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"LIGHT OF LOGIC" AI-MATHEMATICS INTEGRATED TRAINING SYSTEM: A STUDY ON STRENGTHENING SPECIAL CHILDREN'S THINKING AND COGNITION BASED ON ALGORITHMIC ART INTERVENTION

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Abstract: For children with special difficulties in thinking and cognition, traditional intervention methods are often single-dimensional. This project attempts to break disciplinary boundaries and creatively integrate Luban fasteners, a traditional Chinese educational toy, with AI-assisted voice dialogue, painting, clay modeling and other visual arts to form a three-dimensional integrated intervention training program of "traditional educational tools - intelligent interactive technology - expressive art therapy". The project was carried out in a local children's welfare institute with 12 special children for a 4-week training period. Through pre-post comparison and process observation, it was found that compared with peers who only watched animations and played freely, children who received the integrated training had better attention span, work organization and basic logical thinking. We found that mathematical games act as a solid framework for thinking, AI dialogue serves as a patient thinking navigator, and artistic creation becomes a "safe outlet" for emotions and ideas - the three are not simply superimposed, but promote each other, producing an effect of 1+1+1>3.
Keywords: Special children; Integrated intervention; AI assistance; Expressive art therapy; Luban fasteners

1 INTRODUCTION

In classrooms and daily life, some children are misunderstood as "disobedient" or "lazy" due to poor core cognitive abilities such as attention, a sense of order and logical thinking. Existing interventions mostly focus on behavior modification and cognitive training, treating the brain as detachable parts while ignoring the integrality of thinking that requires multi-sensory nourishment. Based on this, this project constructs the "Light of Logic" training system with the core of "mathematical games + AI dialogue + visual art", aiming to explore whether the integration of the three can improve children's concentration, organization and awareness of active questioning, and study the synergetic mechanism among mathematical rules, AI guidance and artistic expression. It attempts to connect cognitive neuroscience with art therapy at the theoretical level, and provide a reference manual including theories, cases and reflections for special education teachers, rehabilitation therapists and parents at the practical level. The study adopts a quasi-experimental design of "non-equivalent control group pre-test and post-test" and collects empirical evidence in a real educational environment.

Special children in welfare institute environments often face dual cognitive and psychological challenges, showing problems such as distractibility, slow development of logical thinking and weak emotional regulation ability. Studies have shown that this group has significantly higher loneliness than ordinary children, with more prominent emotional instability and alienation tendencies, which affect their learning adaptation and social interaction. However, current interventions mainly focus on single-skill training, paying insufficient attention to children's intrinsic motivation and emotional needs, and it is difficult to achieve the coordinated development of cognition and emotion.

In the field of cognitive training, mathematics is widely used in the thinking training of special children due to its inherent logic. Structured games represented by Luban locks, with clear rules and timely feedback, can effectively train observation, planning and reasoning abilities. Artificial intelligence technology provides a new path to solve the problem of personalized education; conversational AI can maintain children's attention, provide unconditional patient companionship, and the experience of "being responded to" itself has therapeutic value. In terms of art intervention, painting and handcraft provide a channel for children's emotional catharsis. The "order processing" spontaneously used by children in their paintings is a visual projection of their internal sense of order, which can become an effective medium for training visual-spatial logic [1,2].

To sum up, mathematical training, AI technology and art intervention respond to children's needs in the three dimensions of logic, emotion and expression respectively. However, current research mostly focuses on single-dimensional intervention, and there is a lack of attempts to systematically integrate the three. Children's cognitive and emotional development are intertwined; simply emphasizing logical training is difficult to sustain, and only focusing on emotional counseling is difficult to improve cognitive ability. Therefore, constructing an integrated intervention system of "mathematical games + AI dialogue + visual art" has important theoretical and practical value. Based on this research gap, this project explores the comprehensive effectiveness of three-dimensional collaborative intervention in strengthening the thinking and cognition of special children.

2 RESEARCH DESIGN OF AI INTEGRATED WITH MATHEMATICS AND VISUAL ART FOR STRENGTHENING SPECIAL CHILDREN'S THINKING

2.1 Research Method

This project adopts a quasi-experimental design of non-equivalent control group pre-test and post-test. The pre-test is used to understand the initial level of the experimental group and the control group, providing a comparison benchmark for the subsequent experimental results, and the intervention effect is evaluated by comparing the changes of the two groups before and after the experiment [3,4].

2.2 Research Subjects and Grouping

Through communication with a local children's welfare institute, 12 special children aged 10-12 were selected to participate in the experiment. Random grouping by drawing lots was adopted: the experimental group with 6 children (coded S01-S06) received a 4-week integrated training; the control group with 6 children (coded C01-C06) carried out regular free activities [5].

2.3 Variable Setting

Independent variable: Level of the experimental group: integrated training of "mathematical games + AI dialogue + visual art"; Level of the control group: regular free activities [6,7].
Dependent variables: (1) Attention span: recording the task duration with a mobile phone timer in the "Luban fastener disassembly task"; (2) Logical thinking performance: recording by grade through observing whether children can answer questions such as "why" in AI dialogue.

2.2 Intervention Process for Strengthening Special Children's Thinking

2.2.1 Introduction to research projects

Introduction to research projects is shown in Table 1.

Table 1 Introduction to Research Projects

Research Project	Content Description
Luban Fastener Challenge	Children attempt to disassemble Luban fasteners of appropriate difficulty, and their attention span and strategies are recorded
AI Dialogue	Children use an AI dialogue applet with companionship, and their interactive performance is recorded
Thematic Painting and Space Clay Modeling	Carry out creative handcraft and painting around themes, and observe spatial perception and practical ability

2.2.2 Intervention implementation process

(1) Phase 1: Preparation stage
Week 1: Project team members entered the welfare institute and established trust and affinity with the children.
Week 2: Pre-tests were conducted on both groups, including attention span in Luban fastener tasks, performance in maze maps, and emotion and participation [8,9].
(2) Phase 2: Intervention stage, 4 weeks in total
Week 1: The children were generally unadapted to structured activities. S01 threw away the Luban fastener in less than 2 minutes; S03 ignored the requirement of speaking; most paintings were random doodles.
Strategy adjustment: We lowered the requirements, replaced Luban fasteners with simpler ones; guided children to start with AI dialogue; art activities were completely free to cultivate interest, and praised every small progress with stickers.
Weeks 2-3: Positive changes: The children began to get used to the rhythm. After AI told a story, S05 could say "The little rabbit first... pulled the radish... then... went home". When painting, S01 would say "First draw a round head". However, S05 still needed reminders for attention [10].
Week 4: Significant progress: The children's initiative increased. S04 would take the initiative to ask "I want to play the hardest lock". During AI dialogue, children's answering sentences became longer, and they could use simple logic of "because... so...". They began to conceive when painting; for example, S02 would arrange the positions first and then color when painting "My Home".
(3) Phase 3: Post-measurement
Implementation of post-test: After the 4-week training, post-tests were conducted on both groups. The form and content of the post-test were basically the same as the pre-test, only the specific questions were changed to avoid affecting the results.

2.3 Measurement Tools and Data Recording Methods

2.3.1 Data collection and collation

All pre-test and post-test record forms, daily observation notes, photos of works taken and other materials were collected. All observation records were sorted and classified for preparation of analysis.

2.3.2 Data recording methods

(1) Real-time recording: During the activities, the responsible members scored on the record forms.
(2) Post-event supplement: After the activities, the members recalled and supplemented the specific performance details of each child against the record forms.
(3) Photo assistance: Photos were used to record children's works as auxiliary evidence for observation.

3 EMPIRICAL RESPONSES OF "LIGHT OF LOGIC": QUANTITATIVE AND QUALITATIVE ANALYSIS OF COGNITIVE DEVELOPMENT

By integrating quantitative and qualitative data, this section expounds the changes of the experimental group in the three dimensions of attention persistence, behavioral sense of order and logical thinking, and compares with the control group to evaluate the intervention effect.

3.1 Data Collection and Description

To quantify the intervention effect, unified behavioral task evaluations were conducted on both groups in the pre-test and post-test, focusing on attention span, order sense score and logical thinking score. The comparison of the average pre-test and post-test data of the two groups of children is shown in the following Table 2.

Table 2 Comparison of Mean Values of Core Cognitive Indicators of the Experimental Group and the Control Group before and after Intervention

Group and Evaluation Stage	Attention Persistence (Average Duration)	Order Sense Performance (Average Score/10 points)	Logical Thinking Performance (Average Score/10 points)
Experimental Group (Pre-test)	4 min 58 s	2.83	2.50
Experimental Group (Post-test)	6 min 15 s	4.33	4.50
Control Group (Pre-test)	5 min 23 s	2.67	3.00
Control Group (Post-test)	5 min 44 s	2.83	3.16

Comparison of mean values of core cognitive indicators of the experimental group and the control group before and after intervention is shown in Table 2.
All three indicators of the experimental group were significantly improved in the post-test: the average attention span increased by 1 min 17 s, and the average scores of order sense and logical thinking increased by 1.50 points and 2.00 points respectively. The changes of the control group in the same period were slight, indicating that regular activities have limited promoting effect on cognitive ability. The study also established a process file including activity records, work evolution and AI dialogue fragments.

3.2 Multi-dimensional Analysis of Intervention Effects

3.2.1 Attention persistence: from transient distraction to intentional maintenance

In the early stage of intervention, the experimental group generally had difficulties in tasks requiring sustained cognitive input. For example, in the first Luban fastener task, more than half of the children (such as S01, S02, S05, S06) shifted their attention within 4 minutes, and the average attention span was lower than required by the task. With the progress of the intervention, their attention maintenance ability showed phased improvement.
Adaptation period (Weeks 1-2): Children began to learn to face a single task. At this time, external incentives and the game nature of the task itself were the key maintaining factors.
Improvement period (Weeks 3-4): The attention span increased, with typical performances that children could explore independently until the end of the task (such as S04 and S06 completing the disassembly of Luban fasteners), rather than terminating in advance due to setbacks.
Analysis: The improvement of attention benefits from the structured design of intervention activities: mathematical games capture attention with clear goals and progressive difficulty; AI dialogue trains the distribution and maintenance of auditory attention; artistic creation requires sustained attention to the complete process from conception to completion.

3.2.2 Sense of order and organization: from behavioral disorder to initial pattern emergence

(1) Organization of behavior: In the early stage of intervention, children lacked planning in activity transition and material collection; in the later stage of intervention, their self-organization ability was significantly improved. For example, S02 would place tools independently and in an orderly manner before art activities, and S05 and S06 could abide by the rules of taking turns and waiting when distributing items.

(2) Serialization of language expression: The temporal logic words embedded in the AI dialogue script had a demonstration effect on children. From initial one-word responses to simple description of events. For example, S03 could say "The little rabbit pulled the radish first, then went home" when retelling a story.
(3) Logicalization of work structure: Children's art works gradually developed from random doodles to thematic and structured creations. Comparing S04's messy paintings in the first week with the structurally complete clay model of a kitten in the fourth week, it can be seen that their understanding of the relationship between the whole and parts and their creative planning ability have been significantly improved.
Analysis: The sense of order stems from the inherent sequential requirements of activities: mathematical puzzles, AI dialogue and step-by-step artistic creation all make children perceive the sequence of things development. In the successful experience of orderly tasks, their understanding and application of rules and sequences are constantly strengthened.

3.2.3 Logical thinking: from result-oriented to process exploration

Children in the experimental group showed a shift from focusing on results to attempting to reason about processes in terms of logical thinking.
(1) Evolution of problem-solving strategies: In mathematical games such as Luban fasteners, children's behavior changed from blind trial and error in the early stage (such as S01 pulling the fasteners at will) to purposeful observation and strategic attempts (such as S04 observing the structure first and then choosing the force point), forming a "hypothesis-verification" mode, which is the initial embodiment of logical thinking.
(2) Application of simple causal relationships: In AI dialogue and daily communication, children began to try to use causal words. In the third week, S01 took the initiative to ask "Why is the sky blue?", showing his willingness to explore the reasons behind phenomena.
(3) Demonstration of spatial and planning ability: In painting and handcraft, children showed initial planning of spatial layout. For example, when painting "My Home" in the later stage, S04 would first determine the relative positions of the house, trees and sun before coloring, reflecting spatial logic and pre-conception ability.
Analysis: Mathematical games prompt children to continuously observe, compare and infer; the "why" questions in AI dialogue directly stimulate causal thinking; artistic creation provides a non-verbal space for logical expression. The combination of the three embodies abstract logical training into operable and perceptible experiences.

3.2.4 Typical case analysis

To reveal the individual differences and internal mechanisms of intervention effects, child S04 in the experimental group with a representative progress track was selected for analysis.
Baseline level: The pre-test showed that S04 was at a low level in the group in terms of attention (185 s), order sense (3 points) and logical thinking.
Key growth nodes in the intervention process:
(1) Initial self-confidence established in the mathematics module: Successfully completing the Luban lock challenge (381 s) in the first week and obtaining a strong sense of efficacy, which became the motivation for subsequent participation in challenges.
(2) AI module promoting language organization: From passive acceptance to taking the initiative to ask "AI to tell a story", and using sequence words in retelling, indicating that his language organization ability was improved under the demonstration of structured dialogue.
(3) Art module realizing the externalization of conception: His works changed from messy paintings to a structured clay model of a "kitten", clearly showing the evolution of thinking from disorder to order.
(4) Post-test results and interpretation of growth mode: In the post-test, S04's three indicators were significantly improved (attention 345 s, order sense 4 points, logical thinking 4 points). His growth track interprets the synergetic development path of "obtaining a sense of efficacy from mathematical challenges → internalizing orderly expression through AI interaction → externalizing and consolidating structured thinking through artistic creation".
To further explain the interaction of each module, the following table summarizes S04's behavioral performance at key nodes and the corresponding module functions.
Key behavioral performance and corresponding development of case S04 in three-dimensional intervention is shown in Table 3.

Table 3 Key Behavioral Performance and Corresponding Development of Case S04 in Three-dimensional Intervention

Intervention Stage	Performance in Mathematics Module	Performance in AI Module	Performance in Art Module	Developmental Significance
Early Stage (Week 1)	Successfully completed the Luban lock and obtained a sense of efficacy	Passive communication, mostly silent	Messy paintings with no clear shape	Established confidence in mathematical success
Middle Stage (Week 3)	Took the initiative to challenge more difficult fasteners, with extended attention span	Could retell AI stories and use sequence words	Smooth lines and emerging composition awareness	AI dialogue internalized orderly expression, and art began to attempt structure
Late Stage (Week 5)	Could observe and attempt strategically	Took the initiative to ask "why"	Created a structurally complete clay model	Improved logical reasoning ability, and conception ability was externalized into concrete works

4 CONCLUSION AND FUTURE THINKING

The three-dimensional integrated intervention model of "mathematical games + AI guidance + visual art" adopted in this project has improved the abilities of children in the experimental group in the three core dimensions of attention persistence, sense of order and logical thinking, and the performance is better than that of the control group. The intervention model produces an effect of "1+1+1>3". Mathematical games provide a logical framework, AI dialogue acts as a thinking navigator, and visual art serves as an emotional outlet. The three permeate each other and form a cognitive strengthening system.

Tool flexibility: Children's interests are easy to shift. It is suggested to replace activity tools with the same functions in a timely manner according to individual situations (such as replacing different handcraft materials) to maintain participation.

Evaluation objectivity: This study mainly relies on manual observation, which has subjectivity. Standardized psychological scales should be introduced in the future to make the evaluation results more reliable and valid.

Consolidate the scientific foundation: Expand the sample size, adopt randomized controlled trials and long-term follow-up to build a more solid evidence system.

In-depth technology development: Cooperate with AI companies or universities to develop adaptive AI software specially designed for special children to realize intelligent interaction and personalized intervention.

COMPETING INTERESTS

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