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# The effect of concreteness on children's ability to detect common proportion

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## Abstract

Two experiments were conducted to investigate kindergartener's ability to recognize common proportions across different instantiations. Both experiments varied between subjects the degree of concreteness of the instantiations used during training. In Experiment 1, when explicit training was given, participants who learned with either the concrete or generic material successfully transferred their knowledge to match common proportions involving novel objects. However, in Experiment 2 when no explicit instruction on proportion was given (participants were only shown two examples), only participants who were shown the generic examples successfully matched proportions with novel object. Participants who were shown concrete examples were unable to do so. These findings suggest that simple relations such as the concept of proportion can be picked up spontaneously from generic instantiations, while concrete instantiations do not promote this spontaneous structure learning.

**Keywords:** Cognitive Science; Psychology; Education; Transfer; Relations, Structure Recognition.

## Introduction

The ability to recognize common relations across different situations is essential for many cognitive tasks such as interpretation of analogies, acquiring abstract concepts (i.e. bigger than), as well as much of mathematical reasoning.

One finding that has emerged from research on analogy is that the ability to detect common relational structure is not always easy and tends to improve through the course of development. Most researchers agree that a relational shift occurs in development (e.g. Gentner, 1988; Gentner & Ratterman, 1991). Early in development, children are more likely to attend to object-level similarities between systems or displays and overlook relations. Later in development, people become more likely to attend to relational similarities. For example, when given a simple metaphor such as a plant stem is like a straw, children's interpretation is often based on superficial attributes, such as both are thin and straight. Adults tend to interpret such metaphors through deeper relations; in this case, both can carry water (Gentner, 1988).

One category of theoretical accounts of relational development is that the relational shift is knowledge-driven (Brown, 1989, Brown & Kane, 1988; Gentner, 1988,

Gentner & Ratterman, 1991, Vosniadou, 1989). By such accounts, domain-specific knowledge is the primary predictor of ability to attend to relations. In support of this position, there is considerable evidence that while young children may fail to reason analogically (i.e. based on relational structure) in many instances, they can reason analogically in contexts that are familiar to them (see Gentner, Ratterman, Markman, & Kotovsky, 1995 for discussion). For example, Gentner (1977a, 1977b) found that when 4-year-old children were shown a picture of a tree and asked, "If a tree had a knee, where would it be?", they interpreted the relational correspondence and responded as accurately as adults. Additionally, Brown and Kane (1988) conducted a study of preschool children, aged 3 to 5 years. Children learned problem-solving strategies presented to them through example problems. The problems involved simple biological mechanisms such as mimicry and camouflage. Young children did reason analogically to apply solution strategies to solve analogous problems. Domain-specific knowledge appears to be an important factor in relational development.

## Concreteness

Another factor that has been shown to affect reasoning and the detection of common relations is the concreteness of the learning material. The term "concrete" is often interpreted as something tangible, the opposite of abstract or intangible. We suggest that concrete and abstract are not dichotomous, but rather lie on a continuum over which the amount of communicated information varies. For a fixed relational concept, instantiation A is more concrete than instantiation B if A communicates more information than B. By this interpretation, physical objects are more concrete than images of objects because the physical objects communicate additional information such as sensory information. Also, familiar and contextualized entities are more concrete than unfamiliar or decontextualized entities because more is known about familiar, contextualized entities than about the later. Therefore, for example, contextualized mathematics problems are more concrete than decontextualized, strictly symbolic mathematical equations.

## Effects of Concreteness on Relational Tasks

DeLoache and her colleagues (DeLoache, 1995a, 1995b, 1997, 2000) have investigated the development of children's symbol use. Successful symbol use requires the detection of common relations. For example, to effectively use a map as a symbol for a real location, one must recognize the common relations between entities on the map and their real-world analogs. Young children have difficulty using concrete, perceptually rich objects as symbols. In a series of studies, 2½ to 3-year-old children were shown a 3-dimensional scaled model of a real room and told that a stuffed animal was hidden in the actual room. The experimenter then placed a miniature toy in the model telling the children that the location of the miniature toy in the model corresponded to the location of the actual toy in the real room. The children were then asked to retrieve the real toy. Only 16% of the children were able to make errorless retrieval of the actual toy. The children were then asked to retrieve the miniature toy. The accuracy of the miniature toy retrieval was 88% implying that the poor performance on the retrieval of the actual toy was not due to inability to remember the location, but an inability to realize that the model symbolically represented the actual room. In subsequent studies, the salience of the model was decreased by putting it behind a glass window. Under this condition, more than half of the participants accurately retrieved the toy. Similarly, when children were shown the location in a picture and not a 3-dimensional model, 80% of participants ably retrieved the real toy. In sum, decreasing the concreteness of the object increased the ease of its symbolic use.

By 3 years of age, most children are successful in such a task. However, when the 3-year-old study participants were encouraged to play with the model first only 44% of them successfully retrieved the toy, compared to 78% of 3-year-olds who retrieved the object with no opportunity to play. The physical interaction with the model made it more difficult for the children to treat it as a symbol.

Not only has concreteness been shown to affect children's analogical reasoning, there is also evidence that it can hinder the ability of adults to detect common relations (Kaminski, Sloutsky, & Heckler, 2006). Undergraduate students who learned a novel mathematical structure through a concrete example were unable to recognize the same structure in a novel context. At the same time, students who learned the concept through generic black symbols were very accurate in recognizing the structure in a novel context. The hindering effect of concreteness on adults' ability to recognize underlying relational structure is also suggested by studies of analogical transfer in which learners were unable, or less able, to transfer complex knowledge to novel analogues when the knowledge was acquired in a concrete format (Goldstone & Sakamoto, 2003; Goldstone & Son, 2005; Kaminski, Sloutsky, & Heckler, 2008; Sloutsky, Kaminski, & Heckler, 2005).

Taken together, prior research shows that concreteness can hinder the detection of simple relations for young

children and, further along in development, concreteness can hinder adults' ability to recognize relational structure and transfer more complex knowledge. However, little research has been conducted on how concreteness affects children's ability to recognize novel relations that are more complex than simple analogies but less complex than advanced mathematical concepts.

## Overview

The purpose of the present research was to consider how a simple relation that underlies a more advanced mathematical concept is acquired by young children through instantiations of different degrees of concreteness. The relation considered was that of proportion, which is the foundation of the concept of fraction. Two experiments investigated the effect of concreteness on children's ability to acquire and transfer knowledge of proportions.

Kindergarten students were asked to match common proportions across instantiations involving images of different objects. Concreteness of the training material was varied between subjects. All training and testing was presented on the computer; to manipulate the degree of concreteness, proportions were either instantiated through generic black and white circles or through more concrete, perceptually rich cupcakes.

In Experiment 1, participants were first given training in common proportion and then asked to match common proportion instantiated through novel items. The goal of Experiment 2 was to investigate the effect of concreteness on children's ability to spontaneously detect common proportions.

## Experiment 1

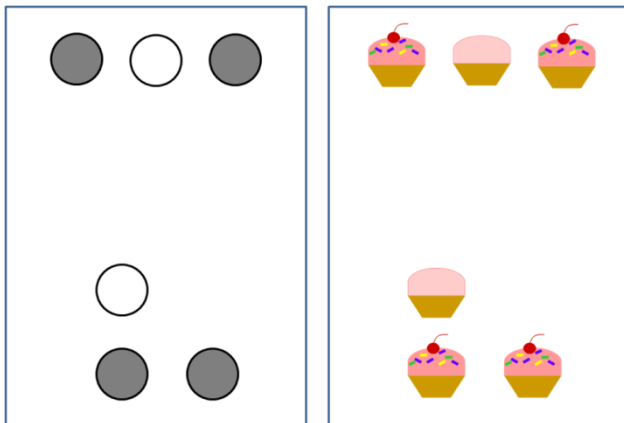
### Method

**Participants** Participants were twenty-six kindergarten students recruited from middle-class, suburban schools in the Columbus, Ohio area (10 girls and 16 boys,  $M = 5.9$  years,  $SD = .24$  years).

**Materials and Design** The task was to match common proportions across different displays of items. Participants were randomly assigned to one of two conditions: Generic or Concrete. In the Generic condition, all training represented proportions as black circles out of black and white circles. In the Concrete condition, all training presented proportions as cupcakes with sprinkles out of cupcakes with and without sprinkles.

The experiment had two phases. The first phase consisted of training and a test of learning. Specifically, participants were presented with two examples and two "non-examples" of common proportions. The first example showed two instantiations of 1/4. This was followed by a non-example showing 1/4 is not the same proportion as 2/4. The second example showed two instantiations of 2/3. The following non-example showed that 2/3 is not the same proportion as

2/5. Figure 1 presents the example of two instantiations of 2/3 for both the Generic and Concrete conditions. Participants were then given six multiple-choice questions with feedback. Participants selected one of four response choices: (1) the correct response, (2) correct numerator, but incorrect denominator, 2/4, (3) correct denominator, but incorrect numerator, 1/3, and (4) incorrect numerator and incorrect denominator, 3/4.

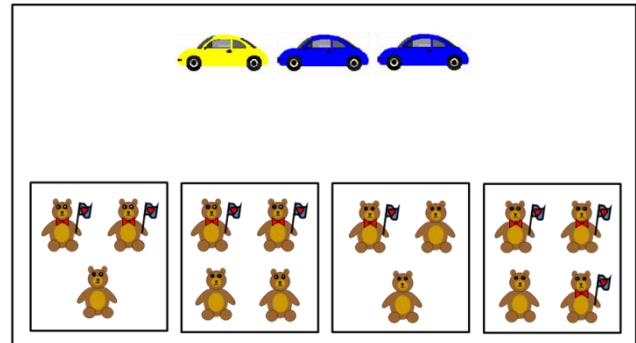


**Figure 1: Example of common proportion from training phase of Experiments 1 and 2 (Generic condition on left, Concrete condition on right).**

Following training, participants were given a six-question test of learning which presented novel proportions in the same format as the training (i.e. circles for the Generic condition and cupcakes for the Concrete condition). For each question, there were four possible response choices of the same format as those presented for the questions with feedback.

The second phase of the experiment was a transfer task in which participants were given 29 multiple-choice questions involving novel objects. Each question presented a proportion of blue cars out of a set of blue and yellow cars. The questions used proportions with denominators (i.e. total number of items in a display) ranging from 2 to 8. For example, one question presented a proportion of 1/2; another question presented a proportion of 3/8. Four possible response choices were presented in the same format as the feedback and learning test questions. Response choices represented proportions using different objects. Many different items were used for response choices and included: black and white squares, red and white squares, red and green apples, connected grey and white bars, connected green and white bars, slices of pizza (present or missing), bears with and without flags, light windows and dark windows of a house, partially full bus seats, partially full table of people, and partially remaining chocolate bar. An example test question is shown in Figure 2: a proportion of 2/3 is represented as

blue cars out of blue and yellow cars. Response choices involve proportions of bears with flags out of bears with and without flags. These choices show: (1) the correct response of 2/3, (2) correct numerator, but incorrect denominator, 2/4, (3) correct denominator, but incorrect numerator, 1/3, and (4) incorrect numerator and incorrect denominator, 3/4.



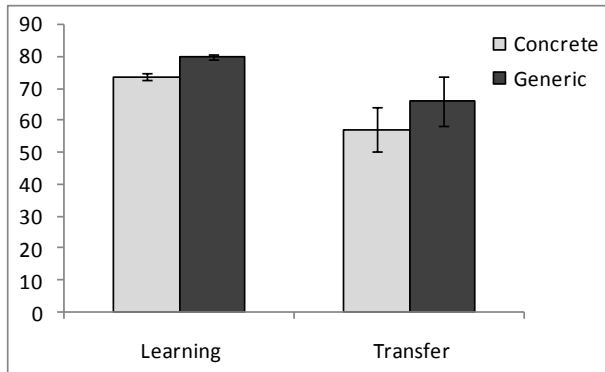
**Figure 2: Example of a test question for Experiments 1 and 2.**

**Procedure** Participants were asked to play a matching game with the experimenter. All training and test questions were presented on the computer. The experimenter told the child that the goal of the game was to match common proportions. During training, the experimenter verbalized which instantiations presented the same proportion and why. For example, in the Generic condition when showing two instantiations of 2/3 (see Generic condition of Figure 1), the experimenter gestured to the top group and stated, “Here is a group of circles. There are three circles all together and two are black”. Then she gestured to the bottom group and stated, “This group of circles has the same proportion of black because there are three circles all together and two of them are black”. Explanations in the Concrete condition were completely isomorphic to those of the Generic condition. Participants proceeded through the test questions at their own pace. The experimenter recorded their responses through the computer.

## Results and Discussion

Children were able to successfully match common proportions. Learning scores in both conditions were well above a chance score of 25% (see Figure 3), one-sample t-tests,  $t_s > 8.1$ ,  $p_s < 0.001$ . No differences were found between conditions, independent-samples t-test  $t(24) = 0.85$ ,  $p = 0.40$ .

Transfer test scores were also above chance in both conditions (see Figure 3), one-sample t-tests  $t_s > 4.5$ ,  $p_s < 0.002$ . There were no differences between conditions, independent-samples t-test  $t(24) = 0.86$ ,  $p = 0.40$ .



**Figure 3: Mean Test Scores in Experiment 1 (% Correct).**

Note: Error bars represent standard error of mean.

Chance score is 25%.

While no significant differences were found between conditions, there was a trend of better performance in the Generic condition on both learning and transfer tests. This trend suggests the possibility that generic instantiations may have an advantage over concrete instantiations under different training conditions. The training in Experiment 1 may have allowed participants to overcome potential obstacles of concreteness.

There are two aspects of the experiment that may have significantly promoted the abstraction of the proportion relation and minimized differences between conditions. First, training questions presented two instantiations simultaneously leading participants to directly compare the two. It has been well-documented that comparison of instances leads to better abstraction of relations than sequential presentation of instances (e.g. Catrambone & Holyoak, 1989; Loewenstein, Thompson, & Gentner, 1999; Gentner, Loewenstein, Thompson, 2003). Also, training involving non-examples encouraged participants to contrast the relational differences between the two proportions. Furthermore, test questions also presented multiple instantiations which may have encouraged participants to compare and contrast the different instances.

In addition to the format of both training and testing promoting comparison, another facilitating factor is that participants were given explicit training in which the experimenter directly stated and gestured to commonalities and differences across proportions. This explicit instruction may have encouraged attention to be focused on relations. Therefore, the design of the experiment might have allowed participants to overcome the potential hurdle of abstracting common relations from concrete instances.

It has been argued that in many situations, concrete instantiations hinder analogical transfer because the extraneous information communicated through concrete instantiations captures attention and diverts it from relational structure (Kaminski, Sloutsky, Heckler, 2008; Kaminski, Sloutsky, Heckler, in press). Because attention is diverted to the superficial, the learner is unable to detect common relations across isomorphic situations. Generic

instantiations have less extraneous information and therefore are more likely to allow attention to relations.

Therefore, it is possible that concrete instantiations of proportion also divert attention from relational structure, but our training allowed participants to overcome this difficulty. If generic instantiations of proportion are more likely to draw attention to common relations than are concrete instantiations, then differences in proportion-matching ability should be found when participants are not given the benefit of explicit instruction involving comparisons between instances of the same proportion and of different proportions. The purpose of Experiment 2 was to consider this possibility; participants were given no detailed training, only two examples of common proportions.

## Experiment 2

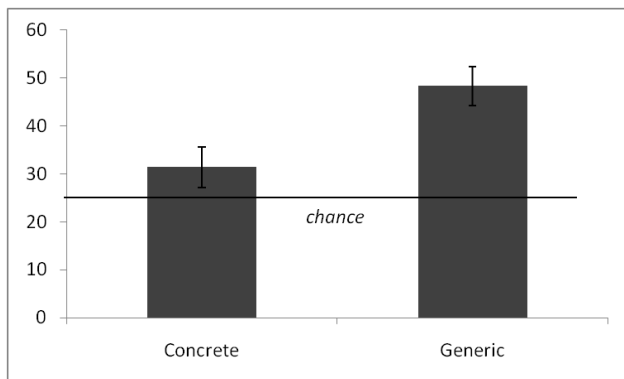
### Method

**Participants** Twenty-four kindergarten students were recruited from middle-class, suburban schools in the Columbus, Ohio area (10 girls and 14 boys,  $M = 5.7$  years,  $SD = .23$  years).

**Materials, Design and Procedure** The materials and procedure of this experiment were similar to those of Experiment 1. However, no explicit training on proportion was given, participants were only shown two examples of common proportion (involving  $1/4$  and  $2/3$ ). As in Experiment 1, there were two between-subject conditions, Generic and Concrete. Participants in the Generic condition saw the examples presented with black and white circles, while participants in the Concrete condition saw examples with cupcakes with and without sprinkles. After these two examples, participants were given a transfer test involving novel objects; this was the same 29-question transfer test used in Experiment 1.

### Results and Discussion

Mean test scores differed significantly between conditions, independent samples t-test,  $t(22) = 2.89$ ,  $p < .001$ , with participants in the Generic condition scoring higher than those in the Concrete condition (see Figure 4). In the Generic condition, scores were above a chance score of 25%, one-sample t-test,  $t(11) = 5.78$ ,  $p < 0.001$ . Scores in the Concrete condition were not above chance, one-sample t-test,  $t(11) = 1.48$ ,  $p = 0.17$ . Therefore, without explicit instruction, participants who saw the concrete examples were unable to recognize common relations between instantiations. At the same time, participants who saw the generic examples were able to recognize the common relations and were also able to abstract the concept of proportion to recognize it when presented through novel items.



**Figure 4: Mean Test Scores in Experiment 2 (% Correct).**

Note: Error bars represent standard error of mean.  
Chance score is 25%.

### General Discussion

This research considered kindergarten children's ability to acquire the concept of proportion and tested their ability to recognize common proportions presented with novel items. Participants were trained with either generic instantiations or concrete instantiations. When participants were shown only two examples, those who saw generic examples were able to spontaneously abstract the relational structure. They successfully recognized common proportions in the test items. Participants who saw concrete examples failed to recognize common proportions. These results extend previous findings on the effect of concreteness on learning and transfer of relations by demonstrating that concreteness can hinder young children's ability to acquire relational knowledge, including relations that are foundational to the acquisition of later mathematical knowledge.

The results of Experiment 1 suggest that there are ways of overcoming the obstacle of concreteness through the design of learning material. Specifically, comparison of concrete instantiations with explicit instruction highlighting common relational structure can allow learners to acquire the concept of proportion and transfer that knowledge to novel instantiations.

While educational design incorporating comparison may allow learners to successfully abstract simple mathematical relations such as proportion, it is unclear whether the process of comparison can erase the advantage of generic instantiations over concrete instantiations for more advanced abstract concepts. Because generic instantiations may allow near spontaneous pick up of relations, they may have an advantage for learning more complex mathematical concepts even when learning involves direct comparison.

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