jiling found that students performed better in projection and graphs' motion transformation than in view and object orientation [7]. Zhang Dongmei concluded that students performed best in the graphs' motion and change dimension and the graphs' folding and expanding dimension, and worst in the reasoning dimension [12]. Zou Jiaye believed that students were unable to synthetically analyze complex graphs and their dynamic transformations [16].

2.1.3 Influencing factors

The factors affecting the development of junior high school students' space concept literacy mentioned by scholars mainly gender, age, and school type. Through investigation, Shi Jian and Gu Jiling obtained that space concept ability of students had a significant difference in school type, but no significant difference in gender. In addition, their ability had a significant positive correlation with math achievement [7]. The findings of Huang Jingshu and He Xiaoya showed that there was a significant difference in key schools and non-key schools, but there was no significant difference between first-year students and second-year students. [8].

2.1.4 Cultivating ways

The research on the cultivating ways mainly focused on the design of mathematics classes. Taking the lesson "Three Views" as an example, Wu Sanyu believed that to better cultivate space concept, classroom transformation was needed [18]. Wang Wei designed puzzles, origami, and modeling activities to develop students' space concept literacy in the lesson "Three-dimensional Graphs and Plane Graphs" [19]. Shen Yiqun and Wang Xiaofeng used the teaching of "Motion of Graphs" as an example to illustrate the important role of mathematical experimental activities [20]. Xue Xingying found that interactive courseware's animation demonstration, hands-on manipulation, and same-screen display functions could effectively promote space concept literacy [21]. Sun Kai deemed that the teaching of "Rich Graphic World" should enable students to experience the abstraction from physical objects to geometric models, and then from geometric models to geometric figures [22]. 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, and develop space concept literacy [23]. Liu Xiaohong analyzed that the cultivation implementation required teachers to flexibly use the textbook, the Geometer's Sketchpad, and the curriculum resources in life [24].

2.1.5 Curriculum resources development

A few scholars developed curriculum resources for space concept literacy. Yang Minyi integrated Geogebra into mathematics teaching, and found that Geogebra-based geometry teaching could effectively develop students' space concept literacy, with a greater improvement in each dimension [15]. Chang Linghuan designed a teaching activity framework based on microteaching, and found that the students' space concept level were significantly improved after microteaching [25]. Zou Jiaye developed an origami extension course. After the course, space concept literacy of most students has been improved to a certain extent compared with that before [16].

It can be seen that the research on the meaning and cultivation of space concept literacy has been more mature, but few scholars have conducted research on the teachers' mastery of space concept literacy, especially the cognitive degree of preservice mathematics teachers. Meanwhile, the cognitive level of teachers profoundly influences the core literacy level of students, therefore, this paper aims to investigate how current preservice mathematics teachers cognize space concept literacy in junior high school and to put forward corresponding suggestions for the training of preservice mathematics teachers.

The research questions identified in this paper are:

1. How about current preservice mathematics teachers' cognitive breadth of space concept literacy?
2. How about cognitive clarity of space concept literacy?
3. How about cognitive accuracy of space concept literacy?
4. What do preservice mathematics teachers believe is the focus of implementing space concept literacy?
5. Whether their cognition of the implementation focus is rational?

2.2 Theoretical Basis

Before starting the research, it is necessary to define the concept of space concept literacy.

Cao Caihan defines space concept as an ability that involves extracting spatial graphs from physical objects, reflecting physical objects from spatial graphs, decomposing simple and basic graphs from complex graphs, finding out basic elements and their relationships from basic graphs, and making graphs from words or symbols [26].

The *Dictionary of Practical Education*, edited by Wang Huanxun, states that space concept is a representation of objects' shape, size and their positional relations (orientation and distance) formed based on space perception [27].

Han et al. add to the above definition that the representation includes the generalized geometric image of an object left in the human brain, the synergy of thinking and external manipulative skills, figurative thinking accompanied by abstract thinking, and abstract thinking accompanied by figurative thinking [28].

Sun et al. believe that space concept is the understanding and grasping of the interrelationship between space and plane based on the direct perception of the surrounding environment, and it is a kind of ability of students to "blur" the boundaries between two-dimensional and three-dimensional space actively, consciously, or automatically [29].

On the basis of a comprehensive overview of the above statements, the *Standards* propose that space concept is one of the main manifestations of the mathematics core literacy in compulsory education, and that space concept literacy mainly refers to the cognition of shape, size, and positional relationship of spatial objects or graphs. Be able to abstract geometric figures according to the characteristics of objects, and imagine the actual objects described according to geometric figures. Be able to imagine and express the spatial orientation of objects and their position relations with each other. Be able to sense and describe the graphs' motion and change. Space concept literacy helps to understand the form and structure of real-life spatial objects and is the empirical basis for the formation of spatial imagination [1]. This is the most authoritative and popular explanation of space concept in China.

3. METHODS

3.1 Instrument

In order to get results closer to reality, this study used semi-structured interview method to conduct the investigation. The interview outline was compiled around the concept and implementation of space concept literacy, which was divided into the following two types of questions:

Question 1:

(1) Please talk about what space concept literacy is.
(2) Please talk about what are the goals of junior high school mathematics for the development of space concept literacy for students.
(3) What do you think is the value of space concept literacy for junior high school students' future development?

Question 2:

(1) How do you think space concept literacy can be implemented in general junior high school teaching (including pre-school preparation, classroom teaching, after-school activities, etc.)?
(2) Can you elaborate on how space concept literacy should be implemented in classroom teaching?

3.2 Participants

Since undergraduates majoring in Mathematics and Applied Mathematics (Teacher Training) and graduates majoring in Subject Teaching (Mathematics) will form the vast majority of mathematics teacher population in elementary and high schools, these two categories of students are defined as preservice mathematics teachers. This study randomly selected 10 senior students and 10 first-year graduate students from the School of Mathematics and Statistics of Shandong Normal University as the research objects. All of them hold senior high school mathematics teacher qualification certificates, but through communication, they all indicated that they would also consider teaching in junior high schools, so they have certain representativeness and can be used as research objects.

3.3 Data Collection

After coordinating the interview time, the semi-structured interview method was used to interview the research subjects and the whole process was recorded after obtaining consent. For those who were unable to conduct offline interviews, QQ voice telephone was used for telephone interviews, and the whole process was recorded after obtaining consent.

3.4 Data Processing

Removing meaningless ums and ahs and other intonations, the contents of all recorded interviews were converted into text, and organized strictly according to the original responses. In order to better analyze the contents of interview material, each sentence was coded, and the numbering contained the following meanings: interviewee's grade level - interviewee's number - question number - sentence number of the question, e.g., No. G-1-1-1 indicated the first sentence of the first question answered by the first interviewed graduate student, and No. U-2-2-2 indicated the second sentence of the second question answered by the second interviewed undergraduate student.

A, B, and C are used to represent the three indicators of space concept literacy connotation, cultivation goals, and value. Secondly, 1, 2, and 3 are used to represent the contents of different entries. Thus, there are nine items, namely, A1, A2, A3, B1, B2, B3, B4, C1, and C2, and the specific coding items are shown in Table 1.

Table 1. Question 1 coding table

Indicator	Label	Contents
A	A1	Space concept literacy is the cognition of spatial objects or graphs
	A2	Space concept literacy studies shape, size characteristics
	A3	Space concept literacy studies positional relation
B	B1	Be able to abstract geometric figures according to object features
	B2	Be able to visualize the actual objects based on geometric figures
	B3	Be able to imagine and express the spatial orientation of objects and their positional relations with each other
	B4	Be able to perceive and describe the motion and change of graphs
C	C1	It is helpful to understand the morphology and structure of spatial objects in real life
	C2	It lays the foundation for the formation of spatial imagination

3.5 Data Analysis

For research questions 1-3, the interview material was compared with the question 1 coding table. For each indicator, we counted the number of people who were able to cognize the indicator, and then the percentage was calculated to obtain the cognitive breadth.

Next, we analyzed the people who can cognize a certain point. The cognition clarity was determined based on the completeness and accuracy of the interview material.

Further, those who could correctly express all the contents of the three indicators were defined as people with accurate cognition, and the percentage of this group to the total number of people was calculated to obtain cognitive accuracy.

For research question 4, the data was analyzed according to a three-tier coding procedure to obtain the common implementation focus. The interviews for question 2(1) were analyzed as shown in Table 2. Firstly, open coding was used to enter the coded sentences into a newly created Excel database to obtain concept clusters consisting of 82 initial concepts, and 19 primary categories were obtained by merging concept clusters with the same attributes. Secondly, in the spindle coding stage, further merge the primary categories and discover the interrelationships among these primary categories to get 7 thematic categories. Finally, selective coding was used to think deeply about the relationships among the thematic categories, and then identify three core categories to summarize the implementation focus.

For research question 5, the research results of question 4 were discussed with the requirements in the *Standards* to judge the cognitive rationality of the implementation focus.

4. RESULTS

4.1 Cognitive Breadth

As shown in Table 3, it is found that the current preservice mathematics teachers can cognize all the points related to space concept literacy in the *Standards*, and for each point, the number of those who can cognize it is more than 50%. Among these, "Space concept literacy is the cognition of spatial objects or graphs", "Space concept literacy studies shape, size characteristics" and "Be able to abstract geometric figures according to object features" are cognized by the most people, with 17 people each able to cognize them, accounting for 85% of the total. "Be able to imagine and express the spatial orientation of objects and their positional relations with each other" and "Be able to perceive and describe the motion and change of graphs" are the least cognized by 11 people, accounting for 55% of the total.

It can be seen that the preservice teachers have a wide range of cognition of space concept literacy. Interestingly, the vast majority of people focuses on individual points, such as the shape of objects and graphs and the transformation of each other, but many people ignore the positional relation of objects and the movement of graphs.

4.2 Cognitive Clarity

The cognitive clarity of preservice mathematics teachers who can cognize a certain point is further analyzed, and the results are shown in Table 4. As a whole, people with a high level of cognition per point are more than those with a low level of cognition, and the clarity percentage of all points reaches 72.6%: 27.4%. Among them, the clarity percentage of A2 and B1 is the highest, reaching 94%: 6%, and the label with the lowest clarity percentage is C1, which reaches 50%: 50%.

It can be seen that preservice teachers have a clear cognition of space concept literacy. The points "Space concept literacy studies shape, size characteristics" and "Be able to abstract geometric figures according to object features" are most clearly cognized, while "It is helpful to understand the form of spatial objects in real life" is the most ambiguous.

4.3 Cognitive Accuracy

As shown in Table 5, the number of preservice mathematics teachers who can accurately cognize the three indicators of space concept literacy are 16, 9, and 10 respectively, accounting for 80%, 45%, and 50% of the total, while only 6 preservice teachers can accurately cognize all three indicators, among which 4 are graduates and 2 are undergraduates.

It can be seen that most preservice teachers can accurately cognize the connotation, while only about half of them can accurately cognize the cultivation goals and value, indicating that half of them are not clear or can not understand the contents of space concept literacy in the *Standards*. Even fewer can cognize all three, and undergraduates perform worse.

4.4 Implementation Focus

As can be seen from Table 6, preservice mathematics teachers generally believe that the implementation of space concept literacy focuses on three aspects: preparation of space concept literacy, cultivation of space concept literacy, and intensification of space concept literacy.

Table 2. Question 2(1) coding table

Open coding	Spindle coding	Selective coding
Guide students to make their own geometric models Guide students to observe graphs and geometry in life Guide students to gather information for a class Conduct space concept level tests	Before class: Students engage in making, observing, and collecting activities	Space concept preparation
Do good instructional design Design appropriate teaching activities, such as observation activities, manipulative activities Choose appropriate teaching tools, such as physical teaching aids, multimedia courseware, geometry software	Before class: Teachers prepare teaching procedures, teaching activities, and teaching tools	
Use material objects to assist in teaching Use multimedia to assist in teaching Use pictures or videos to assist in teaching Use drawing tools to assist in teaching	In class: Use multiple teaching tools	Space concept cultivation
Create situations that relate to real-life Be good at asking questions to guide Lead students to conduct observation, operation activities Focus on group teaching	In class: Design a variety of teaching sessions	
Conduct student-centered teaching Stimulate students' interest in learning Flexibly adjust the teaching contents	In class: Overall control class	
Assign homework that relates to real-life Assign tasks related to measurement, observation, or operation activities Test students' space concept level	After class: Consolidate knowledge	Space concept enhancement
Guide students to observe life and dig math problems Conduct extracurricular activities	After class: Conduct deeper expansion	

Table 3. Cognitive breadth statistics

Indicator	Label	Point	Percentage	Number	Percentage
A	A1	3	100%	17	85%
	A2			17	85%
	A3			16	80%
B	B1	4	100%	17	85%
	B2			12	60%
	B3			11	55%
	B4			11	55%
C	C1	2	100%	14	70%
	C2			13	65%

Table 4. Cognitive clarity statistics

Indicator	Label	Percentage（High: Low）
A	A1	88%：12%
	A2	94%：6%
	A3	81%：19%
B	B1	94%：6%
	B2	67%：33%
	B3	55%：45%
	B4	55%：45%
C	C1	50%：50%
	C2	69%：31%

Table 5. Cognitive accuracy statistics

Indicator	Number	Percentage
A	16	80%
B	9	45%
C	10	50%
A、B、C	6	30%

Table 6. Implementation focus data statistics

Implementation Focus	Concrete Measures	Number	Percentage
Preparation	Students engage in making, observing, and collecting activities	18	90%
	Teachers prepare teaching procedures, teaching activities, and teaching tools	14	70%
Cultivation	Use multiple teaching tools	15	75%
	Design a variety of teaching sessions	14	70%
	Overall control class	8	40%
Intensification	Consolidate knowledge	16	80%
	Conduct in-depth expansion	8	40%

In terms of preparation, the vast majority of preservice teachers believe that implementation should be carried out from two directions: students and teachers, which are mentioned 18 times and 14 times respectively, accounting for 90% and 70%. For students, before class, they need to make preparations related to class contents. Interviewee U-8 indicated that teachers should ask students to make their own geometric models and observe real-life objects. For teachers, it is necessary to design teaching procedures, teaching activities, and teaching tools before class. Interviewee U-10 believed that teachers should set spatial situations closely related to real life. Interviewees U-7 and U-9 considered that teachers should select appropriate teaching tools according to the teaching contents, such as geometric models, ruler and compass, original objects, multimedia courseware, etc.

In terms of cultivation, the focus can be divided into three categories: using multiple teaching tools, designing a variety of teaching sessions, and overall control class, accounting for 75%, 70%, and 40% respectively. Interviewee G-6 cited the use of various teaching tools, such as, in the teaching of motion and variation of graphs, Geogebra, Matlab, Flash and other mathematical software are used to realize dynamic display. When further explaining the teaching sessions, interviewee G-2 mentioned the session of creating life situations, interviewee G-5 mentioned the session of teacher questioning, and interviewee G-10 mentioned the process of observation and manipulation, etc. At the same time, interviewees U-1 and U-3 also paid attention to taking students as the main body in class and constantly monitoring students' class status.

In terms of intensification, the main views of preservice teachers can be roughly divided into knowledge consolidation and in-depth expansion, and the proportion of these two views is 80% and 40% respectively. Interviewee G-4 said that students' space concept level should be tested after class to help teachers reflect on the effectiveness of their teaching. The interviewees who advocated in-depth expansion, such as U-3, believed that students should be further allowed to carry out project-based learning in group cooperation.

4.5 Cognitive Rationality of Implementation Focus

Cognitive rationality is obtained by comparing the views of preservice teachers to the instructional recommendations in the *Standards.*

Preservice teachers believe that different teaching tools and teaching sessions should be used to guide students to conduct independent thinking, group cooperation, and experimental exploration. This is consistent with the *Standards*. Besides, as the *Standards* requires, preservice teachers put forward problem exploration activities related to the life situation in the three aspects of implementation focus mentioned above. In addition, the *Standards* emphasizes the integration of information technology and mathematics teaching. Similar points have been made by preservice teachers. However, preservice teachers have little understanding of content structuring and overall unit instructional design as suggested by the *Standards*, and lack the ability to capture emerging technologies such as AR technology. It can be seen that preservice teachers' cognition about implementation focus is basically rational, but there are also shortcomings.

5. DISCUSSION

In terms of the cognitive breadth, the data shows that almost all preservice mathematics teachers can cognize all the points of space concept literacy, indicating that they have a wide range of cognition. In terms of the specific contents, the cognition degree of the nature and transformation of objects and graphs is high, while the cognition degree of spatial orientation and movement change is low. It can be seen that they are not proficient in every point.

In terms of the cognitive clarity, the data shows that nearly 70% of preservice mathematics teachers have a clear understanding of the cognitive contents, so the cognitive clarity is relatively high. In terms of the specific contents, the cognition of "Space concept literacy studies shape, size characteristics" in connotation and "Be able to abstract geometric figures according to object features" in cultivation goals is the clearest, while the cognition of the practical significance is the vaguest, which shows that the value cognition is low.

In terms of the cognitive accuracy, the data shows that the number of preservice mathematics teachers who can accurately cognize the three indicators only accounts for 30%, indicating that the cognitive accuracy is not high. Looking at the three indicators separately, most can accurately cognize the connotation, but small number of them can accurately cognize the cultivation goals and value, indicating that they do not have a good grasp of the latter two indicators. At the same time, the data shows that the performance of postgraduates is slightly better than that of undergraduates, which is probably because postgraduates have received more professional teacher education and have a better understanding of mathematics core literacy.

Regarding the implementation focus, preservice mathematics teachers believe that the focus should be on three aspects, namely preparation, cultivation, and intensification, which correspond to the three periods of time, namely, before, during, and after class. In terms of preparation, Most agree that it should be implemented from both student and teacher entry points. In terms of cultivation, most suggest that a variety of teaching tools and teaching sessions should be flexibly utilized, and a few are concerned that the class should be reasonably adjusted according to students' status. In terms of intensification, they consider that the implementation focus should not only be on consolidating knowledge at the end of the class but also on expanding it further.

In view of the cognitive rationality, the implementation focus is basically consistent with the *Standards*' requirements for space concept literacy, but there are also some places that preservice teachers have not noticed, such as content structuring, unit instructional design, and emerging teaching technologies. So it can be considered that their cognition of implementation focus is comparatively rational.

6. CONCLUSION

How do preservice mathematics teachers cognize space concept literacy? Through investigation and analysis, this paper draws the following conclusions:

1. The current preservice mathematics teachers' cognitive breadth of space concept literacy is high, and most of them can cognize all the contents.
2. The cognitive clarity of space concept literacy is relatively high. Most preservice teachers have a clear understanding of the cognitive contents, however, their perceptions of the value are more ambiguous.
3. The cognitive accuracy of space concept literacy is not high, and only a few preservice teachers can accurately master all the contents. To be more specific, they perform better in the connotation, while the cultivation goals and value are worse.
4. Currently, it is cognized that the focus of implementing space concept literacy lies in three aspects: preparation, cultivation, and intensification, which are embodied in students' pre-class activities, teachers' pre-class preparation, flexible use of various teaching tools and teaching sessions in class, overall control of class, knowledge consolidation and in-depth development after class.
5. The preservice teachers have a rational cognition of the implementation focus. However, there are some places that they have not noticed, such as content structuring, unit instructional design, and emerging teaching technologies.

Based on the above conclusions, the following suggestions are put forward:

1. In the training of preservice mathematics teachers, colleges and universities should attach importance to the interpretation of curriculum standards, conduct more lectures and forums to explain mathematics core literacy and the latest teaching concepts, and give students more opportunities to experience mathematics classroom teaching in primary and high schools.
2. Preservice mathematics teachers should take the initiative to study and research. They should extensively read literature to understand the connotation and training path of mathematics core literacy, and learn teaching cases of excellent teachers.

The limitation of this study is the small number of objects selected for the survey. Therefore, the sample scope should be expanded in the future, and preservice mathematics teachers of different grades in different universities should be selected for research. In addition, only qualitative research methods were used in this study, and different research methods can be explored to enrich research conclusions in the future.

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CONSENT

As per international standard or university standard, respondents' written consent has been collected and preserved by the author(s).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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