Study on Evaluation of Mathematical Interdisciplinary Learning Based on a Improved SOLO Classification Method

ABSTRACT

Both the "Mathematics Curriculum Standards for Compulsory Education (2022 Edition)" and the "General High School Mathematics Curriculum Standards (2017 Edition, 2020 Revision)" emphasize the implementation of interdisciplinary thematic learning in mathematics. It can be seen that today's society attaches great importance to interdisciplinary learning in mathematics. Many scholars have done a lot of research on the connotation, design methods, and implementation strategies of interdisciplinary learning in mathematics. However, there are very few studies on the evaluation of interdisciplinary learning in mathematics, and there is no specific model that can be applied to the evaluation of interdisciplinary learning in mathematics. Based on this, this article is based on the "SOLO classification evaluation method" and the new curriculum standards. Firstly, it gives the specific division of the "SOLO classification evaluation method" in interdisciplinary learning in mathematics. On this basis, the dimension of emotional attitude is added, and combined with the performance of students in the process of interdisciplinary activities, a new hierarchical evaluation model "SOLO-ID classification evaluation method" for interdisciplinary learning in mathematics is formed to evaluate the level of students' interdisciplinary learning in mathematics, and specific application cases and advantages are given.

Keywords Interdisciplinary learning evaluation, Mathematics, SOLO classification evaluation method, SOLO-ID classification evaluation method

1. INTRODUCTORY

In April 2022, the Ministry of Education, based on the experience in implementing the 2011 edition of the mathematics curriculum standards, promulgated the "Mathematics Curriculum Standards for Compulsory Education (2022 Edition)" [1], which revised the basic nature, basic concepts, curriculum objectives, and curriculum content of the mathematics curriculum in the compulsory education stage. It is stipulated that the content of the mathematics curriculum in the compulsory

education stage consists of four fields: number and algebra, graphics and geometry, probability and statistics, and comprehensive and practical [11,12]. Among them, the comprehensive and practical field mainly focuses on interdisciplinary thematic learning, and appropriately adopts thematic learning and project-based learning methods to design problems with real and relatively complex situations, guiding students to comprehensively use the knowledge and methods of mathematics and interdisciplinary disciplines to solve problems [13,14]. The "General High School Mathematics Curriculum Standards (2017 Edition, 2020 Revision)" [3] also clearly requires "being able to reasonably use mathematical language and thinking for interdisciplinary expression and communication." It can be seen that today's society attaches great importance to interdisciplinary thematic learning, and interdisciplinary has become the trend of educational reform and an important part of future mathematics teaching and evaluation [15-17].

Up to now, many scholars have discussed the connotation, theoretical basis, value, and design strategies of interdisciplinary learning. However, there are very few studies on the evaluation of interdisciplinary learning, and there are even fewer studies specifically on the evaluation of interdisciplinary learning in mathematics, and there is no specific plan that can be applied to the evaluation of mathematics interdisciplinary. Based on this, this article intends to improve the SOLO classification evaluation method to obtain a new model to evaluate the level of students' interdisciplinary learning in mathematics.

This research is guided by the following questions:

(1) What should be evaluated in interdisciplinary learning in mathematics?

(2) How to use a specific mode to evaluate the level of students' interdisciplinary learning in mathematics?

2. LITERATURE REVIEW

In November 2023, Haoyan Feng, Yan Chen, and Weiguo Zhang [7] took the "Counting Skipping Ropes" unit as an example and gave the index construction of the performance evaluation of the interdisciplinary thematic learning in primary school mathematics; in April 2024, Wei Zhou and Minjun Cai [5] summarized the characteristics of the interdisciplinary learning evaluation frameworks abroad, mainly including contextualizing learning tasks, visualizing the learning process, technologizing evaluation methods, and evidencing evaluation results; in the same month, Xinyi Jiang and Yanping Lin [10] constructed the framework for evaluating the interdisciplinary literacy in primary school mathematics; in June, Zhihui Yuan [9] gave

the three major elements of the performance evaluation in primary school mathematics from an interdisciplinary perspective: objectives, tasks, and evaluation; in October, Hongwei Zhu [8] took the "Compound Line Graph" in primary school mathematics as an example and constructed an evaluation system for the interdisciplinary thematic learning in primary school mathematics.

It can be seen that there are very few studies on the evaluation of interdisciplinary learning in mathematics, and no specific mode has been given to evaluate the level of students' interdisciplinary learning in mathematics.

3. EVALUATION CONTENT OF MATHEMATICAL INTERDISCIPLINARY LEARNING

The content of learning evaluation should be guided by learning objectives. Therefore, the evaluation content of interdisciplinary learning in mathematics is the objective of interdisciplinary learning in mathematics.

3.1 The ability of mathematics knowledge and understanding

The essence of interdisciplinary learning in mathematics lies in having a "mathematical flavor"[6]. Through interdisciplinary learning, on the one hand, students can deeply master the basic concepts, principles, and formulas of mathematics, understand their positions in the mathematical system, and be able to use them for logical reasoning and proof. On the other hand, they can also deeply understand the essence and application of mathematics, so as to apply them to a wider range of fields.

3.2 The ability of interdisciplinary knowledge integration

The focus of interdisciplinary learning is on "interdisciplinary". It does not only focus on a single subject of mathematics, but hopes that students can think from multiple perspectives, associate the knowledge learned in different disciplines, and integrate the knowledge and methods of mathematics and other disciplines to form a new knowledge system.

3.3 The ability of problem-solving

Having the ability to integrate interdisciplinary knowledge does not mean having the ability to solve problems. The ability to integrate interdisciplinary knowledge refers to integrate the knowledge and methods of different disciplines to form a new knowledge system or perspective, while the problem-solving ability refers to the ability of using the learned knowledge and methods to find effective solutions through thinking when facing practical problems, which requires a higher level than

the ability to integrate interdisciplinary knowledge and needs to apply the integrated knowledge to practical problems.

3.4 The ability of innovation consciousness and practical

This objective aims to stimulate students' innovative thinking and improve their practical ability of hands-on operation by integrating the knowledge and methods of mathematics and other disciplines. Interdisciplinary learning in mathematics requires students to integrate the knowledge of mathematics with other disciplines according to a specific problem. This integration process is essentially an innovation. Students can explore the essence and application of mathematical knowledge by applying mathematical knowledge to other fields, discovering the parts that can be improved or the methods that can be optimized at present, and thus put forward new mathematical viewpoints, concepts, and methods, promoting the innovation and development of mathematics and other disciplines.

3.5 The ability of communication and cooperation

There are roughly two ways of interdisciplinary learning: interdisciplinary thematic learning and interdisciplinary project-based learning. Both of these learning methods emphasize teamwork, requiring students to learn to play their own advantages in the team, respect the contributions of others, learn to express their views clearly and accurately, communicate effectively with classmates or experts from different disciplinary backgrounds, and learn to cooperate with team members and complete project tasks together.

3.6 Learning attitude and values

The profound significance of interdisciplinary learning not only lies in the expansion of the breadth and depth of knowledge, but also in profound impact on students' learning attitudes and emotional values. By combining learning content with personal interests, real life, and future careers, students' interest in mathematics learning is stimulated, and they are more actively involved in learning. At the same time, the themes of interdisciplinary learning are often far-reaching topics such as social practice and environmental protection. Through social practice, investigation and research, students explore the formation and solution process of problems, cultivating their sense of social responsibility and environmental protection awareness.

At the same time, the 2022 edition of the mathematics curriculum standard points out that the evaluation of interdisciplinary learning should "pay attention to process evaluation and determine the evaluation method according to the teaching

objectives of the theme activities. Not only should attention be paid to students' mastery of teaching content, but also to the degree of students' participation in activities." Therefore, students' performance in interdisciplinary learning activities is also an important part of the evaluation.

Based on the above objectives and requirements, this article constructs a new evaluation method for interdisciplinary learning in mathematics.

4. A NEW MODE OF MATHEMATICAL INTERDISCIPLINARY LEARNING EVALUATION: "SOLO-ID ClASSIFICATION EVALUATION METHOD"

4.1 The connotation of the traditional "SOLO Classification Evaluation Method"

4.1.1 Theoretical Basis of the "SOLO Classification Evaluation Method"

The theoretical basis of the SOLO classification evaluation method [4] mainly comes from multiple fields such as psychology and education. In psychology, inspired by Piaget's theory of cognitive development stage, that is, children's cognitive development is staged, and each stage has its specific cognitive ability. Biggs and Collis found in their research that this staged characteristic not only exists in children's overall cognitive development, but also in the cognitive process of individuals for specific knowledge. Therefore, the SOLO classification evaluation method was proposed. In the field of education, the traditional evaluation method often tests students' knowledge mastery through examinations, while ignoring the evaluation of their thinking process and cognitive structure. Biggs proposed the view of paying attention to the "quality" of students' learning in the book "Evaluating the Quality of Learning: The Structure of the Observed Learning Outcome (SOLO)". He believes that a person's overall cognitive structure cannot be directly detected, but the complexity of the thinking structure shown by a person when answering a specific question can be directly detected. This evaluation method that analyzes the thinking level reached by students when solving a certain problem is the SOLO classification evaluation method.

4.1.2 Evaluation Levels

The SOLO classification evaluation method divides students' cognitive structures from low to high into five levels: pre-structural, unistructural, multistructural, relational, and extended abstract. The specific manifestations are as follows:

Level	Corresponding Thinking Performance Level

Level	Corresponding Thinking Performance Level
Pre-structural	Students basically cannot understand and represent the problem or task, cannot form an effective answer, are logically confused, and have tautologies.
Unistructural	Students can understand the problem or task, but can only provide one relevant piece of information or view, lack consistency, and rush to the conclusion after touching a little.
Multistructural	Students can understand the problem or task and can provide multiple relevant pieces of information or views, but these pieces of information or views are isolated and not connected, and fail to form a knowledge network.
Relational	Students can understand the problem or task and can connect multiple pieces of information or views to form a logical answer and can answer or solve relatively complex specific problems.
Extended Abstract	Students can understand the problem or task and can go beyond the given information, make abstract generalizations, form a deep understanding and creative answers, and show a stronger sense of research and innovation.

4.2 Improvement of the SOLO Classification Method in Interdisciplinary Learning Evaluation

This section adjusts the specific division of SOLO according to the objectives of interdisciplinary learning in mathematics. At the same time, since the SOLO classification evaluation method only focuses on the result of students' learning: the change of cognitive level and does not pay attention to the process of students' learning, this article also adds the evaluation of the learning process to the SOLO classification evaluation method, and the improved SOLO classification evaluation method is called the "SOLO-ID classification evaluation method".

4.2.1 Specific Division of the SOLO Classification Evaluation Method in Mathematical Interdisciplinary Learning

The previous section described the five-level division of the traditional SOLO classification evaluation method, namely pre-structural, unistructural, multistructural,

relational, and extended abstract. Combined with the objectives of interdisciplinary learning in mathematics, the SOLO classification evaluation method can be specifically divided as follows:

Level	Performance	Specific Manifestations in Mathematical Interdisciplinary Learning
Pre-structural	Students basically cannot understand and represent the problem or task, cannot form an effective answer, are logically confused, and have tautologies.	Students' mathematics knowledge is chaotic and cannot accurately understand the requirements of the problem.
Unistructural	Students can understand the problem or task, but can only provide one relevant piece of information or view, lack consistency, and rush to the conclusion after touching a little.	Students can only focus on mathematics and cannot associate with the knowledge of other disciplines.
Multistructural	Students can understand the problem or task and can provide multiple relevant pieces of information or views, but these pieces of information or views are isolated and not connected, and fail to form a knowledge network.	Students can associate with the knowledge of mathematics and other disciplines, but cannot connect these knowledge to form a new knowledge system and cannot use them.
Relational	Students can understand the problem or task and can connect multiple pieces of information or views to form a logical answer and can answer or solve relatively complex specific	Students can integrate and apply the multidisciplinary knowledge they think of and initially solve practical problems in the real world.

Level	Performance	Specific Manifestations in Mathematical Interdisciplinary Learning
	problems.	
Extended Abstract	Students can understand the problem or task and can go beyond the given information, make abstract generalizations, form a deep understanding and creative answers, and show a stronger sense of research and innovation.	Students can not only solve practical problems, but also conduct in-depth research and make pioneering innovations.

4.2.2 Incorporating Emotional Attitude Objectives

Based on the above specific division of the SOLO classification evaluation method in mathematical interdisciplinary learning, considering the emotional attitude objective in the interdisciplinary learning objective, the SOLO classification evaluation method is further improved as follows:

Level	Specific Manifestations in Mathematical Interdisciplinary Learning
Pre-structural	Students' mathematics knowledge is chaotic and cannot accurately understand the requirements of the problem.
Unistructural	Students can only focus on mathematics and cannot associate with the knowledge of other disciplines.
Multistructural	Students can associate with the knowledge of mathematics and other disciplines, but cannot connect these knowledge to form a new knowledge system and cannot use them.
Relational	Students can integrate and apply the multidisciplinary knowledge they think of and initially solve practical problems

Level	Specific Manifestations in Mathematical Interdisciplinary Learning
	in the real world.
Extended Abstract	Students can not only solve practical problems, but also conduct in-depth research and make pioneering innovations.
Emotional Attitude and Values	Students can not only solve problems innovatively, but also have positive emotional experiences and correct value recognition in this process.

4.2.3 Paying Attention to the Process of Students' Participation in Interdisciplinary Learning Activities

Interdisciplinary learning activities require every student to participate, divide the work, practice personally, and jointly complete a project task. But how to examine the participation degree of students in this process? At the summary and display stage after the project, each member of the group can be required to come on stage to talk about which part they are responsible for in this project and what work they have done, and multiple teachers can score together. At the same time, in the process of carrying out interdisciplinary learning activities, teachers should also pay attention to the situation of each group in real time, observe everyone's participation degree, and make records. Students who perform very outstandingly and have a high participation degree in the project process can be upgraded, while those who perform poorly and do not actively participate can be downgraded.

4.3 A New Interdisciplinary Evaluation Mode: "SOLO-ID Classification Evaluation Method"

Combining the above steps, the "SOLO-ID classification evaluation method" is specifically manifested as follows:

Grade	Level	Specific Manifestations in Mathematical Interdisciplinary Learning
A	Emotional Attitude and Values	Students can not only solve problems innovatively, but also have positive emotional experiences and correct value recognition in this process.

Grade	Level	Specific Manifestations in Mathematical Interdisciplinary Learning
B	Extended Abstract	Students can not only solve practical problems, but also conduct in-depth research and make pioneering innovations.
C	Relational	Students can integrate and apply the multidisciplinary knowledge they think of and initially solve practical problems in the real world.
D	Multistructural	Students can associate with the knowledge of mathematics and other disciplines, but cannot connect these knowledge to form a new knowledge system and cannot use them.
E	Unistructural	Students can only focus on mathematics and cannot associate with the knowledge of other disciplines.
F	Pre-structural	Students' mathematics knowledge is chaotic and cannot accurately understand the requirements of the problem.

At the same time, students who perform very outstandingly and have a high participation degree in the project process can be upgraded, while those who perform poorly and do not actively participate can be downgraded, but it should be specially noted as a reminder. For example, Li Ming can only be rated as B level in terms of cognitive structure level division, but he served as the person in charge in the task process, coordinated the work of team members, resolved conflicts among team members, actively communicated with teachers, and took the initiative to undertake more tasks, so he can be upgraded to A level, but it should be written: A level (project process bonus) to encourage everyone to actively participate in the activity process.

5. APPLICATION CASE

5.1 Case of Mathematical Interdisciplinary Project-Based Learning: "My Suggestions to the Principal on the Campus Greening Situation and Improvement"

5.1.1Theme Determination

A proposal is a specific suggestion, plan, or scheme put forward by an individual or a group in a formal occasion or organization, aiming to solve a certain problem, improve a certain work, or promote a certain cause. By asking students to make proposals, their critical thinking ability can be exercised, making them more proficient in independent thinking and problem-solving, and cultivating their sense of responsibility because students need to be responsible for their own proposals and cultivating their innovation consciousness, enabling them to discover problems in the real world and have the courage to break through and innovate.

The plane rectangular coordinate system and the methods for solving the areas of regular and irregular figures are the key knowledge in junior high school mathematics and have strong practical applicability in life. Combined with the actual situation of the campus and the discussions among teachers of other disciplines, the theme is determined as "My Suggestions to the Principal on the Campus Greening Situation and Improvement".

This theme has extensive educational value. It can guide students to understand nature, protect the environment, be brave in breaking through and innovating, learn to express their views in multiple languages such as mathematics and words, solve practical problems, understand the construction and structure of the campus, experience the ingenuity therein, enhance students' love for the campus, and let students realize that they are a part of the school, thus cultivating their sense of responsibility.

5.1.2Project Learning Objectives

(1)Master the drawing method of the plane rectangular coordinate system and the method for solving the area of irregular figures.

(2)Through on-site investigations, record the distribution, area, vegetation, terrain, etc. of the green belts on the campus, draw a plane structure diagram, and learn to analyze problems by combining multidisciplinary knowledge.

(3)Through group cooperation, combine the knowledge of mathematics, geography, biology, art, and other disciplines to create proposals, improve the ability of interdisciplinary expression, communication, and problem-solving, enhance innovation consciousness, and cultivate a sense of responsibility.

5.1.3 Project Implementation

(1)Inform students in advance and form study groups

Before the formal start of the project, inform students of the specific arrangements and evaluation criteria of the project activities, guide students to divide into groups on their own, and the group members should cooperate with each other to complete the project activities.

(2)Determine the driving task

Through the joint discussion of teachers of multiple disciplines, the driving task of this project is determined as: put forward suggestions for the improvement of campus greening to the principal, and in the suggestions, the rationality of the suggestions should be explained by combining the knowledge of mathematics, biology, geography, art, and other aspects, and cultivate the ability of being brave in innovation, communication and expression, and planning and arrangement.

(3)Carry out project learning activities

Task 1: Understand the greening situation on the campus

The prerequisite for making suggestions is to understand the current situation. The mathematics teacher, biology teacher, and geography teacher jointly lead the students to conduct investigations in various parts of the campus, record the distribution status of the campus greening, calculate the area of each green belt, query what plants are planted in the green belt and what their growth conditions are, etc.

Task 2: Learn the solution method of the area of irregular figures and the application of the plane rectangular coordinate system

The shapes of some green belts are irregular, and the knowledge of the solution method of the area of irregular figures needs to be used to calculate their areas. The teacher guides the students to abstract the irregular green belts into plane figures and calculate their areas. At the same time, use the plane rectangular coordinate system to draw the distribution map of each green belt on the campus.

Task 3: Analyze and improve, and draw the improved plan view

After the on-site investigation, the group jointly analyzes whether the current greening distribution is reasonable and whether the planting of vegetation is reasonable, considering the ornamental and practical values of plants, querying materials or asking teachers, giving more reasonable suggestions, and using art knowledge and information technology to draw the improved effect diagram.

Task 4: Summarize the results and write a proposal

Summarize all the processes such as investigation, analysis, and suggestions, query materials to learn the writing method of the proposal, and complete the writing of a proposal through group cooperation.

5.2 Evaluation - Application of the "SOLO-ID Classification Evaluation Method"

The teacher judges according to the final version of the proposal submitted by the group according to the following standards:

Grade	Level	Specific Manifestations in the Project
A	Emotional Attitude and Values	Students can not only solve problems innovatively but also experience the beauty of the campus in this process, and improve positive value recognition such as the awareness and sense of responsibility of protecting the campus and the environment.
B	Extended Abstract	Students put forward innovative ideas in the proposal or used unique technological means.
C	Relational	Students can integrate and apply the multidisciplinary knowledge they think of, making the final proposal both scientific and reasonable and exquisite and beautiful.
D	Multistructural	Students considered this problem from multiple perspectives, but did not comprehensively apply them to the actual improvement, or the integration was not perfect enough.
E	Unistructural	Students only considered this problem from the perspective of mathematics and did not reflect the application of other disciplines.
F	Pre-structural	The application of mathematical knowledge in the student's proposal is incorrect, and the key to the problem is not grasped.

After the project is completed, a summary report is carried out, and each member of the group should come on stage to talk about their role in the team, what work they have done, and what content they have completed. The teacher can upgrade those who perform outstandingly in the group and downgrade those who perform poorly.

6. ADVANTAGES OF THE "SOLO-ID ClASSIFICATION EVALUATION METHOD"

Based on theoretical analysis and practical research, the new evaluation model "SOLO-ID Classification Evaluation Method" has the following advantages:

(1)It has a solid theoretical foundation. The "SOLO-ID Classification Evaluation Method" is an improvement made on the basis of the traditional SOLO classification evaluation method, combined with the actual situation of interdisciplinary learning in mathematics, and has a reliable theoretical foundation.

(2)It takes into account the performance of students in interdisciplinary learning activities in mathematics, which meets the requirements of paying attention to the process put forward in the 2022 edition of the mathematics curriculum standard.

(3)It attaches great importance to the examination of abilities and the changes in emotional attitudes. The mere mastery of mathematical knowledge is only a lower level in the "SOLO-ID Classification Evaluation Method", and interdisciplinary literacy, problem-solving ability, innovation consciousness, and emotional attitude are the top priorities, which is more in line with the requirements of talent cultivation in the new era.

(4)It is conducive to comprehensively evaluating the comprehensive quality of students. The "SOLO-ID Classification Evaluation Method" not only considers mathematical knowledge and skills but also mathematical abilities, and pays attention to both results and processes.

(5)It improves the enthusiasm of students to participate in interdisciplinary activities in mathematics. Since the performance of students in the activity process will directly affect their evaluation, students are more actively involved in the process of interdisciplinary activities.

Conclusion : the "SOLO-ID Classification Evaluation Method" gives the evaluation criteria for interdisciplinary learning in mathematics in the form of hierarchical evaluation, comprehensively considers students' knowledge level, interdisciplinary ability, problem-solving ability, and innovation consciousness, pays attention to the process, improves the enthusiasm of students to participate in

activities, and provides a reference for the further promotion of interdisciplinary learning in mathematics.

COMPETING INTERESTS

Authors have declared that no competing interests exit.

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