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Review of Empirical Research on the Concrete-Representational-Abstract Teaching Strategy in Improving Mathematical Ability of Children with Autism Spectrum Disorder

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Abstract

On the basis of a systematic review of 12 pieces of empirical research abroad, it was found that current research objects were limited to specific age groups, the design forms were monotonous, and most of them were carried out with the accompaniment of professionals, the tasks were completed in a controlled environment, the targets focused on basic skills and the strategy application was limited, and the effect evaluation system was not yet perfect. Research should promote the diversity of intervention targets to broaden strategy application in the future, try different design methods and standardized design operation processes, explore the goal of stratification to increase research depth, design natural diverse collaborative intervention plan and conduct multi-faceted result verification, improve multi-dimensional effect verification, and provide enlightenment for intervention practices in China.

Keywords

Concrete-representational-abstract teaching strategy; mathematical ability; children with autism spectrum disorder.

1. Introduction

Mathematical ability is individual psychological characteristic that makes one safely complete mathematical activities[1], "Mathematics Curriculum Standards for Compulsory Education (2022 Edition)" emphasizes making students master fundamental knowledge and skills with the aid of mathematical learning, and developing core mathematical literacy and social responsibility[3]. Autism Spectrum Disorder (ASD) is disease group which is mainly manifested as social disorder and restricted behavior, it belongs to developmental disorders [4], and its diagnostic criteria have been revised in DSM-V to use autism spectrum disorder collectively call pervasive developmental disorder except Reiter's syndrome[5–6]. Children with ASD generally is characterized by lower overall mathematical ability and significant difference: due to influence of executive function and attention deficit, their mathematical ability lags behind that of peers in general[7–9]; their ability tends to differentiate into two modes—high achievement and low achievement, but high achievers are only in the minority and present uneven skill development [10–11]; as age increases and learning contents become abstract, the gap with peers gradually widens [12-13]. Given this dilemma, the Concrete-Representational-Abstract (CRA) teaching strategy offers effective intervention methods, this strategy helps children deepen their conceptual understanding and establish knowledge connections through concrete, representational, and abstract three-stage progressive teaching[14], recent studies have found that CRA guidance strategy is effective in teaching addition, subtraction, and multiplication to students with ASD [15–16]. CRA utilizes the advantages of visual support and clear instructions, which fits the learning characteristics of students with ASD. This research systematically reviewed empirical literature on CRA intervention in mathematical ability of children with ASD

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from 2014 to 2025, analyzed research limitations and proposed prospects, in order to provide theoretical and practical references for ASD mathematics education in China.

2. Research Methods

This paper adopted a systematic review method, conducted literature collection and screening through three steps: keyword search, initial screening, and full-text screening, ultimately determined empirical literatures meeting the research criteria, and provided reliable research foundation for subsequent analysis. First, literatures were collected via keyword searches, "Concrete-Representational-Abstract/CRA," "Virtual- Representational-Abstract/VRA," "Autism Spectrum Disorder/ASD," and "Mathematics Ability/Mathematical Computation/Word Problem Solving", these four sets of keywords were used in four foreign language core databases for search: Web of Science, EBSCO, Sage Journals, and PMC, the search period was limited to January 2014 to July 2025, the search scope was peer-reviewed journals. Secondly, highly relevant literatures to the research topic were screened by browsing literature abstracts and keywords, literatures with duplicate publication and cannot obtain the full text were deleted to complete the preliminary literature screening. Finally, on the basis of the pre-established criteria for literature inclusion and exclusion, the full-text reading and rigorous verification were conducted for preliminary screened literatures, 12 English empirical literatures were included in the end.

By consulting other review research, this research established the inclusion criteria of literatures: (1) the literatures must be paper in English-language journal, with full text available, the research content is complete and the argument is sufficient; (2) the research type must be a peer-reviewed empirical investigation, CRA/VRA strategy intervention experiments were conducted around improving mathematical ability; (3) the intervention objectives must involve at least one child with autism spectrum disorder, and the research clearly reports the basic information of the objectives; (4) the CRA/VRA strategy as the core intervention method, and the intervention process has clear implementation steps and operational details; (5) the research focused on improving the mathematical ability of children with autism, with clear research questions, methods, and conclusions, and reported detailed intervention data related to mathematical ability, such as accuracy, independence, and observer consistency. Exclusion criteria for literatures include: (1) non-English literatures, review/comment category, book chapters, conference proceedings, or other non-empirical literatures; (2) papers that do not involve children with autism spectrum disorder as intervention subjects, or only focus on other special populations for research; (3) paper that use CRA/VRA strategy as the primary intervention method, or only mention the names of the strategy without explaining the usage condition of specific strategy; (4) papers without clear data support for the intervention results of mathematical ability, lack clear research questions, methods, or conclusions. The basic information of the literatures is summarized in Table.1 below.

3. Research Findings

This part of the research wll review and analyze the selected literatures from seven dimensions: intervention targets, research design, intervention objectives, intervention executors, intervention environments, intervention strategies, and intervention effects, detailed information is shown in in Table 1.

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Table 1. Summary of Basic Information of Literatures

Year	Author	Intervention Target	Research Design	Intervention Objective	Intervention Executor	Intervention Environment	Intervention Strategy	Intervention Effect
2014	Flores[17]	7 primary school students aged 5-12 with autism, gender unclear	paired sample t-test	single digit addition and subtraction	researcher	classroom, one-on-one to one on three offline teaching	CRA +strategy teaching model	instant effect: significant improvement in calculation accuracy
2015	Stroizer[18]	3 boys with autism	multiple-baseline across behaviors	carry addition, reverse subtraction, multiplication within 5	researcher	classroom, 1 month, 5 days a week, 60 minutes of offline group teaching each time	CRA+" mnemonic strategy +mnemonic strategy	instant effect: improved calculation accuracy; maintenance effect: skills can be maintained after intervention
2016	Yakubova[19]	4 primary school boys with autism	multiple-baseline across skills	subtraction, addition, and numerical comparison	researcher	separate office in the education center, offline teaching	CRA + video demonstration	instant effect: improved calculation accuracy; maintenance effect: skills can be maintained after intervention
2018	Washington[20]	2 high school students with autism accompanied by intellectual disabilities, gender unclear	multiple-baseline across subjects	borrowing subtraction calculation and word problems	researcher	separate classroom, offline teaching	CRA + video demonstration	instant effect: accuracy improvement in solving word problems; social validity: high acceptance between teachers and students
2018	Ma[21]	2 second grade boys with autism and 1 second grade girl with autism	multiple-detection across subjects	"part-part-whole" addition and subtraction word problems	researcher	small room next to the resource room, offline teaching,	CRA+COMPS	instant effect: improvement in addition accuracy
2019	Hammons[22]	3 6-year-old primary school students with autism and 1 11-year-old middle school student with autism, gender unclear	multiple-detection across subjects	single digit addition	researcher	separate classroom, at least 3 times a week, no more than 30 minutes of one-on-one offline teaching each time	VRA	instant effect: accuracy improvement in solving word problems; maintenance effect: skills can be stably maintained
2021	Root[23]	2 13-year-old boys with autism	multiple-detection across subjects	multiplication word problems	researcher	room next to the classroom, one-on-one offline teaching	VRA	instant effect: improvement in accuracy and problem-solving independence; maintenance effect: skill is stable after intervention
2022	Bouck[24]	1 seventh grade boy with autism	multiple-detection across subjects	division with remainder	researcher	through ZOOM (online platform), once a week, one-on-one online for no more than half an hour each time	VRA＋SLP	instant effect: improvement in calculation accuracy; maintenance effect: skills can be maintained for a long time; social validity: positive parental evaluation
2023	Kaya[25]	1 7-year-old girl with autism	multiple-detection across skills	single digit addition and subtraction, understanding digits	researcher	home living room, one-on-one offline teaching	CRA	Instant effect: improvement in accuracy and independence; maintenance effect: skills can be stably maintained
2023	Long[26]	4 girls with autism	multiple-detection across subjects	two-digit number borrowing subtraction	researcher	through ZOOM (online platform), once a week, one-on-one online teaching for no more than 40 minutes each time	VRA＋SLP	instant effect: Improvement in step execution accuracy and problem-solving accuracy; maintenance effect: skills can be maintained
2023	Goya[27]	2 11-year-old high school students with autism, gender unclear	multiple-baseline across behaviors	one step, two-step, three-step algebraic equation solving	researcher	resource classrooms in regular schools, one-on-one offline teaching	CRA	instant effect: improvement in step execution accuracy and problem-solving accuracy; maintenance effect: skills can be maintained
2024	Alabdulaziz M[28]	5 primary school students with autism, gender unclear	single subject experimental design (unclear specific type)	fraction calculation ability (simple true fraction, addition and subtraction calculation with fraction)	researcher	school resource room/separate classroom, one-on-one offline teaching	video teaching +CRA + self-monitoring checklist	instant effect: significant improvement in accuracy; maintenance effect: higher skill stability; generalization effect: transferable among different question formats

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(1) Intervention Targets

12 existing pieces of empirical research totally involved 34 intervention targets with ASD. Firstly, in the number of intervention targets, there are significant differences in the number of intervention targets in different research, intervention targets fluctuate between 1-7 people, small sample designs with 1-4 people account for 75% of the total, only a study has 7 subjects, overall, small sample studies are the main. Secondly, in terms of gender distribution, only 7 out of 12 studies explicitly reported subject gender information, while the rest 5 did not specify gender. In the 7 studies that clearly reported gender, a total of 26 subjects were included, including 22 males and 4 females, the proportion of males was significantly higher than that of females, and the overall gender distribution was uneven. In addition, from the distribution of educational stages, the intervention targets are concentrated in 5-14 years old, only covering the primary to junior high school stage, among which 9 studies mainly focused on the primary school stage, and only 2 studies involved the junior high school stage, the ASD group aged 15 and above has not yet been included in the research scope. Finally, from the perspective of individual barrier characteristics, research has limited attention to associated disorder, only 1 out of 12 studies explicitly mentioned the intellectual disability in subjects, a study did not whether there is associated disorder, the rest 10 studies only focused on the ASD group alone, without paying attention to subgroups with other disorders.

(2) Research Design

By analyzing the experimental designs of 12 existing pieces of empirical research, it was found that all research used single subject experimental research design, among which there were 5 multiple-detection designs across subjects, 3 multiple-baseline designs across behaviors, 1 multiple-baseline design across skills, 2 single subject designs without specific types, and only 1 used paired sample t-test. It can be seen that in the empirical research on applying CRA teaching strategy to intervene in the mathematical ability of children with ASD, the main research method is the multiple-detection design across subjects in a single subject experimental design. Due to the strong heterogeneity of children with ASD, it is difficult to select a group of subjects with highly consistent developmental levels, therefore, a single subject design has become the most suitable research method in this field. The multiple-detection design across subject includes many ASD children with different characteristics but similar developmental stages, it can test the intervention effect on a wider range, improve the representativeness of the sample and the external validity of the research results. Furthermore, the multiple-detection design adopts intermittent data collection, and intervention can be carried out without waiting for the baseline to be completely stable, which can significantly save research time and implementation costs, and is more suitable for small-sample and refined special education intervention research.

(3) Intervention Objectives and Contents

By analyzing the intervention objectives and contents of 12 pieces of existing empirical research, it was found that all research focused on improving the mathematical ability of children with autism spectrum disorder, and the intervention contents involved various aspects such as basic calculations, digit knowledge, mathematical problem-solving, and advanced operations; for the specific intervention targets, they mainly included two aspects: mathematical calculation ability and mathematical problem-solving ability. Addition and subtraction of one-digit numbers, subtraction, multiplication, division, fraction calculation, and digit recognition with borrowing and carry, and algebraic equations with one to three steps were included. From the perspective of skill extension, 6 out of 12 studies used skill maintenance as an intervention goal and tested skill stability through tracking after intervention; another 8 items used skill generalization as intervention focus, focusing on the transfer of task types, calculation forms, and learning scenarios. Overall, the intervention objectives mainly focused on academic mathematical skills training, centered around mastery

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of operations and problem-solving, and widely valued skill maintenance and cross situational transfer.

(4) Intervention Executors

By analyzing the situation of intervention executors in 12 pieces of existing empirical studies, it can be seen that when the identity of intervention executors is relatively single in existing studies, in order to ensure the accuracy, standardization, and effectiveness of intervention implementation, the above 12 studies are all conducted by the researchers themselves as intervention executors, and there has not been the situation where frontline teachers, parents, or other educational personnel in schools intervene alone. In addition, specialized standardized training was conducted before the intervention began, including CRA teaching procedures, teaching tool usage methods, teaching process demonstrations, feedback skills application, and data collection methods, etc., which ensure the consistency of the executors' teaching. From the current situation, interventions in this field are still mainly carried out by researchers, and the stable mode of transition to regular teaching scenarios in schools has not yet been formed, and the exploration of teachers as daily educational subjects participating in intervention implementation is still relatively limited.

(5) Intervention Environments

By analyzing the intervention environments and forms of 12 pieces of existing empirical research, it was found that the intervention scenarios were mainly focused on quiet, enclosed, and structured offline spaces, including regular classrooms, resource classrooms, exclusive teaching spaces, and home environments, two other studies used online ZOOM platforms for remote intervention. The teaching organization is predominantly one-on-one teaching, in which a total of 10 studies use one-on-one mode, and two studies use small-scale group teaching, the group size controlled is at 2-3 people. The intervention duration is relatively fixed, the duration of a single teaching is mostly within 30-40 minutes, which fits the attention characteristics of children with autism. Overall, the intervention environment is mainly low interference and structuring, teaching form is predominantly individualized teaching, and online and group teaching only appear as supplementary forms.

(6) Intervention Strategies

By analyzing the intervention strategies of 12 piecers empirical studies, the intervention of existing research can be divided into two categories: single strategy intervention and combination strategy intervention, the core is implemented around the two basic strategies: concrete-representation-abstraction (CRA) and virtual-representation-abstraction (VRA), presenting the characteristics of "CRA/VRA strategy plays a dominant role, supplemented by diverse methods".

1. Single CRA or VRA Intervention Strategy

In terms of single intervention strategy, a total of 4 studies only used CRA or VRA strategy for teaching. Two of the studies used a single CRA strategy, focusing on basic operations, digital cognition, and algebraic equation skill teaching; the other two studies used a single VRA strategy, virtual teaching aids as the main support to carry out single digit addition and multiplication word problem teaching, both of which achieved mathematical skill acquisition through a step-by-step progression.

2. Combination Intervention Strategy

In terms of combination intervention strategies, 8 studies have used CRA/VRA strategy and other auxiliary methods to intervene together, which are the main intervention forms at present. The common combination methods mainly include the following types: first, CRA strategy + strategy teaching model + mnemonic strategy to enhance memory of the calculation process; second, CRA strategy + video demonstration, the strategy combining VRA with CRA is used to promote understanding of the solution process; third, the combination of CRA strategy

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and conceptual model teaching (COMPS), and it is used for teaching the part-whole relationship in addition and subtraction word problems; fourth, the combination of VRA and Systematic Layout Planning (SLP) is used to promote independent problem-solving; fifth, the video teaching (VM)+CRA strategy + self-monitoring checklist are used in the teaching of fractional operations, which consolidates the stability and accuracy of skills.

(7) Intervention Effect

12 studies all have confirmed that CRA/VRA strategy can effectively enhance the mathematical ability of children with ASD. In immediate effects, children's accuracy, independence, and step completion in tasks such as basic operations and algebraic equations were significantly improved; in maintenance effect, tracking tests of 6 studies showed that skills remained stable 2-4 weeks after the intervention ended; in generalization effect, 8 studies have shown that the skills acquired through practice can achieve cross-task and cross-situational transfer; in social validity, 3 studies received positive feedback from teachers, parents, and children, they believed that the strategies fit children's characteristics, operated clearly, and were suitable for various teaching scenarios.

4. Summary and Outlook

Studies has made significant progress in using CRA teaching strategy to enhance the mathematical ability of children with autism spectrum disorders. From the perspective of research subjects, the focus has gradually expanded from the initial primary school stage to the junior high school stage, and the contents have also extended from basic operations to more abstract mathematical fields such as algebra and fractions, in implementation methods, the intervention method has shifted from classroom teaching to remote teaching, home intervention, and the combination of various intervention methods, which can effectively integrate the visual advantages, preference for structured and personalized features of children with ASD, and most studies emphasize the generalization of skills, promoting the transfer of mathematics learning to real academic environments or daily life. However, there are still some shortcomings in current research, most of the subjects are children aged 5-14 years old, and the sample gender ratio is unbalanced, research on ASD in preschool and adult settings is still blank; in terms of research design, single subject experiments are main, and the intervention execution subject is limited to researchers, it is not extended to educators and companions who can truly come into contact with these children, such as teachers and parents. In addition, the implementation standards and supervision evaluation mechanism of the intervention plan have not yet been formed, the evaluation indicators mainly focus on immediate accuracy, without considering the attention of execution functions (shopping calculation ability, time management, etc.) and comprehensive intervention effect; the subjects in social validity assessment are relatively single, and the contents mostly stay at surface satisfaction survey, lacking in-depth verification of the long-term applicability and generalization effect of interventions. Given the shortcomings of existing empirical research, this research proposes the following outlooks for research in the future.

(1) Expanding Application Boundaries and Achieving Diversity of Intervention Targets and Objectives

Future research should break the limits of current research, broaden the application scope of CRA teaching strategy, and deepen its intervention depth. In terms of intervention targets, it is necessary to break the limits of age, gender, and types of obstacles, and extend the intervention scope to preschool mathematics enlightenment and middle school advanced mathematics learning stages. Moreover, female subjects were included in a balanced manner, with a focus on the ASD group with comorbidity characteristics such as intellectual disability and delayed language development. The standardized assessment was conducted before intervention and

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the unified evaluation framework was established to ensure the rigor and generalizability of research conclusions. In terms of intervention objectives, the hierarchical system of "basic skill +advanced content + functional application" was established to break the limits of single basic operations and expanded to complex mathematical tasks. In addition, functional tasks were designed in combination with real-life scenarios, promoted the transformation of mathematical skills into practical applications, and achieved the coordinated development of academic ability and life adaptation ability.

(2) Optimizing the Implementation System and Promoting the Upgrading of Research Design and Intervention Modes

Future research should enrich the types of research designs, break the limits of single subject designs, introduce controlled experiments, mixed studies, and other models, compare the effect differences between CRA strategy and traditional teaching, single strategy and combination strategy, analyze the independent effects and optimal combinations of auxiliary methods, and enhance the pertinence of strategies. Innovating teaching and intervention modes, expanding the application scenarios of VRA virtual teaching aids, exploring simple home teaching and group classroom teaching modes, and breaking the limits of "one-on-one" and closed training rooms. Furthermore, building a collaborative system of diverse educators, transforming the intervention subjects into frontline special education teachers, ordinary teachers, and parents, carry out standardized special training, expanding the intervention scenarios to natural environments such as families and communities, strengthening the generalized application of skills, and achieving the implementation from research to practice.

(3) Improving the Evaluation Mechanism and Building the Multidimensional Effectiveness Verification System

Future research can focus on the four core dimensions: real-time, maintenance, generalization, and social validity, refine evaluation contents, and innovate evaluation methods. In terms of immediate effectiveness, the evaluation needs to break single accuracy indicator, comprehensively consider problem-solving standardization, learning independence, as well as children's participation and emotional state. In terms of maintenance effect, the evaluation can extend the tracking period to 1-3 months, increase the number of tests, and use layered consolidation training to strengthen long-term effect. In terms of generalization effect, the evaluation should be extended to real-life scenarios, test the transfer and application ability of skills under different scenarios and guidance from different interveners. Finally, we can try to expand the evaluation subject of social validity, incorporate multi-perspective evaluation, evaluate the promotion value in combination with intervention costs and implementation difficulty, optimize the implementation process, and meet the needs of frontline teaching and home tutoring.

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