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A Study on the Impact of Representational Forms of Concepts in Elementary School Mathematics on the Degree of Transfer Occurrence

Yue Huang

Beijing University of Posts and Telecommunications, China
huangy@bupt.edu.cn

Ruirui Zhai

Beijing University of Posts and Telecommunications, China
ruirui@bupt.edu.cn

Lin Jiang

China Agricultural University, China
Jiang-lin@cau.edu.cn

Abstract: *Educators aspire for learners to proficiently apply acquired knowledge across diverse contextual scenarios. Facilitating knowledge transfer involves employing varied methodologies in the construction of instructional materials. Regrettably, extant research lacks a comprehensive examination of the efficacy of these methodologies in specific applications. Drawing upon cognitive psychology principles, this research delineates three representations of instructional materials conducive to knowledge transfer: the amalgamation of conceptual content and digital applications, the integration of conceptual content with situational queries, and the fusion of two situational queries. Subsequently, a cohort comprising 63 third-grade students undergoes experimentation to discern the differential impacts of the aforementioned instructional material configurations on both knowledge acquisition and transfer. Findings indicate a general convergence in the acquisition of mathematical knowledge and transfer capabilities, albeit with discernible variations in the domain of problem-solving sub-skills. Specifically, instances of excessive familiarity with situations facilitate knowledge acquisition but do not necessarily correlate with enhanced transfer acquisition. This underscores the recommendation that educators incorporate instructional materials wherein learners possess a moderate level of familiarity with the given situations during the design phase, thereby fostering concurrent development of transfer acquisition and knowledge acquisition.*

Keywords: primary mathematics, transfer, learning outcomes, problem representation

1. Introduction

The advent of the digital age has led countries to place greater emphasis on the development of skills and competencies in foundational education. This trend is evident in various countries, including the United States' Mathematics Curriculum Standards (Yu & He, 2019), France's Mathematics Curriculum Standards for Compulsory Education (2018 edition) (Zhang & Wu, 2022), Australia's Mathematics Curriculum Standards (ACARA, 2024), Japan's Guidelines for Learning Guidance (2017) (Li & Shi, 2018) and Singapore's Curriculum Standards (Zhang & Chen, 2023). Mathematics education at the K-12 level in China places always significant emphasis on nurturing students' cognitive abilities. Notably, various mathematics curriculum standards, including the Successive Elementary School Mathematics Guidance Syllabus (1992) (Cao, 2000), Nine-year Compulsory Education Full-time Primary School Mathematics Syllabus (Trial, 2000) (Ma, 2000), Nine-year Compulsory Education Full-time Primary School Mathematics Syllabus (Trial Revision, 2001) (Ministry of Education of the People's Republic of China, 2001), and Mathematics Curriculum Standards for Compulsory Education (2011 Edition) (Ministry of Education of the People's Republic of China, 2012), underscore the significance of fostering students' mathematical thinking abilities. The latest Compulsory Education Mathematics Curriculum Standards (2022 Edition) places a strong emphasis on "thinking about the real world using mathematical thinking" (Wang & Liu, 2022). Within the spectrum of cognitive skills, the ability for transfer in problem-solving stands out as particularly crucial, because the fundamental purpose of education is to provide useful learning experiences that differ from initial learning contexts (Lobato, 2006). Recognizing the impracticality of comprehensively covering all knowledge, skills, and problem-solving methodologies within K-12 education, educators aim to instill in students the capability to generalize insights from singular instances. This involves the application of prior knowledge and experiences to navigate problem-solving in various current or future scenarios. Consequently, the ongoing challenge for educators lies in optimizing the design of instructional materials to facilitate the transfer of previously acquired knowledge, aiming to enhance the efficacy of learning in both present and future contexts—a pedagogical process commonly referred to as "transfer." This study investigates the different representational forms that constitute "prior learning" content and examines their impact on the degree of transfer. The aim is to provide empirical evidence and practical guidance for current foundational education reforms.

2. Literature Review

2.1. Transfer

Various definitions of transfer exist. The classical definition of transfer is described as "the partial repetition of prior behavior in a new context." However, this definition is criticized by several scholars for its perceived narrowness and rigidity, given that individuals may not invariably apply identical learning strategies across diverse transfer contexts (Bransford & Schwartz, 1999). For instance, individuals may engage in market shopping without prior knowledge of price calculations, yet those with previous mathematical education may find it easier to adapt to such calculations (Schwartz et al., 2005). Recognizing the limitations of the classical definition, scholars have proposed expanded conceptualizations of transfer. This includes viewing transfer as the influence of previously acquired knowledge and skills on novel learning experiences (Gick & Holyoak, 1983), the transference of learning experiences from one context to another (Feng & Feng, 2011), the application of previous problem-solving strategies to address new challenges (Mayer & Wittrock, 1996), or the impact of learning with certain materials in one setting on learning with different materials in alternative contexts (Perkins & Salomon, 1992). These broader definitions encompass a diverse array of scenarios where prior learning shapes subsequent learning endeavors. A comprehensive interpretation posits that transfer encompasses the broad influence of prior knowledge, skills, strategies, or principles on the acquisition of new knowledge (Durwin, 2020). This encompasses a spectrum of previously acquired content, including knowledge, skills, strategies, or principles. The inquiry into whether knowledge, skills, strategies, or principles exert a more pivotal role in new learning is a fundamental consideration.

An illustrative historical experiment, Thorndike's 'Shape Perception' conducted in 1901 (Islam, 2015), utilized college students as subjects to learn the computation of figure area, subsequently applying this knowledge to estimate the area of other geometric figures. The experiment incorporated 90 parallelograms as source material, with the target problem involving the area of various geometric figures (e.g., squares, trapezoids, triangles, circles). Findings revealed that the greater the similarity between the target problem figure and the parallelogram in shape, the higher the accuracy of college students' estimations. Thorndike postulated the same element theory, asserting that identical elements play analogous roles in both previous acquisition and new learning. Judd's underwater target practice experiment (Judd, 1908), categorizing children into experimental groups exposed to principles of optical refraction and underwater vision, and a control group devoid of such instruction, demonstrated significantly superior performance in the experimental group. This underscores the utility of general principles derived from prior learning experiences in facilitating new learning. Another experiment involving children assessing the influence of absolute stimuli (grayscale variations matching the food's grayscale) versus relative stimuli (darker grayscales on two distinct pieces of paper) revealed a predilection for children to employ relative stimuli in their judgments. Consequently, the interplay between previous learning experiences significantly influences new learning outcomes. It is evident that the diverse design of preceding learning content crucially affects the results of subsequent learning endeavors. In the context of problem-solving transfer, the content of prior learning is typically designated as the source problem, while the new problem assumes the role of the target problem.

2.2. Promoting Transfer via Analogical Strategies

In the process of problem solving, analogical strategies are frequently employed to facilitate the process of transfer. This includes promoting relational reasoning in children (Walker et al., 2018), searching for procedural similarities to enhance the process of analogical transfer (Chen, 2002), and designing clicker questions to stimulate transfer (Son & Rivas, 2016). Analogical reasoning involves the problem-solver recognizing correlations between solutions to previous problems and the current problem. Subsequently, a new operational approach is generated by mapping the elements of the former solution to those of the current problem (Anderson, 2009). The analogical transfer process can be delineated into four distinct stages, including (1) the encoding and representation of the source problem and the target problem; (2) the extraction of the source problem based on the representation of the target problem; (3) the construction of a mapping relationship between the source problem and the target problem, along with the adaption of solution principles from the source problem to the target problem; and (4) if there is no corresponding schema induction when encoding the source problem, then schema induction will be performed when applying the source problem solution to the target problem (Qu & Zhang, 2000). The degree of similarity between the source problem and the target problem emerges as a pivotal determinant of transfer attainment. Identification of those similarities hinges upon learners' representations of past and present problems. Consequently, the construction of problem representations by learners assumes a critical role in elucidating mathematical problem-solving processes (Cifarelli, 1998). Different forms of mathematical problem representations can stimulate different types of analogical transfer (Snoddy & Kurtz, 2021), including near transfer based on "situation-similar situation" and far transfer based on "situation-principle/method-new situation" (Li, 2022).

2.3. Designing the source for analogical transfer

Modern transfer research provides a variety of 'source' design methods to promote transfer, including the learning of abstract concepts, the learning of concrete examples, and the learning of various representations of both concepts and problems.

2.3.1. Abstract concept

The transfer of concepts is often understood as a form of analogical reasoning (Goldstone & Son, 2005). Abstract concepts represent dependencies between specific variables. The theory of analogical reasoning explains transfer as a process of discerning and reasoning about relationships between variables in the source and target problems. The learning and understanding of abstract concepts with universal significance make it possible for students to understand phenomena that exist in different domains yet share fundamental characteristics in essence. Many studies have addressed the role of providing abstract principles for transfer (Kaminski et al., 2008). Generally, the more abstract a concept is, the broader the range of specific problems it can represent, and the greater the potential scope of transfer. Mathematical problems mostly relied on abstract principles for practical problem-solving. Abstract concepts serving as the 'source' of learning materials primarily include 'conceptual equation' and 'computational equation.' The former refers to the formula that reveal the essence of a concept from their form, while the latter involves formulas deformed for computation convenience. Conceptual formula intuitively expresses the essential meaning of a concept, aiding learners in understanding, memorization, and transfer. Even in a far transfer, it shows a positive effect. Although computational equation is compact and convenient for calculation, it may obscure the relationship between the components within the formula (Atkinson et al., 2003).

In primary school mathematics, there are numerous descriptions of abstract principles, with a typical example being the operations of mathematical symbols formatted as 'object (condition) operator object (condition) operator object (conclusion),' such as the addition operation '3+4=7.' Another example includes formulas representing relationships, as shown in Table 1, where 'Speed × Time = Distance' signifies an abstract representation of the relationship between body speed, time, and distance. As student progress to the fifth grade and learn to represent numbers with letters, they acquire the ability to understand the further abstract representation of the formula 'V × T = S.' This representation is essentially a subset of the higher-level abstract representation 'A × B = C,' capable of representing a broader range of problem types such as 'the number of single objects × the number of piles = the total number of objects.'

Table 1

Abstract Concepts in Primary School Mathematics

Concept	Example	Representational meaning	Degree of abstraction	Scope of application
Literal type formula	Speed × time = distance	The multiplicative relationship between speed, time, and distance	General	Specific problem categories
Alphabetic formula with specific meaning	V×T=S	The multiplicative relationship between V, T, and S with specific meaning	Higher	Specific problem categories
General Alphabetic Formula	A×B=C	Multiplicative relationship among three entities	High	General problem type
Logical form	Object (condition) operator object (condition) operator object (conclusion)	The general relationship among three entities	Highest	The most general type of problem

2.3.2. Specific examples

Worked-example learning refers to the learning process where the learner induces implicit abstract knowledge from examples with detailed problem-solving steps to solve new problems (Xu & Zhu, 2000). Examples are the primary form of learning mathematical knowledge (Du & Lin 2018). They demonstrate the application of new abstract concepts to concrete problems and reflect the problem-solving process itself. Example-based learning facilitates the transfer and application of knowledge beyond the realm of mathematics, enabling the utilization of mathematical knowledge or methods to solve problems in real-life context. Examples provide learners with objects to imitate, comprising three components: problem, solution, and comment. The 'problem' describes the issue to be solved, the 'solution' presents the specific steps for problem-solving, and the 'Comment' explain each step of the problem-solving process, informing learners of the reasons or bases for the solution. 'Comment' can be presented to learners in written form along with the 'problem' and 'solution,' or delivered orally during the learner's problem-solving process.

Sample examples often help learners understand problem-solving process in form of a step-by-step presentation of problem-solving process. Learners consciously use examples to solve the target problem, which is a process of analogical transfer of problem-solving. Within this cognitive process, learners have the opportunity to extrapolate the common abstract principles shared between the worked example and the target problem, fostering the development of cognitive skills. The development of cognitive skills is acknowledged to have a positive impact on problem-solving outcomes (Atkinson et al., 2003; Renkl et al., 2004). Researchers commonly employ two strategies to design effective examples aimed at promoting transfer of problem-solving: (1) Designing examples with diverse forms of representation, encouraging learners to discern commonalities across varied representational formats and (2) providing learners with a series of examples that exhibit significant commonalities to reinforce acquired knowledge.

2.3.3. Multiple representations

Researchers also provide learners with multiple forms of representations for concepts or principles, aiming to enhance learners' understanding. This involves guiding learners to identify similarities and differences among various representations, thereby fostering transfer or the integration of diverse information into a coherent structure. An exemplar approach to learning multiple representations simultaneously involves grasping an abstract concept alongside a concrete case (Colhoun et al., 2008). As one progresses through academic levels, mathematics textbooks increasingly incorporate more abstract concepts and formulas, reflecting a heightened degree of abstraction. In this study, the combination of concepts (formulas, principles) and contextualized problems serves as a strategy for presenting multiple representations of concepts. While concepts aid students in constructing the fundamental representation of a problem, contextualized problems elucidate the application-level understanding of the concept.

3. Experimental study

The primary objective of this study is to conduct a comparative analysis of the impact of diverse representations of source materials on learners' transfer abilities. The investigation employs the travel problem within the context of primary school mathematics as the experimental stimulus. This problem type exemplifies a classical mathematical word problem, focusing on the quantitative relationships among distance, time, and speed, thereby presenting a prototypical quantitative reasoning challenge. At the primary school level, the travel problem is pivotal in both teaching and poses notable challenges. Effectively solving the travel problem necessitates a profound comprehension of the quantitative relationships embedded in its concepts, requiring adherence to the fundamental formula ('Speed × Time = Distance'). In practical problem-solving process, elucidating the specific meanings of speed, time, and distance within the given situation is crucial. Subsequently, extracting the corresponding numerical values is imperative, occasionally prompting a modification of the basic formula ('Time = Distance/Speed'). Furthermore, certain scenarios demand multi-step computations, such as encountering problems within the travel problem, involving intricate relationships like 'the distance before the encounter = the sum of speeds of two individuals × the time taken for the encounter = the distance covered by A before the encounter + the distance covered by B before the encounter.'

3.1. Experimental participants

A cohort comprising two classes of third-grade primary school students, totaling 63 participants, underwent testing in this study. These 63 subjects were randomly distributed across three groups, each consisting of 21 students. The groups were designated as follows: the concept + application group (Group1), the problem +problem group (Group2), and the concept +problem group (Group3).

3.2. Experimental content

The test content in this study pertains to the comprehensive calculation methodology of speed and distance. Third-grade students have previously acquired the fundamental concepts (speed, time, and distance) and rudimentary calculation methods for problems involving speed and distance. However, they have not yet been introduced to the four basic arithmetic operations or the comprehensive calculation method for distance. The elementary calculation method for distance, as shown in Figure 1, is accomplished through a two-step procedure. Figure 2 shows the comprehensive problem-solving method for distance calculation, with the first line providing a general conceptual explanation, and the actual problem-solving conducted through a one-step procedure outlined in the second line.

Figure 1

Pre-knowledge of Students with Speed and Distance Problems

Speed × Time = Distance
Distance 1 + Distance 2 = Total Distance

Figure 2

Knowledge to be Learned with Speed and Distance Problems

Total speed × Total time = Total Distance
(Speed 1 + Speed 2) × (Time 1 + Time 2) = Total Distance

Even if the solutions obtained by students are correct, this study determines that transfer has not occurred if students employ the problem-solving method illustrated in Figure 1. Conversely, if students utilize the problem-solving method shown in Figure 2, it is considered that the learning materials serving as the source for transfer have influenced the resolution of the target problem, indicating the occurrence of transfer, even if their solution is incorrect.

3.2.1. The Source learning content

The source learning content is categorized into three representational modes, as shown in Figure 3, including abstract formula concepts and numerical application examples (Group 1:

concept + application); two context problems with superficial structural similarity but inconsistent internal structure (Group 2:problem + problem); and a combination of abstract formula and a contextual problem (Group 3:concept + problem).

Figure 3

Examples of Source Learning Materials

- **Group 1: Concept + Application**

  Total speed × time = total distance

  (Speed 1 + Speed 2) × (Time 1 + Time 2) = Total Distance

  (50 meters per second + 60 meters per second) × 30 seconds = 110 meters per minute × 30 minutes = 3300 meters

- **Group 2: Question + Question**

  (1) Two cars are driving towards each other, car A is driving from place A to place B, and car B is driving from place B to place A. The speed of car A is 50 kilometers per minute, and the speed of car B is 60 kilometers per minute. After 5 minutes of meeting, how far is the distance between A and B?

  (2) Two cars are driving towards each other, car A is driving from place A to place B, and car B is driving from place B to place A. The speed of car A is 50 kilometers per minute and the speed of car B is 60 kilometers per minute. Car A stops after driving for 5 minutes. Car B starts driving. After driving for 5 minutes, the driver meets car A and asks how far is the distance between A and B?

- **Group 3: Concept + Question**

  (1) Total speed × total time = total distance

  (Speed 1 + Speed 2) × (Time 1 + Time 2) = Total Distance

  (2) Two cars are driving towards each other, car A is driving from place A to place B, and car B is driving from place B to place A. The speed of car A is 50 kilometers per minute, and the speed of car B is 60 kilometers per minute. After 5 minutes of meeting, how far is the distance between A and B?

3.2.2. The Target problem

Figure 4

An example of a target problem

Xiao Ming and Xiao Jun set out from their homes to gather at the same time. Xiao Ming can walk 40 meters in one minute. Xiao Jun's speed is 20 meters per minute. After five minutes, Xiao Ming saw Xiao Jun and asked Xiao Ming how far is the distance between Xiao Ming and Xiao Jun's home?

Table 2

Analysis of Source Problem and Target Problem on Surface Characteristics and Internal Structure

	Surface features (context and object)					Internal structure (problem solving mode)
	Object	**Direction**	**Distance**	**Speed**	**Time**	
Source problem	Car	Driving towards each other	From A place to B place	Each speed of Vehicle A and B	Two-car traveling time	Total Speed × Total Time = Total Distance (number)
Target problem type A	People	Walking towards each other	From Xiao Ming's home to Xiao Jun's home	Each speed of Xiao Ming and Xiao Jun	Two-person walking time	
Target problem type B	People	-	-	Each paper-cut speed of Xiao Hong and Xiao Ming	Each time of Xiao Hong and Xiao Ming.	
Target problem type C	People	Walking towards each other	From Xiao Ming's home to Xiao Jun's home.	Each walking speed of Xiao Ming and Xiao Jun	Two-person walking time	Total Time = Total Distance/ Total Speed Total Time = Total Distance/ (Speed 1 + Speed 2)

The target problem consists of a set of problems characterized by differences in both surface features and internal structures from the source learning materials. Surface features encompass contextual elements and operational objects, constituting the semantic components of the questions. Internal structure refers to the problem-solving patterns or the conceptual principles required to unravel the problem. Figure 4 shows an example of a target problem. The set of target problems includes a series of variations that either alter surface features (e.g., transforming a car into a person) or modify the internal structure of the questions (e.g., transitioning from "total speed × total time = total distance (quantity)" to "total time = total distance/total speed"). Specific details are outlined in Table 2. Target problem type A comprises a set of questions that share similarities in both surface characteristics and internal structure with the source problem. Target problem type B encompasses a set of questions that exhibit similarities in their internal structure to the source problem but diverge in surface characteristics. Conversely, type C represents a series of questions that display similarities in surface characteristics to the source problem while differing in their internal structure.

3.3. Experimental procedure

The experiment is divided into three stages: the learning material stage, the learning control stage and the transfer test stage (see Table 3). During the learning material phase, learners engage with source problems characterized by three different representations. To facilitate optimal learning, a methodology involving initial problem-solving followed by answer correction is employed in this phase. Specifically, participants are initially presented with various source problems and allowed 10 minutes for problem-solving. Subsequently, the correct answers are provided, enabling participants to revise and correct their responses. The learning control phase is designed to assess whether participants have acquired the content of the source problems. The test questions in this stage mirror the representations of the source problems. For example, if the representation of the source problem in Group 1 is the direct provision of the formula '(Speed1 + Speed2) × (Time1 + Time2) = Total Distance,' then the corresponding test question in the learning control phase involves filling in the blanks in the formula, prompting participants to complete '(Speed1 + Speed2) × (Time1 + Time2) = ___ × ___ = ?' Similar to the learning material stage, participants are initially granted 5 minutes for problem-solving, followed by the provision of the correct answers to assist in rectifying their responses.

The transfer test was conducted after a half-day interval. Learning materials were studied around 8 a.m. in the first class of the day, and the transfer test was administered in the last class of the day, with an interval of 5 classes and a lunch break in between. The test comprised 13 questions. The first question was the repetition of the source question, completed by all groups except Group 1. Question 1 essentially involved the direct application of the acquired knowledge and did not pertain to transfer. The remaining transfer questions were divided into three sets (3 + 4 + 5), totaling 12 questions.

Table 3

Lab 1 Process and Group Tasks

<table>
<tr><th>Group
(21 persons)</th><th>Material learning
(15 m)</th><th>Learning control
(10 m)</th><th>Post-test
(40 m)</th></tr>
<tr><td>Group 1</td><td>Concept + Application</td><td>• Copying of words and concepts
• An examination of the application of numerical computation</td><td rowspan="3">The same 13 questions, including 4 groups of questions:
• Direct application of the same question (1 question)
• Questions with the same surface features and the same internal structure (4 questions)
• Questions with different surface features but the same internal structure (3 questions)
• Questions with the same surface features but different problem structures (5 questions)</td></tr>
<tr><td>Group 2</td><td>Question + Question</td><td>• Two Situational Problems</td></tr>
<tr><td>Group 3</td><td>Concept + Question</td><td>• Copying of concepts
• Examination of similar situational questions</td></tr>
</table>

3.4. Experimental Results

3.4.1. Results of homogeneity of variance test

Table 4

Levene's Test for Error Variance Equality

	F	df1	df2	Sig.
Knowledge acquisition	1.048	8	180	.391
Transfer acquisition	1.998	8	180	.062

Table 4 shows the results of homogeneity of variance test. The Sig. Value of knowledge acquisition was 0.391, and the Sig. Value of transfer acquisition was 0.062, both exceeding 0.05. Given the homogeneity of variance, analysis of variance (ANOVA) could be conducted.

3.4.2. Knowledge acquisition and transfer acquisition

The study includes two independent variables (source problems with different representation forms, and target problems with different categories) and two dependent variables (knowledge acquisition and transfer acquisition). In terms of statistical data, a score of 1 is assigned for correct problem-solving during knowledge acquisition, and 0 for incorrect responses. A score of 1 was assigned for successful transfer and 0 for unsuccessful transfer. Knowledge acquisition and transfer acquisition were counted separately and do not entirely overlap. A student may solve a problem correctly without experiencing transfer if they used an old method instead of the new one. In such cases, knowledge acquisition was scored as 1 and transfer acquisition as 0. I Conversely, if a participant used the new method during the problem-solving process, even if other errors occurred, such as calculation mistakes (multiplication errors) or the use of incorrect units, it was counted as successful transfer. In this scenario, knowledge acquisition was scored as 0, while transfer acquisition was scored as 1. As shown in Table 5, where groups 1.0-3.0 correspond to the three experimental groups learning different combinations of representational forms in the source materials.

Table 5

Descriptive Statistics

	Group	Mean value	SD.	N
knowledge acquisition	1.0	1.500	1.3188	21
	2.0	2.476	1.6036	21
	3.0	2.458	1.9086	21
Total		2.145	1.5616	
transfer acquisition	1.0	0.542	0.7559	21
	2.0	1.587	0.8345	21
	3.0	1.569	0.9283	21
Total		1.232	0.991	

The overall knowledge acquisition across the three groups (2.145) surpassed the transfer acquisition (1.232). Group 2 (concept + problem) demonstrated the highest knowledge acquisition in solving target problems (2.476), followed by Group 3 (problem + problem) with a slightly lower knowledge acquisition score (2.458), and Group 1 (concept + application) exhibited the lowest knowledge acquisition (1.50). Similarly, Group 2 (concept + problem) exhibited the highest transfer acquisition (1.587), followed by Group 3 (problem + problem) with a slightly lower transfer acquisition score (1.569), and Group 1 (concept + application) displayed the lowest transfer acquisition (0.542).

3.4.3. Intersubjective effect test

Conducting tests for between-subjects effects on the result data, as shown in Table 6, revealed significant effects for each "group" (changes in the representational form of the source problem) concerning both knowledge acquisition ($F=10.395$, $p<0.05$) and transfer acquisition ($F=27.867$, $p<0.05$).

Table 6

Between-Subjects Effects Test

	Dependent variable	Type III sum of squares	df	Mean Square	F	Sig.	Partial Eta square
Group	knowledge acquisition	43.89	2	7.315	10.395	.038	.104
	transfer acquisition	51.006	2	8.501	27.867	.000	.236

3.4.4. Multiple comparisons of groups

Further exploring the multiple comparisons between "groups," LSD tests were employed. The results, as presented in Table 7, indicated significant differences ($p<0.05$) in both knowledge acquisition and transfer acquisition between Group 1 (concept + application) and Group 2 (concept + problem), as well as between Group 1 and Group 3 (problem + problem). However, there was no significant difference ($p>0.05$) observed between Group 2 and Group 3.

Table 7

Multiple Comparisons of 'Groups'

Dependent variable	(I) Group	(J) Group	Mean Difference (I-J)	Standard error	Sig.	95% confidence interval	
						Lower limit	Upper limit
knowledge acquisition	1.0	2.0	-.976	.4341	.028	-1.845	-.108
		3.0	-.958	.4194	.026	-1.797	-.119
	2.0	3.0	.018	.4341	.967	-.851	.886
transfer acquisition	1.0	2.0	-1.119	.2859	.000	-1.691	-.547
		3.0	-.95*	.2762	.001	-1.511	-.406
	2.0	3.0	.161	.2859	.576	-.411	.733

4. Discussion

4.1. The Influence of Representational Forms of Source Materials on Knowledge Acquisition and Transfer Acquisition in Target Problem

Across all representational forms of source materials, the results of knowledge acquisition were consistently higher than those of transfer, indicating that facilitating transfer was more challenging than acquiring knowledge. This difficulty may arise from the lower age of the learners (third grade), leading to challenges in their analogical reasoning and discrimination of concepts. The various representational forms of materials also exhibited a similar trend in influencing both overall knowledge acquisition (correct problem-solving) and transfer acquisition in target problems. Specifically, there was a positive correlation between knowledge acquisition and transfer acquisition, implying that the mastery of concepts and problem-solving impacted learners' transfer outcomes.

We hypothesized significant differences in the transfer acquisition among the three representational forms of materials. While there were noticeable differences in transfer acquisition between Group 1 (concept + application) and Group 2 (problem + problem), as well as between Group 1 and Group 3 (concept + problem), no significant difference was observed between Group 2 and Group 3. Notably, Group 2 (problem + problem) demonstrated the highest levels of knowledge and transfer acquisition, whereas Group 1 (concept + application) exhibited the lowest correctness rates in problem-solving and transfer acquisition. This suggested that, for third-grade primary school children, without teacher prompts, relying solely on self-study of textual materials made it challenging to transfer abstract concepts to concrete contextual problems. Therefore, learning through the exploration of specific contextual problems is imperative. Pure conceptual and numerical application learning, devoid of contextual understanding and practical problems, typically proves ineffective in the realm of problem-solving.

4.2. The Influence of Situational Factors

Further exploration of the test results within the target problem revealed the crucial role of situational factors. Knowledge acquisition result for Problem 6 (cutting a five-pointed star) was the highest at 95%. This could be attributed to the hands-on experience that most students have had with this problem, making it a very familiar real-life situation. However, the transfer acquisition for Problem 6 was not the highest, as learners' resolution of this problem was not based on their understanding and mastery of the current learning content but rather stemmed from previous learning and life experiences. Overly familiar life situations could hinder transfer acquisition. In contrast, for Problem 8 (the flow of blood in blood vessels), knowledge acquisition decreased linearly (only 10%), while transfer rates increased (attempting the new learning content but not solving it correctly). This was because learners found the problem context unfamiliar, prompting them to attempt to bypass surface features and directly extract the internal structure for problem-solving.

5. Conclusion and Limitations

Educators aim for learners to apply their acquired knowledge widely to various specific situations. However, in actual application, students struggle to solve new problems by recognizing the similarities between existing and new problems. While there are numerous design strategies for source materials to facilitate transfer in previous research, there is a lack of comparative assessment of their transfer performance in specific contexts such as primary school mathematics problem-solving.

This study, grounded in cognitive psychology theory, summarized three representational forms of source materials to promote transfer: the combination of concepts and numerical application, the combination of concepts and contextual problems, and the combination of two contextual problems. The experiment involved 63 third-grade primary school students, comparing the differential impacts of the three representational combinations on knowledge acquisition and transfer acquisition. In the overall trend, knowledge acquisition and transfer acquisition showed a positive correlation. However, in the detailed problem-solving context, the results were not entirely consistent.

The primary reason for this outcome is the crucial role of situational elements in the design of contextual problems (source materials). Contextual problems are integral for understanding learning and are more influential in problem-solving transfer than the different representational forms of the problems themselves. Primary school children rely more on context than on the representation form of problems to identify and solve problems. When solving problems with similar contexts, regardless of whether their internal structures are consistent with previously learned problems, children tend to use earlier familiar experiences and methods to solve problems. For low-difficulty problems, children can complete them directly without much thought, as it becomes an automated process. For high-difficulty problems, children may not know how to think and resort to using mature experiences rather than newly learned ones to solve problems. However, when solving moderately difficult problems with dissimilar contexts, children have the flexibility to use and validate new methods. Therefore, the study suggests that teachers, when designing source materials to facilitate transfer, do not necessarily need to design contexts that learners are overly familiar with to promote knowledge acquisition. Instead, designing moderately familiar contexts allows students more time for contemplation and analysis that helps promote transfer acquisition.

This study also has some limitations. First, it only compares the impact of different representational forms of concepts on the degree of transfer, without explaining the mechanisms of transfer from an internal cognitive perspective. Future research could address this issue by examining the situation from the perspectives of memory structure and children's information processing methods. Second, the experimental sample in this study is limited, as participants are drawn from a single region, which may restrict the validity of the conclusions. Future studies could expand the scope of the experimental research and further analyze the subjects in terms of their knowledge base, cognitive characteristics, and learning habits to enhance the validity of the conclusions.

References

ACARA.(2024). General capabilities. https://v9.australiancurriculum.edu.au/.

Anderson, J. R. (2009). *How can the human mind occur in the physical universe?* Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195324259.001.0001

Atkinson, R. K., Catrambone, R., & Merrill, M. M. (2003). Aiding transfer in statistics: Examining the use of conceptually oriented equations and elaborations during subgoal learning. *Journal of Educational Psychology, 95*(4), 762–773. https://doi.org/10.1037/0022-0663.95.4.762

Atkinson, R. K., Renkl, A., & Merrill, M. M. (2003). Transitioning from studying examples to solving problems: Effects of self-explanation prompts and fading worked-out steps. *Journal of Educational Psychology, 95*(4), 774–783. https://doi.org/10.1037/0022-0663.95.4.774

Bransford, J. D., & Schwartz, D. L. (1999). Chapter 3: Rethinking transfer: A simple proposal with multiple implications. *Review of Research in Education, 24*(1), 61-100. https://doi.org/10.3102/0091732X024001061

Cao, Y. (2000). Several understandings of the "nine-year compulsory education full-time primary school mathematics teaching outline (trial revised edition)." *Reference for Primary School Teaching*, (09), 29-31.

Chen, Z. (2002). Analogical problem solving: A hierarchical analysis of procedural similarity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*(1), 81–98. https://doi.org/10.1037/0278-7393.28.1.81

Cifarelli, V. V. (1998). The development of mental representations as a problem solving activity. *The Journal of Mathematical Behavior, 17*(2), 239-264. https://doi.org/10.1016/S0364-0213(99)80061-5

Colhoun, J., Gentner, D., & Loewenstein, J. (2008, July). Learning abstract principles through principle-case comparison. In V. Sloutsky, B. Love, & K. McRae (Eds.) *Proceedings of the 30th Annual Conference of the Cognitive Science Society* (pp. 1659-1664). Cognitive Science

Society.
Du, X., & Lin, H. (2018). The impact of presentation modes for explanations on pupils' mathematical example-based learning. *Journal of Mathematics Education, 27*(5), 52-56.
Durwin, C. C., & Reese-Weber, M (2020). *EdPsych modules (*4th Ed.) (p. 237). Sage Publications.
Feng, Z. & Feng, J. (2011). *A New theory of teaching: Principles of structured and targeted educational psychology.* Beijing Normal University Press.
Gick, M. L. & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology, 15*(1), 1-38.
Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *The Journal of the learning Sciences, 14*(1), 69-110. https://doi.org/10.1207/s15327809jls1401_4
Islam, M. H. (2015). Thorndike theory and it's application in learning. *At-Ta'lim: Jurnal Pendidikan, 1*(1), 37-47.
Judd, C. H. (1908). The relation of spatial intelligence. *Educational Review, 36*, 28-42.
Kaminski, J. A., Sloutsky, V. M., & Heckler, A. F. (2008). The advantage of abstract examples in learning math. *Science, 320*(5875), 454-455.
Li, C. (2022). Laying a logical thinking ladder for students. *Journal of Mathematics(China)*, *61*(10), 25-28+43.
Li, S., Shi, N., & Zhang, Y. (2018). A review of the new amendment about the primary school mathematics study guidelines in Japan. *Curriculum, Teaching Material and Method 38*(09),128-133.
Lobato, J. (2006). Alternative perspectives on the transfer of learning: History, issues, and challenges for future research. *The Journal of The Learning Sciences, 15*(4), 431-449.
Ma, Y. (2000). Understanding and knowledge of the "nine-year compulsory education full-time primary school mathematics teaching outline (trial revised edition)." C*urriculum, Teaching Material and Method,* (07), 20-25.
Mayer, R. E., & Wittrock, M. C. (1996). Problem-solving transfer. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 47–62). Macmillan Library Reference USA; Prentice Hall International.
Ministry of Education of the People's Republic of China. (2001). *Mathematics curriculum standards for full time compulsory education* (Experimental Draft). Beijing Normal University Press.
Ministry of Education of the People's Republic of China. (2012). *Mathematics curriculum standards for full time compulsory education* (2011 Edition). Beijing Normal University Press.
Perkins, D. N., & Salomon, G. (1992). Transfer of learning. In *International Encyclopedia of Education*, 2, 6452-6457.
Qu, Y. & Zhang, M. (2000). A review of analogical transfer. *Advances in Psychological Science* (02), 50-55.
Renkl, A., Atkinson, R. K., & Große, C. S. (2004). How fading worked solution steps works–a cognitive load perspective. *Instructional science, 32,* 59-82.
Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. *Transfer of Learning from a Modern Multidisciplinary Perspective, 3*(1), 1-51.
Snoddy, S., & Kurtz, K. J. (2021). Preventing inert knowledge: Category status promotes

spontaneous structure-based retrieval of prior knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 47*(4), 571.

Son, J. Y., & Rivas, M. J. (2016). Designing clicker questions to stimulate transfer. *Scholarship of Teaching and Learning in Psychology, 2*(3), 193–207.

Walker, C. M., Hubachek, S. Q., & Vendetti, M. S. (2018). Achieving abstraction: Generating far analogies promotes relational reasoning in children. *Developmental Psychology, 54*(10), 1833–1841.

Wang, G., & Liu, J. (2022) Strengthening the core competency orientation and improving the curriculum standards system: A comparative study based on the primary section of compulsory education curriculum standards: Mathematics (2011 Edition) and compulsory education curriculum standards: Mathematics (2022 Edition). *Curriculum, Teaching Material and Method, 42*(07), 4-11. https://doi.org/10.19877/j.cnki.kcjcjf.2022.07.023

Xu, Y., & Zhu, X. (2000). Several studies on example design in example-based learning. *Psychological Dynamics,* (02), 45-49.

Yu, G., & He, L. (2019). Mathematics curriculum standards in primary school in USA and their revelation. *Teaching & Administration*, (35), 56-58.

Zhang, Q., Chen, Y., & Deng, Q. (2023). A comparative study on the new curriculum standards for primary school mathematics in China and Singapore: A cross border exploration based on content, objectives, and methods. *Teaching Monthly Primary School Edition (Mathematics),12,*52-56.

Zhang, Y., & Wu, J. (2022). Comparative study of Chinese and French figures and geometry from the perspective of mathematical knowledge and core competencies-based on the compulsory education curriculum standards of France (2018 version) and China(2011 version). J*ournal of Mathematics Education, 31* (01), 70-78.

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