ANALOGICAL REASONING IN CHILDREN

Usha Goswami,
Institute of Child Health, University College London, 30 Guilford St., London WC1N1EH, U.K.
E-mail: u.goswami@ich.ucl.ac.uk

Analogical thinking is the basis of much of our everyday problem solving. 'Analogy pervades all our thinking, our everyday speech and our trivial conclusions as well as artistic ways of expression and the highest scientific achievements' (Polya, 1957). The central role of analogy in human cognition underlines the importance of understanding the development of reasoning by analogy in children. However, until fairly recently, there was little interest in analogical development among researchers in child psychology.

This was because the most famous developmental psychologist, Piaget, had argued that analogical skills did not develop until early adolescence, and this conclusion had not been challenged. Rather than seeing analogy as a fundamental cognitive process, Piaget saw analogy as a sophisticated reasoning strategy that emerged after the primary years. The main reason was that, according to Piaget's general theory of logical development, the ability to see relations between relations (to use 'higher-order relations') was a hallmark of the final stage of logical reasoning, called the 'formal operational' stage. Formal operational reasoning required children to operate mentally on the results of simpler operations. A simpler operation was finding relations between objects (these simpler logical operations were called 'concrete operations'). As analogies required children to reason about relational similarity rather than about relations between objects, it appeared to be a typical formal operational skill.

Piaget's theory of logical development is the most widely-taught theory in cognitive developmental psychology and in education. It has also been used as a basis for research in many related areas (e.g., in theorising about the cognitive processes in reading development). If Piaget's conclusions about the relative mental sophistication of analogical reasoning turn out to be incorrect, then the implications for educational practice are immense.

Piaget's conclusions were based on experiments using a pictorial version of the standard test for analogical reasoning (used in IQ testing), the 'item analogy'. In item analogies, two items A and B are presented to the child, a third item C is presented, and the child is required to generate a D term that has the same relation to C as B has to A. Sucessful generation of a D term requires the use of the relational similarity constraint. For example, if the child is given the items '*cat is to kitten as dog is to* ?', she is expected to generate the solution term 'puppy'. The response 'bone', which is a strong associate of dog, would be an error. Another example is the analogy '*Bicycle is to handlebars as ship is to* ?'. Here the relation constraining the choice of a D term is 'steering mechanism', and so a child who offered the completion term 'bird' would not be credited with understanding the relational similarity constraint. Piaget's theory that analogical reasoning was absent in children until adolescence was based on item analogies such as these. Younger children tested by Piaget offered solutions like 'bird' to the *bicycle/ship* analogy, giving reasons like 'both birds and ships are found on the lake'. Piaget's interpretation of his research was that younger children solved analogies on the basis of associations. Children only became able to reason on the basis of relational similarity at around 11-12 years of age.

THE ROLE OF RELATIONAL FAMILIARITY IN ANALOGICAL DEVELOPMENT

Closer inspection of Piaget's experimental methods suggest a serious flaw, however. Piaget had not checked whether the younger children in his experiments understood the relations on which his analogies were based (relations such as 'steering mechanism'). Their failure to solve the item analogies in his experiments could thus have arisen from a lack of knowledge of the relations being used. Item analogies based on **unfamiliar** relations would obviously **underestimate** analogical ability.

The solution is to design analogies based on relations that are known to be highly familiar to younger children from cognitive developmental research. Simple causal relations such as *melting*, *wetting* and *cutting* are known to be understood between the ages of 3 and 4 years, and relations between real world objects such as *'trains go on tracks'* and *'birds live in nests'* are familiar to 4- and 5-year-olds. Item analogies such as *'playdoh is to cut playdoh as apple is to cut apple'* and *'bird is to nest as dog is to doghouse'* can thus be used to examine whether 3- to 5-year-olds have the ability to reason by analogy.

For this young age group, a picture-based version of the item analogy task was developed (Goswami & Brown, 1989, 1990). The task was presented as a 'game' about matching pictures. The children were shown a 'game board' with four slots for pictures, the slots being grouped in two pairs for the A:B and C:D parts of the analogy. As the children watched, the experimenter presented the first three terms of a given analogy (e.g., pictures of a bird [A], a nest [B], and a dog [C]). As the pictures were presented, the child was asked to name each one to ensure that they were familiar. The child was then asked to predict the picture that was needed to finish the pattern. This was intended to see whether children could generate an analogical solution spontaneously, without seeing the solution pictures.

Following this, the experimenter showed the child a choice of solution terms. For the *bird/dog* analogy, these were pictures of a dog *house*, a *cat*, another *og*, and a *bone*. The different choices were designed to test different theories of analogical development. The correct choice, which would indicate analogical ability, was the doghouse. The associative choice was the bone. Selection of the bone would be expected if younger children rely or associative reasoning to solve analogies, as Piaget had claimed. The other choices were a 'mere appearance match' choice (the second dog), and a semantic match (the cat). 'M appearance' matching is a term coined by Gentner (1989) to refer to the matching or object or 'surface' similarities when attempting to solve analogies (such as choosing another dog to match the dog in the Cterm) Gentner has suggested that younger children might rely on object similarity rather than relational similarity in reaching analogical solutions (Gentner, 1989).

The picture matching game showed that* children tested (4-, 5- and 9-year-olds) performed at levels significantly above chance in the analogy task, selecting the correct comp tion term 59%, 66% and 94% of the time respectively. There was no evidence of mere appearance matching. Although many younger children were shy of making predictions prior to seeing the solution choices, those who were more confident showed clear analogical abili ty on this measure as well. For example, when 4-year-old Lucas was given the analogy *bird is to nest as dog is to ?*, he first predicted that the correct solution was *puppy*. He argued, quite logically, "Bird lays eggs in her nest [the nest in the B-term picture contained three eggs] - dog - dogs lay babies, and the babies are - umm - and the name of the babies is puppy!" Luc had used the relation *type of offspring* to solve the analogy, and was quite certain that he was correct. He continued "I don't have to look [at the solution pictures] — the name of the baby is puppy!" Once he looked at the different solution options, however, he decided that the dog *house* was the correct response.

The matching game also included a contpol task to ensure that the correct solution to the analogy was not simply the most attractive pictorial match for the C term picture. Here the children were simply shown the C term picture along with the correct solution term and the distractors, and were asked to choose which picture 'went best' with the C term picture. For example, the children were shown the picture of the dog, and were asked to choose the best atch from the pictures ofthe doghouse, bone, second dos and cat. In this unconstrained task, he children were as likely to select the asso- ative match (bone) as the analogy match (doghouse). Additionally, although the children adily agreed that another match could be correct in the control condition (9 year olds: 76%, 4 vear olds: 82%), they were not so flexible in the analogy condition, where most ofthem said that only one answer could be correct (9 year folds: 89%, 4 year olds: 60%). This shows awareness of the relational similarity constraint that governs truly analogical responding. The children understood that the correct completion term for the analogy had to link the C and D terms by the **same** relation that linked the A and B terms. Notice that Lucas was using the relational similarity constraint when he generated the solution 'puppy' for the *bird/dog* analogy. This cognitive flexibility displays a full understanding of analogy, and provides evidence of truly mental operations, thereby meeting Piaget's original criteria for the presence of 'true' analogical reasoning.

From the picture analogy game, we know that the ability to reason by analogy is present by at least age 4. However, the analogy game may still have underestimated analogical ability. This is because relational familiarity was not measured independently of analogical success. Instead, it was simply assumed that familiar relations had been selected for the analogies, leaving open the possibility that the younger children may have failed in some trials because the relations used in those particular analogies were unfamiliar to them. Alternatively, some children may have failed some analogies because they were actually reasoning about relations that were **different** from those intended by the experimenter — like Lucas.

THE RELATIONSHIP BETWEEN RELATIONAL KNOWLEDGE AND ANALOGICAL RESPONDING

The idea that children's analogical performance depends on their relational knowledge has been called the *'relational familiarity' hypothesis.* In order to establish whether children's use of analogical reasoning is knowledge-based, dependent on relational familiarity rather than analogical ability, relational knowledge **as well as** analogical ability needs to be assessed. This can be done by changing the control task in the picture matching game. The appropriate control task measures children's knowledge of the relations being used in the analogies that are presented in the item analogy task.

A second set of analogy experiments using the picture matching game were thus carried out to test the relational familiarity hypothesis. This time, item analogies based on physical eausal relations like *melting*, *cutting* and *wetting* were used. These relations are acquired early in development, between 3 and 4 years of age. Children were given analogies like *'chocolate is to melted chocolate as snowman is to* ?', and *'playdoh is to cut laydoh as apple is to* ?'. Knowledge of the causal relations required to solve the analogies was measured by giving the children pictures of items that had been causally transformed (e.g., cut playdoh, cut bread, cut apple), and asking them to select the causal agent responsible for the change from a set of pictures of possible agents (e.g., a knife, water, the sun).

This 'causal relations' version of the picture matching game was given to children aged 3, 4 and 6 years of age. The results showed that both analogical success and causal relational knowledge increased with age. The 3-year-olds solved 52% of the analogies and 52% of the control sequences, the 4-year-olds solved 89% of the analogies and 80% of the control sequences, and the 6-year-olds solved 99% of the analogies and

100% of the control sequences. There was also a significant **conditional** relationship between performance in the two conditions, as would be predicted by the relational familiarity hypothesis. This conditional relationship showed that individual children's performance in the analogy task was intimately linked to those individual children's knowledge of the corresponding causal relations. Analogical success had thus been shown to be highly dependent on relational knowledge. These experiments showed that Piaget's theory of analogical development could no longer be upheld. If analogy is one of the basic cognitive processes underlying intellectual development, then it should be found at work in many other areas of cognition.

ANALOGIES IN COGNITIVE DEVELOPMENT

Analogies in Piagetian Tasks

An elegant theory of how analogical reasoning may contribute to performance in Piagetian logical tasks has been proposed by Halford (1993). Halford's basic claim is that much logical reasoning is analogical. According to his theory, children can use representations of everyday relational structures as a basis for analogies to new, isomorphic problems that share the same relational structures. For example, in order to solve a Piagetian transitive inference problem of the form *Tom is happier than Bill, Bill is happier than John, who is happiest?* a child can use an analogy from a familiar ordered stucture that may already be represented in memory. An example is the ordering structure **A above B above C.** Halford has suggested that all of Piaget's logical tasks that are characteristic of the 'concrete operational' stage of logical development (transitive reasoning, class inclusion, conservation) require analogical mappings based on pairs of relations.

In order to test the idea that Piagetian 'concrete operational' tasks can be solved by using appropriate analogies, therefore, we must first examine children's ability to map pairs of relations. This can be done by extending the classical analogy task by linking the A and B terms by two relations rather than one. Goswami Leevers, Pressley and Wheelwright (1998) designed a set of analogies based on pairs of physical causal relations, extending the technique used by Goswami and Brown (1989). We asked 3-, 4-, 5- and 6-year-old children to make relational mappings based on either single causal relations like **cut, paint,** and **wet,** or pairs of causal relations, like **cut** + **wet** and **mend + paint.** This experimental paradigm provides a relatively pure test of the ability to make analogies about pairs of relations.

Our experiment had four conditions, a single-relation analogy condition (e.g., *apple:* cut *apple:: hair: cut hair),* a double-relation analogy condition (e.g., *apple: cut, wet apple:: hair: cut, wet hair),* a single-relation control condition and a double-relation control condition. In the control conditions, the children were asked to select the picture of the causal agent or the pair of causal agents responsible for the causal changes shown in the analogies, following Goswami and Brown (1989).

Children's performance in the analogy and the control conditions was then examined as a function of Condition and Age. The pattern of the results was remarkably similar to the pattern found in the causal relations analogies used by Goswami and Brown (1989). There was a close correspondence between analogy performance and performance in the relational knowledge control conditions for both the single relation and the double relation analogies. For the single relation conditions, the 3-year-olds solved 33% of the analogies and 46% of the control sequences, the 4-year-olds solved 51% of the analogies and 63% of the control sequences, the 5-year-olds solved 72% of the analogies and 76% of the control sequences, and the 6-year-olds solved 89% of the analogies and 88% of the control sequences. For the double relation conditions, the 3-year-olds solved 13% of the analogies and 31% of the control sequences, the 4-year-olds solved 50% of the analogies and 50% of the control sequences, the 5-year-olds solved 62% of the analogies and 74% of the control sequences, and the 6-year-olds solved 78% of the analogies and 91% of the control sequences. Analyses demonstrated no interaction between age and number of relations, although the main effect of number of relations almost reached significance, reflecting the fact that children of all ages found the double relation analogies and control sequences more difficult than the single relation analogies and control sequences. Goswami et al. concluded that the ability to solve analogies based on pairs of relations was governed by relational familiarity. As long as familiar relational structures are chosen as a basis for analogy, therefore, young children should be able to use analogies to help them to solve Piagetian reasoning tasks.

Analogies in a Transitive Mapping Task

Halford has suggested that familiar ordered structures may provide useful analogies for transitive reasoning tasks. Family members provide a familiar example of an ordering structure based on size, as in most families the father (F) is taller than the mother (M), and the mother is taller than the young child (C). If knowledge of the familiar relational structure $F > M > C$ is present in young children, then children who have mentally represented this relational structure should be able to solve transitive mapping tasks using less familiar relations.

Goswami (1995) examined this hypothesis using Goldilocks and the Three Bears as a familiar example of family size relations (Daddy Bear > Mummy Bear > Baby Bear). Three- and 4-year-old children were asked to use the relational structure represented by the Three Bears as a basis for solving transitive ordering problems involving perceptual dimensions such as temperature, loudness, intensity, and width. The transitive mapping test was presented by asking the children to imagine going to the Three Bears' house, and then to imagine looking at their different belongings. This imagination task constituted a fairly abstract test. For example, the imaginary bowls of the Three Bears' porridge could be either **boiling hot, hot, warm,** and the child had to decide which bowl of porridge belonged to which bear. In order to give the correct answer, the child had to map the transitive height ordering of Daddy, Mummy, and Baby Bear to the different porridge temperatures, giving Daddy Bear the boiling hot porridge, Mummy Bear the hot porridge, and Baby Bear the warm porridge (these mappings do not follow the original fairy tale, in which Daddy Bear's porridge was too salty, and Mummy Bear's was too sweet).

The results showed that the percentage of correctly ordered mappings approached ceiling for the 4-year-olds for most of the dimensions used. The lowest levels of performance occurred for **width** (of beds, 62% correct), and hardness (of chairs, 76% correct), and the highest occurred for **temperature** (of porridge, 95% correct). Performance with the width dimension (wide bed, medium bed, narrow bed) was possibly affected by worries that a baby could fall out of a narrow bed, as many children allocated the medium bed to Baby Bear. They were then left without a bed for Mummy Bear. The 3-year-olds produced correctly ordered mappings for only some of the dimensions, performance being above chance (17%) for the dimensions of temperature of porridge (31% correct), pitch of voice (31% correct), and height of mirrors (62% correct, but an isomorphic relation). Relational familiarity and real-world knowledge about family size relations seem to have helped the 3-year-olds with these particular dimensions. The children are unlikely to have based their correct mappings on the story, as none of these dimensions was mentioned in the **Three Bears** book that was read to them as part of the study.

Analogies in a Class Inclusion Task

Families also provide a familiar example of an inclusive relationship, as family members can be divided into two distinct sub-sets, parents and children, both of which are members of the total set of family members (Halford, 1993). In order to see whether the family as a familiar example of inclusive relations could act as a basis for successful performance in Piagetian class inclusion tasks, Goswami, Pauen and Wilkening (1996) devised the 'create-a-family' paradigm. In this paradigm, children were shown a toy family, for example a family of toy mice (2 large mice as parents, 3 small mice as children). Their job was to create analogous families (2 parents and 3 children) from an assorted pile of toys (such as toy cars, spinning tops, balls and helicopters). After the children had correctly created 4 analogous families, they were given 4 class inclusion problems involving toy frogs, sheep, building blocks and balloons. The classinclusion problems were posed using collection terms ('group', 'herd', 'pile', 'bunch'). The children in Goswami et al.'s study (4- to 5-year-olds) had all failed the traditional Piagetian class inclusion task, which was given as a pretest ("Are there more red flowers or more flowers?"). A control group of children received the same class inclusion problems using collection terms, but did not receive the 'create-a-family' analogy training session.

Goswami et al. found that more children in the 'create-a-family' analogy condition than in the control condition solved at least 3 of the 4 class inclusion problems involving frogs, sheep, building blocks and balloons. This effect was particularly striking at age 4, in which no improvement at all was found in the control group with the collection term wording. It should be remembered that all of the children had previously failed Piagetian class inclusion tasks. Goswami et al. argued that this improvement was a result of the use of analogies based on a representation of family structure.

Analogies in Foundational Domains

One popular view of cognitive development is that conceptual development can be understood in terms of three 'foundational' domains. These are the domains of naive biology, naive physics, and naive psychology (Wellman & Gelman, in press). Wellman and Gelman argue that, rather than developing a monolithic understanding of the world, young children develop distinct conceptual frameworks to describe these 'foundationaP domains, even though many concepts will be represented more than one of these foundational fra works (for example, persons are psychological entities, biological entities and physical entities). Wellman and Gelman suggest that children will use at least two levels of analysis with in any framework, one that captures surface phenomena (mappings based on attributes) and another that penetrates to deeper levels (mappings based on relations). This means that anal ogies should be at work within foundational domains. Although no-one has yet studied t role of analogies in the foundational domain on psychology ('theory of mind'), studies of the role of analogies in developing conceptual understanding in the domains of naive biology and naive physics can be found.

*Analogy as a **Mechanism** for **Understanding** Biological Principles*

Evidence that analogy is an importat mechanism for understanding biological principles comes from a series of studies by Inag ki and her olleagues. They were interested in how often children would base their predictio about biological phenomena on analogies to people: the 'personification' analogy. As human beings are the biological kinds best known to young children, it seems plausible that childrem may use their biological knowledge about people to understand biological phenomena in other natural kinds. For example, Inagaki and Sugiyama (1988) asked 4-, 5-, 8- and 10-year olds a range of questions about various properties of 8 target objects, including "Does x breathe?", "Does x have a heart", "Does x feel pain if we prick it with a needle", and "C x think?". The target objects were people, rabbits, pigeons, fish, grasshoppers, trees, tulips and stones. Prior similarity judgements had established that the target objects differed in their similarity to people in this order, with rabbits being rated as most similar and stones being rated as least similar. The children all showe a decreasing tendency to attribute the physiological properties ("Does x breathe") to the t get objects as the perceived similarity to a pe

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son decreased. Apart from the 4-year-olds, very few children attributed physiological attributes to stones, tulips and trees, and even 4-year-olds only attributed physiological properties to stones 15% of the time. A similar pattern was found for the mental properties ("Can x think?"). This study supports the idea that preschoolers' understanding of biological phenomena arises from analogies based on their understanding of people.

Analogy as a Mechanism for Understanding Physical Principles

Evidence that analogy is an important mechanism for understanding physical principles comes from a series of studies by Pauen and her colleagues. Pauen has studied children's understanding of the principles governing the interaction of forces, by using a special apparatus called the 'force table'. The force table consists of an object that is fixed at the centre of a round platform. Two forces act on this object, both represented by plates of weights. The plates of weights hang from cords attached to the central object at either 45', 75' or 105' to each other. The children's job is to work out the trajectory of the object once it is released from its fixed position. Their predictions concerning this trajectory are scored in terms of whether they consider only a single force (plate of weights), or whether they integrate both forces in order to determine the appropriate trajectory. The force table problem is presented to the children in the context of a story about a King (central object) who has got tired of skating on a frozen lake (the platform) and who wants to be pulled into his royal bed on the shore. Children aged 6, 7, 8 and 9 years of age were tested.

Pauen found that most of the younger children (80 - 85%) predicted that the king would move in the direction of the stronger force only (the larger plate of weights). An ability to consider the two forces simultaneously was only shown by some of the 9-year-olds (45%). Such integration rule responses were shown by the majority of the adults tested (63%). Pauen speculated that this may have been because the children who received the plates of weights applied a balance scale analogy to the force integration problem. A balance scale analogy gives rise to one-force-only solutions, which are incorrect.

This idea about the balance scale analogy was prompted by the comments of the children themselves, who said that the force table reminded them of a balance scale (presumably because of the plates of weights). This led Pauen to propose that the children were using spontaneous analogies in their reasoning about the physical laws underlying the force table, analogies that were in fact misleading. To investigate this idea further, Pauen and Wilkening (in press) gave 9-year-old children a training session with a balance scale prior to giving them the force table problem. One group of children received training with a traditional balance scale, in which they learned to apply the one-force-only rule, and a second group of children received training with a modified balance scale that had its centre of gravity below the axis of rotation (a 'swing boat' suspension). This modified balance scale provided training in the integration rule, as the swing boat suspension meant that even though the beam rotated towards the stronger force, the degree of deflection depended on the size of **both** forces.

Following the balance scale training, the children were given the force table task with the plates of weights. A third group of children received only the force table task, and acted as untrained controls. Pauen and Wilkening argued that an effect of the analogical training would be shown if the children who were trained with the traditional balance scale showed a greater tendency to use the one-force-only rule than the control group children, while the children who were trained with the modified balance scale showed a greater tendency to use the integration rule than the control group children. This was exactly the pattern that they found. The children's responses to the force table problem varied systematically with the solution provided by the analogical model. These results suggest that the children were using spontaneous analogies in their reasoning about physics, just as we have seen them do in their reasoning about biology.

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