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A Survey on Mathematical Problem-Solving Skills and Mathematical Core Literacy among Middle School Students in Sichuan, China

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Abstract

With the transformation of China's economic structure, there is a growing demand for high quality talents in the society. Cultivating students' Mathematical problem-solving skills and Mathematical core literacy has become an important mission of mathematics education. This study aimed to investigate Mathematical problem-solving skills and Mathematical core literacy among Middle school students in Sichuan Province. A cross-sectional survey research design was used to randomly select a sample of 57 students from a Eighth-grade class in Sichuan Province M High School. And it was measured by Mathematical problem-solving skills scale and Mathematical core literacy test. The study found that in Mathematical problem-solving skills, students ‘performance in the four dimensions of“Understand the Problem”, “Devise a Plan” and“Carry Out the Plan”, “Look Back and Reflect”were low; Regarding Mathematical core literacy, students demonstrated excellent performance in Arithmetic Ability, good performance in Geometric Intuition, Spatial Conception, Data Conception, and Creativity, moderate performance in Abstraction Ability and Reasoning Ability, while their performance in Modeling Conception and in Application Awareness were low. This study will provide concrete support for regional educational development and optimization of teaching strategies.

Keyword: Mathematical Problem-Solving Skills, Mathematical Core Literacy, Polya's Problem-Solving Model, Mathematical Competency, Sichuan China

Introduction

In recent years, China's Ministry of Education (MOE) has gradually promoted a shift in mathematics education from traditional knowledge transfer to practical application and problem solving (MOE, 2019). To achieve this shift, various Chinese ministries have been working hard to promote reforms. For example, in 2022, the Chinese Ministry of Education (MOE) promulgated the compulsory mathematics curriculum standards and emphasized the development of students' ability to identify, formulate, analyze and solve problems (MOE, 2022a). Mathematical problem-solving is a standard activity for learners at all stages of education (Kandemir & Gür, 2009).According to Hartono (2014), Mathematical problem-solving is a complex task that requires strong reasoning and logical thinking skills. Mathematical problem-solving skills involves understanding the problem, developing a plan, executing the plan and giving feedback. Research has shown that Mathematical problem-solving skills are important skills for developing students to solve real-world problems independently (Dixon, 2005). Mathematical problem-solving involves the use of logical reasoning and mathematical modelling to cope with complex real-life problems (Fadillah & Wahyudin, 2022). Chinese students excel in mathematical problem solving in the PISA test. In 2009 and 2012, Shanghai represented mainland China on PISA and ranked first (OECD, 2010). In 2018, students from Beijing, Shanghai, Jiangsu, and Zhejiang (BSJZ, China) won first place globally again (OECD, 2019). These students come from economically developed regions of China. However, the performance of Mathematical problem-solving skills of students from relatively economically weaker regions in Western China has not been fully studied.

Since 2011, core literacy has gradually received national attention and was formally introduced into the Chinese education system in 2013 as an important part of education reform (MOE, 2022b). The connotation of the mathematical core literacy includes three components and nine dimensions, which are inseparable. It can be said that the ‘nine dimensions’ are the concretization of the ‘three components’. The Curriculum Standards (2022) propose that the three components of the mathematical core literacy include: 1) being able to observe the real world through mathematical vision; 2) being able to think about the real world through mathematical thinking; and 3) being able to express the real world in mathematical language (MOE, 2022a). At the junior high school level, mathematical core literacies are abstraction ability, arithmetic ability, geometric intuition, spatial conception, reasoning ability, data conception, modelling conception, application awareness, and creativity (MOE, 2022a).

There is a close correlation between Mathematical problem-solving skills and Mathematical core literacy. On the one hand, the Chinese Compulsory Education Mathematics Curriculum Standards (2022) explicitly emphasize the problem-solving process as a pathway to develop Mathematical core literacy(MOE, 2022a). On the other hand, studies have demonstrated the important role that Mathematical core literacy plays in the mathematical problem-solving process. For example, Muniroh et al. (2017) showed that developing students' abstraction skills through the Polya problem solving step can effectively improve their ability to solve algebraic problems. Reasoning is a way of thinking that is needed when solving problems. It can combine multiple ideas to gain new knowledge and draw conclusions (Hasanah et al., 2019; Wulandari & Wutsqa, 2019). Mathematical modelling establishes a connection between mathematics and the real world, transforming real-life problems into mathematical equations and solving problems according to real-world significance (Arseven, 2015). However, there is no current research exploring the close association between Mathematical problem-solving skills and Mathematical core literacy. Therefore, there is a need to simultaneously investigate the current status of students' Mathematical problem-solving skills and Mathematical core literacy and to analyze the associations between them, especially the interplay between these competencies when certain competencies are weak.

Sichuan is the most populous province in western China, and the largest province in science and education. At the end of 2022, there were 23,000 schools of all levels in the province, with 16,377,000 students and 1,263,000 teaching staff, and it has built the fifth largest modern education system in China and the largest in western China (Feng, 2023). Sichuan, as an important area of national strategic programmers such as 'One Belt, One Road', the Yangtze River Economic Belt, and the Chengdu-Chongqing Twin Cities Economic Circle, needs many talents to support it (Feng, 2023). The education in Sichuan Province has a difficult mission, so that the construction of education in Sichuan Province is very urgent. Through the field research on the education situation in Sichuan Province, it is found that there still exists the problem of unbalanced supply of high-quality education resources and incomplete development of education (Feng, 2023). This status quo affects the overall quality of students, especially in the development of Mathematical problem-solving skills and Mathematical core literacy which may face many challenges. Therefore, this study aims to investigate the Mathematical problem-solving skills and Mathematical core literacy of students in Sichuan Province, including specific performance and weaknesses. And to analyze the connection between Mathematical problem-solving skills and Mathematical core literacy. To explore whether they are related and how they interact with each other in specific problem-solving processes.

In summary, although existing studies have investigated the current status of Mathematical problem-solving skills and Mathematical core literacy, there is a lack of research on students' Mathematical problem-solving skills and Mathematical core literacy of students in central and western China. This study investigated the current status of Mathematical problem-solving skills and Mathematical core literacy among students in Sichuan Province and revealed the intrinsic connection between Mathematical problem-solving skills and Mathematical core literacy. This study will provide specific mathematical support for regional educational development to improve teaching strategies to enhance students' Mathematical problem-solving skills and Mathematical core literacy.

Methods

This study used a cross-sectional survey research design. A class of 57 students was randomly selected from Grade 8 of School M in Sichuan Province as the study population. The class was also surveyed and tested with a 100% recall rate. The research instruments included the Mathematical problem-solving skills scale and the Mathematical core literacy test. The Mathematical problem-solving skills scale is based on the four steps of Polya's problem-solving model (Understand the Problem, devise a Plan, Carry Out the Plan, Look Back and Reflect), with each step as a dimension, and each dimension containing 2-3 items, totaling 9 items; and a 5-point Richter scale, ranging from 'strongly disagree' (1 point) to 'strongly agree' (5 point). The Mathematical core literacy test was designed based on 9 dimensions, with one test question per dimension and a total score of 10 points per question. The scale is divided into 5 levels (every 2 points). Specifically, 0-2 is weak; 2-4 is low; 4-6 is moderate; 6-8 is good; and 8-10 is excellent. Two experts in Mathematics Education conducted content validity tests on the questionnaire, the paper and its scoring criteria to ensure the scientific validity and applicability of the instrument. The results of the reliability analysis showed that the Cronbach alpha coefficient of the Mathematical problem-solving skills scale was 0.957 and the Cronbach alpha coefficient of the Mathematical core literacy test was 0.858, which both indicated that the instruments had a high reliability. Data analyses were conducted using SPSS software and mainly descriptive statistical analyses were performed to reveal students' performance in in Mathematical problem-solving skills and Mathematical core literacy.

Results

The purpose of this study was to investigate the current status of Mathematical problem-solving skills and Mathematical core literacy of students in M secondary school in Sichuan Province. The results showed that there were significant differences in students' performance on the dimensions of Mathematical problem-solving skills (see Table 1 and Figure 1). Students' performance on the dimension “Understand the Problem” was low with a mean of 2.75. The scores of U1 (M=3.26, SD=1.11) and U2 (M=2.25, SD=0.95) showed that students were conscious of actively identifying the information in the problem but had difficulty in understanding the topic. had difficulty in understanding the questions. Specifically, on U1, only 8.8% of students disagreed and 14% chose ‘strongly disagree’, indicating that most students were aware of actively identifying the question. On U2, 54.4% of students chose ‘Disagree’ and 17.5% chose ‘Strongly Disagree’, which indicates that most students lacked a clear understanding before solving the problem. In addition, students' performance on the “Devise a Plan” dimension was low, with a mean value of 2.58. The results of P1 (M=3.19, SD=1.01), P2 (M=2.28, SD=0.84), and P3 (M=2.28, SD=0.86) indicated that students were conscious of their problem-solving strategies, but they relied on them. to develop solution strategies, but their reliance on single concepts and especially their ability to extract and integrate concepts is inadequate. Especially in P2 and P3, more than 54.4% reported that they could not extract appropriate concepts and more than 45.6% reported that they could not combine concepts.

The students ‘performance in the dimension “Carry Out the Plan” was at a low level with a mean value of 2.59. Although the mean score of E1 was 3.21 (SD=1.08), 33.33% of the students chose to be neutral; the results of E2 (M=1.96, SD=1.01) showed the students’ ability in actively thinking about alternatives. The results of E1 showed that only 25.8% of the students were able to execute the plan in a structured manner, while the results of E2 showed that 78.9% of the students were not able to think of alternatives in a proactive manner. Students' performance on the “Look Back and Reflect” dimension was low with a mean of 2.69. Data from R1 (M=3.09, SD=1.01) showed that 3.5% of students chose “Strongly Disagree” and 3.5% chose “Disagree”. R1 (M=3.09, SD=1.01) shows that the percentage of those who selected ‘Strongly Disagree’ (3.5%) and ‘Disagree’ (26.3%) is not much different from the percentage of those who selected ‘Strongly Agree’ (8.80%) and ‘Agree’ (24.6%). However, the R2 (M=2.30, SD=0.80) with 49.1% of the students choosing ‘disagree’ and 14% choosing ‘strongly disagree’ indicates that most of the students had difficulty in effectively translating the learning experience into strategies for solving other problems.

Table 1
Score and Description of each Dimension of Mathematical Problem Solving Skills

	Item	Description	N	Mean	Standard Deviation (SD)
Understand the Problem	U1	I will proactively identify important information in a question before solving it.	57	3.26	1.11
	U2	I will be able to understand the requirements of the question and be clear about the meaning of each known condition.	57	2.25	0.95
	Total		57	2.75	0.95
Devise a Plan	P1	I will consciously develop clear steps or strategies before solving a problem.	57	3.19	1.01
	P2	I am able to identify the appropriate concepts to use from the requirements of a question.	57	2.28	0.84
	P3	I will consider combining different mathematical concepts rather than relying only on a single concept.	57	2.28	0.86
	Total		57	2.58	0.83
Carry Out the Plan	E1	I am able to follow my plan and complete each step in an organized way.	57	3.21	1.08
	E2	When obstacles arise, I will actively think about alternatives rather than giving up.	57	1.96	0.91
	Total		57	2.59	0.94
Look Back and Reflect	R1	After solving a problem, I will reflect on my performance in solving the problem and look for areas of improvement.	57	3.09	1.01
	R2	I will think about how I can apply this problem-solving experience to other similar problems.	57	2.30	0.80
	Total		57	2.69	0.79

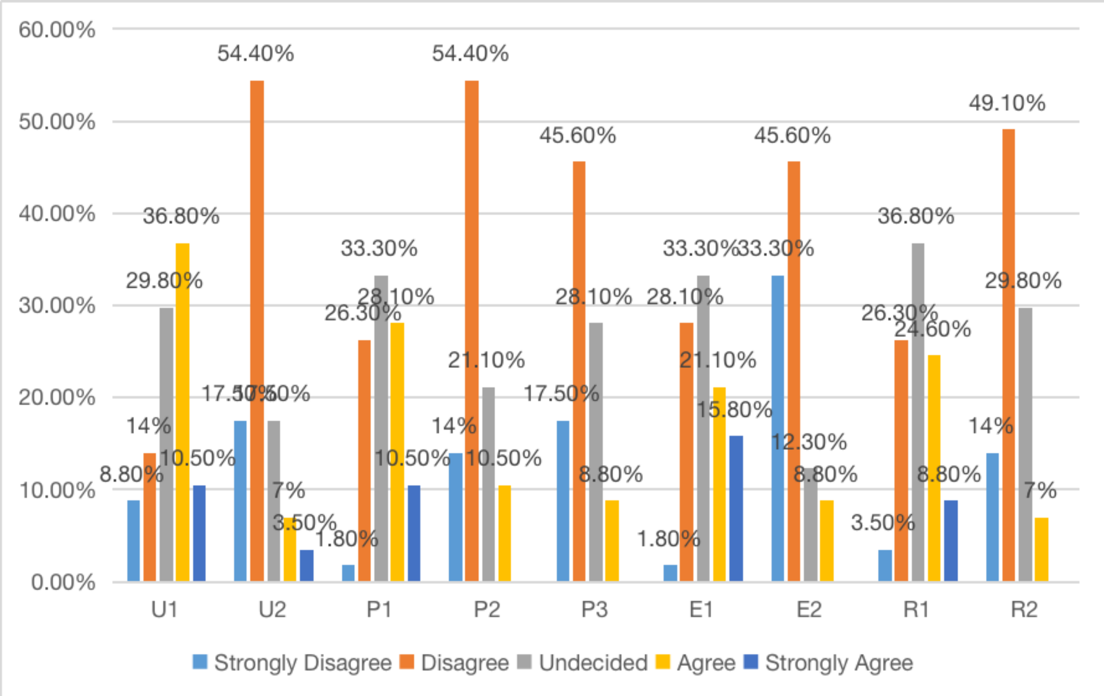

Figure 1 Frequency distribution of 9 dimensions of mathematical problem-solving skills

The results showed that the students' level of development in the different Mathematics core literacies was uneven (see Table 2 and Figure 2). The results showed that students performed excellent in Arithmetic Ability, with a mean score of 8.37 and a standard deviation of 1.46. 52.63% of the students were able to obtain a score of 8-10, while 35.09% were able to obtain a score of 6-8. This shows that students are solid in basic arithmetic operations, and most of them are able to complete the tasks correctly with a high degree of proficiency and accuracy. Students performed good in Geometric Intuition with a mean score of 6.28 and a standard deviation of 1.58. 43.86% of students scored 6-8. 38.60% scored 4-6. This indicates that the majority of students were able to understand and apply geometric concepts and possessed some geometric reasoning skills.

Related to this, the overall performance of students in Spatial Conception was good with a mean score of 7.26 and a standard deviation of 1.59. Close to 50% of the students scored in the range of 6-8, and the percentage of students in the lower band was only 7.02%. This shows that students' spatial perception is relatively strong, and most of them possess strong three-dimensional spatial understanding and positional relationship perception. In addition to Spatial Conception, students performed good in Data Conception, with a mean score of 7.4 and a standard deviation of 1.57. 45.61% of the students scored in the range of 6-8 points, and 26.32% scored in the range of 8-10 points. This indicates that students possessed a strong understanding of data handling and statistical concepts and were able to analyze and apply data well. Students performed good in Creativity with a mean score of 6.12 and a standard deviation of 1.51. 43.86% of students‘scores were clustered in the range of 4-6 and 36.84% of students’ scores were clustered in the range of 6-8. Most of the students were able to demonstrate some creative thinking and a unique approach to problem solving.

In addition, in terms of Abstraction Ability, the mean score of students was 4.63 with a standard deviation of 1.46. The scores were mainly concentrated in the moderate level, with

45.61% of the students scoring 2-4, which indicated that they were weak in identifying the conditions and variables and were only able to partially identify the information and make a preliminary understanding of the information. 40.35% of the students scored 4-6 and were able to identify most of the information but remained vague in the abstraction of information relationships. Deficiencies in Abstraction Ability also affected students' Reasoning Ability, which was moderate overall, with a mean score of 4.74 and a standard deviation of 1.38. 52.63% of students scored 4-6, indicating that their logical reasoning process was generally sound but not sufficiently rigorous; 33.33% of the students scored 2-4, indicating a break in their chain of reasoning or insufficient logical coherence.

The overall level of students' Modeling Conception was low, with a mean score of 3.44 and a standard deviation of 1.13. Nearly 60% of the students scored 2-4, indicating that they had difficulties in transforming their mathematical knowledge into a model and lacked systematic Modeling Conception and competence. Students' poor performance in Modelling Conception subsequently affects their performance in practical application situations. The overall level of students' Application Awareness was low with a mean score of 2.79 and a standard deviation of 1.26. 45.61% of the students scored 0-2 and 43.86% scored 2-4. This indicates that they have significant problems in understanding practical application situations.

Table 2
The Score Distribution of 9 Dimensions of Mathematical Core Literacy

Dimension	Mean	Standard Deviation
Abstraction Ability	4.63	1.46
Arithmetic Ability	8.37	1.40
Geometric Intuition	6.28	1.58
Spatial Conception	7.26	1.59
Reasoning Ability	4.74	1.38
Data Conception	7.4	1.57
Modeling Conception	3.44	1.13
Application Awareness	2.79	1.26
Creativity	6.12	1.51

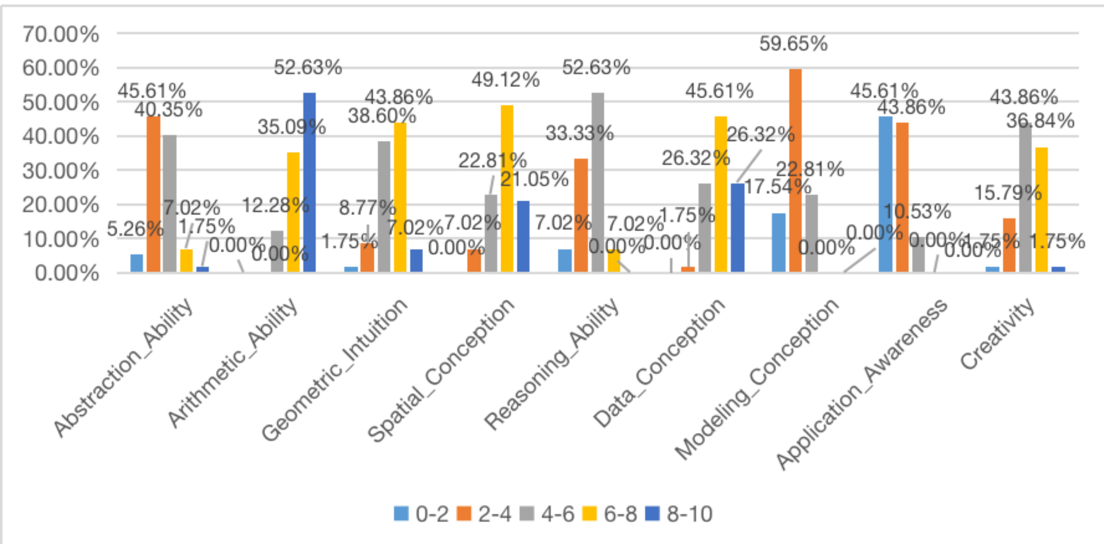

Figure 2 Frequency distribution of 9 dimensions of mathematical core literacy

Discuss

In Understand the Problem, students are able to consciously and proactively identify information in the problem but lack in-depth understanding before solving the problem. This may affect their problem-solving skills and learning outcomes. Research has shown that deep understanding is the key to effective problem solving as it involves a comprehensive understanding of the nature of the problem, its structure and potential solutions (Sinaga et al., 2023).On Devise a Plan, students showed some awareness but relied on a single concept and were particularly deficient in extracting and integrating concepts. The dependency may lead to a lack of flexibility and creativity when faced with complex problems and an inability to effectively apply multiple knowledge and skills to solve problems (Lee et al., 2024). This may stem from the fact that students often lack cross-curricular learning opportunities to make connections between different disciplines, thus limiting their ability to integrate knowledge.

In Carry Out the Plan, students were able to follow the steps of the plan but were unable to actively think of alternative solutions to the problem. This is consistent with previous research on the lack of critical thinking training: students often lack training in evaluating and choosing between different solutions during the learning process (Chinofunga et al., 2024).In 'Look Back and Reflect', students have difficulty in applying what they have learnt and their learning experiences to solve real-world problems. This may be since traditional teaching methods may place too much emphasis on memorization and comprehension at the expense of application and practice of knowledge (Hmelo-Silver, 2004). Students may lack timely feedback and guidance when attempting to solve real-world problems, resulting in their inability to effectively apply what they have learnt.

More importantly, there is a correlation between the students' Mathematical problem-solving skills and competence in Mathematical core literacy. In this study, students excelled in Arithmetic Ability and performed good in Data Conception, which indicated that they possessed a high level of proficiency in basic computational tasks and data processing skills. Arithmetic Ability can affect students' overall cognitive abilities including memory, attention, and logical reasoning (Thevenot et al., 2023). Eaves et al. (2022)showed that students with stronger Arithmetic Ability were more able to select advanced problem-solving strategies.

Students performed good in Spatial Conception and Geometric Intuition, reflecting a better understanding of graphical perception and spatial relationships. Through a good understanding of spatial relationships, students can more effectively identify and manipulate shapes, understand abstract mathematical concepts, and apply these concepts to solve real-world problems (Harris, 2023). Spatial thinking skills can also help students reason and make effective decisions when solving complex problems. For example, in geometry problems, students need to be able to visualize and manipulate the shape and position of three-dimensional objects, an ability that is directly dependent on their spatial thinking skills (Battista et al., 2018). By developing and strengthening this ability, students will not only improve their math's performance, but also enhance their overall competence in Science, Technology, Engineering and Mathematics (STEM) (Pritulsky et al., 2020).The level of Creativity performs good. Through cooperative group learning, students can inspire each other, stimulate creativity, and work together to solve complex problems (Kumar, 2020). Creativity helps students make connections between different concepts and ideas. This ability to integrate knowledge from various areas is crucial for solving complex problems that require a multidisciplinary approach (Minai et al., 2021).

Students scored Moderate on Abstraction Ability and Reasoning Ability. In terms of Abstraction Ability, students have difficulty in distilling the relationships between key concepts and conditions when faced with complex mathematical problems; they are unable to determine which variables and conditions are important and which information is redundant, which affects their ability to develop effective teaching strategies. This view is supported by Ningsih and Hidayati (2022) who argued that abstraction is the process of embedding mathematical concepts, and if the mathematical concepts are embedded correctly, students will be able to solve problems. In terms of Reasoning Ability, students are unable to use known theorems to derive new results or have difficulty transferring prior knowledge to new problems. This affects students' thinking process and undermines their confidence in active thinking and problem solving. Hasanah et al. (2019) showed that Reasoning is essential thinking in problem solving to combine multiple knowledge to derive new conclusions.

On Modeling Conception and Application Awareness, students' performance was low, indicating that they have difficulty in applying their mathematical knowledge to real-world situations. In the case of Modelling Conception, students had difficulty in translating real-life problems into mathematical problems or mathematical models. This resulted in their inability to apply their knowledge and concepts to real life and solve problems. Relevant studies have shown that mathematical modelling establishes a link between mathematics and the real world by translating real problems into mathematical equations and solving problems based on real-world meanings (Arseven, 2015). As far as Application Awareness is concerned, students are unable to explain the real world in terms of mathematical concepts, let alone make connections between different disciplinary knowledge to solve real-life mathematical problems. Lack of Interdisciplinary Learning Environments: Students often lack interdisciplinary learning environments to make connections between different disciplines in their learning process (Stephan et al., 2021).

Conclusion

In this study, we explored students' performance on different dimensions of Mathematical problem-solving skills and Mathematical core literacy. The results showed that students' performance in “Understand the Problem”, “Devise a Plan”, “Carry Out the Plan”, and “Look Back and Reflect” are all at the lower end of the scale. Students were able to actively identify information in ‘Understand the Problem’, but lacked in-depth understanding, which affected the effectiveness of the solution. In ‘Devise a Plan’, students were aware but lacked flexibility in extracting and integrating multiple concepts, suggesting that the ability to integrate knowledge could be improved. In addition, students lacked critical thinking in ‘Carry Out the Plan’ and had difficulty in applying different solutions flexibly, which prevented them from finding effective solutions to real-world problems. In the ‘Look Back and Reflect’ stage, students had difficulty in applying what they had learnt to new problem situations, reflecting the inadequacy of traditional teaching methods in strengthening the application of knowledge.

Regarding Mathematical core literacy, students demonstrated excellent performance in Arithmetic Ability, good performance in Geometric Intuition, Spatial Conception, Data Conception, and Creativity, moderate performance in Abstraction Ability and Reasoning Ability, while their performance in Modeling Conception and in Application Awareness were low.

Contribution

This study provides significant theoretical and practical contributions by investigating the mathematical problem-solving abilities and mathematical core literacy of students in Sichuan Province, as well as their interplay. Theoretically, the research delves into how specific dimensions of mathematical core literacy—such as abstraction ability, reasoning ability, modeling awareness, and application awareness—interact during problem-solving processes, filling a critical gap in existing studies that often analyze these abilities in isolation. Practically, the findings highlight the major challenges faced by students in economically underdeveloped regions of Western China in developing mathematical problem-solving abilities and core literacy. These insights not only offer targeted guidance for curriculum design and teaching strategies in Sichuan but also provide valuable references for other regions with similar economic and educational conditions. This dual contribution underscores the importance of tailoring teaching methods and strategies to regional needs, offering practical and theoretical support for enhancing students' mathematical problem-solving abilities and core literacy while promoting educational equity.

Significance

This study provides a critical lens into the current state of mathematical problem-solving skills and mathematical core literacy among students in Sichuan Province, particularly in the context of economically underdeveloped regions. The findings offer a nuanced understanding of students' specific strengths—such as arithmetic ability and geometric intuition—and weaknesses, including application awareness and modeling conception. This detailed profiling of student competencies serves as a foundation for educators to develop more targeted and effective teaching strategies.

Limitation

The limitation of this study is that the sample is limited to students in one district and the results may not be generalizable to other districts. In addition, this study used only quantitative methods, which provided general trends but lacked in-depth qualitative analyses to explore in detail the challenges and thinking processes that students encountered during specific problem-solving processes. Also, the data collection relied on students' self-reports, which may have subjective bias and affect the objectivity of the results.

Further Study

In future studies, consideration could be given to expanding the sample to include students from different regions to verify the generalizability of the findings. In addition, qualitative research methods, such as interviews or observations, can be used to gain insights into the actual difficulties and thinking patterns encountered by students in the process of problem solving, to supplement quantitative research. In addition, attempts can be made to develop and apply teaching programmes and evaluate their effectiveness in enhancing students' Mathematical problem-solving skills and Mathematical core literacy.

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