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Analogical reasoning as a learning process

Analogy plays an important role in learning and instruction. As J. D. Bransford, J. J. Franks, N. J. Vye and R. D. Sherwood noted in 1989, analogies can help students make connections between different concepts and transfer knowledge from a well-understood domain to one that is unfamiliar or not directly perceivable. For example, the circulatory system is often explained as being like a plumbing system, with the heart as pump.

The analogical reasoning process

Analogical reasoning involves several sub-processes: (1) retrieval of one case given another; (2) mapping between two cases in working memory; (3) evaluating the analogy and its inferences; and sometimes, (4) abstracting the common structure. The core process in analogical reasoning is mapping. According to structure-mapping theory, developed by D. Gentner in 1982, an analogy is a mapping of knowledge from one domain (the base or source) into another (the target) such that a system of relations that holds among the base objects also holds among the target objects. In interpreting an analogy, people seek to put the objects of the base in one-to-one correspondence with the objects of the target so as to obtain the maximal structural match. The corresponding objects in the base and target need not resemble each other; what is important is that they hold like roles in the matching relational structures. Thus, analogy provides a way to focus on relational commonalities independently of the objects in which those relations are embedded.

In explanatory analogy, a well-understood base or source situation is mapped to a target situation, that is less familiar and/or less concrete. Once the two situations are aligned – that is, once the learner has established correspondences between them -- then new inferences are derived by importing connected information from the base to the target. For example, in the analogy between blood circulation and plumbing, students might first align the known facts that the pump causes water to flow through the pipes with the fact that the heart causes blood to flow through the veins. Given this alignment of structure, the learner can carry over additional inferences: for example, that plaque in the veins forces the heart to work harder, just as narrow pipes require a pump to work harder.

D. Gentner and P. Wolff in 2000 set forth four ways in which comparing two analogs fosters learning. First, it can highlight common relations. For example, in processing the circulation/plumbing analogy, the focus is on the dynamics of circulation, and other normally salient knowledge – such as the red color of arteries and the blue color of veins – is suppressed. Second, it can lead to new inferences, as noted above. Third, comparing two analogs can reveal meaningful differences. For example, the

circulation/plumbing analogy can bring out the difference that veins are flexible whereas pipes are rigid. In teaching by analogy, it is important to bring out such differences; otherwise students may miss them, leading them to make inappropriate inferences. Fourth, comparing two analogs can lead learners to form abstractions, as amplified below.

What makes a good analogy

As D. Gentner suggested in 1982, to facilitate making clear alignments and reasonable inferences, an analogy must be structurally consistent – that is, it should have one-to-one correspondences and the relations in the two domains should have a parallel structure. For example, in the circulation/plumbing system analogy, the pump cannot correspond to both the veins and the heart. Another factor influencing the quality of an analogy is systematicity: analogies that convey an interconnected system of relations, such as the circulation/pumping analogy, are more useful than those that convey only a single isolated fact, such as "The brain looks like a walnut." Further, as K. J. Holyoak and P. R. Thagard argued in 1995, an analogy should be goal-relevant in the current context.

In addition to the above general qualities, several further factors influence the success of an explanatory analogy, including base specificity, transparency, and scope. Base specificity is the degree to which the structure of the base domain is clearly understood. Transparency is the ease with which the correspondences can be seen. Transparency is increased by similarities between corresponding objects and is decreased by similarities between non-corresponding objects. For example, in 1986 D. Gentner and C. Toupin found that four-to six-year-old children succeeded in transferring a story to new characters when similar characters occupied similar roles (e.g., squirrel(chipmunk; trout(salmon), but they failed when the match was cross-mapped, with similar characters in different roles (e.g. squirrel(salmon; trout(chipmunk). The same pattern has been found with adults. Transparency also applies to relations. In 2001 Bassok found that students more easily aligned instances of 'increase' when both were continuous (e.g., speed of a car and growth of a population) than when one was discrete (e.g., attendance at an annual event). Finally, scope refers to how widely applicable the analogy is.

Methods used to investigate analogical learning

Much research on analogy in learning has been devoted to the effects of analogies on domain understanding. For example, in 1987 B. H. Ross found that giving learners analogical examples to illustrate a probability principle facilitated their later use of the probability formula to solve other problems. In classroom studies from 1998, D. L. Schwartz and J. D. Bransford found that generating distinctions between contrasting cases improved students' subsequent learning. As reported in 1993, J. Clement used a technique of bridging analogies to induce revision of faulty mental models. Learners were given a series of analogs, beginning with a very close match and moving gradually to a situation that exemplified the desired new model.

Another line of inquiry focuses on the spontaneous analogies people use as mental models of the world. This research generally begins with a questionnaire or interview to elicit the person's own analogical models. For example, W. Kempton in 1986 used interviews to uncover two common analogical models of home heating systems. In the (incorrect) valve model, the thermostat is like a faucet: it controls the

rate at which the furnace produces heat. In the (correct) threshold model, the thermostat is like an oven: It simply controls the goal temperature, and the furnace runs at a constant rate. Kempton then examined household thermostat records and found patterns of thermostat settings corresponding to the two analogies. Some families constantly adjusted their thermostats from high to low temperatures, an expensive strategy that follows from the valve model. Others simply set their thermostat twice a day -- low at night, higher by day, consistent with the threshold model.

Analogy in children

Research on the development of analogy shows a relational shift in focus from object commonalities to relational commonalities. This shift appears to result from gains in domain knowledge, as D. Gentner and M. J. Rattermann suggested in 1991, and perhaps from gains in processing capacity as suggested by G. S. Halford in 1993. In 1989 A. L. Brown showed that young children's success in analogical transfer tasks increased when the domains were familiar to them and they were given training in the relevant relations. For example, 3-year-olds can transfer solutions across simple tasks involving familiar relations such as stacking and pulling, and six-year-olds can transfer more complex solutions. In 1987 K. Inagaki and G. Hatano studied spontaneous analogies in 5-6-year-old children by asking questions such as whether they could keep a baby rabbit small and cute forever. The children often made analogies to humans; such as "We cannot keep the baby in the size forever because he takes food. If he eats, he will become bigger and bigger and be an adult." Children were more often correct when they used these personification analogies than when they did not. This suggests that children were using humans – a familiar, well-understood domain – as a base domain for reasoning about similar creatures

Retrieval of analogs: the inert knowledge problem

Learning from cases is often easier than learning principles directly. Despite its usefulness, however, training with examples and cases often fails to lead to transfer, because people fail to retrieve potentially useful analogs. For example, M. L. Gick and K. J. Holyoak found in 1980 that participants given an insight problem typically failed to solve it, even when they had just read a story with an analogous solution. Yet, when they were told to use the prior example, they were able to do so. This shows that the prior knowledge was not lost from memory; this failure to access prior structurally similar cases is, rather, an instance of "inert knowledge" – knowledge that is not accessed when needed.

One explanation for this failure of transfer is that people often encode cases in a situation-specific manner, so that later remindings occur only for highly similar cases. For example, Ross in 1984 gave people mathematical problems to study, and later gave them new problems. Most of their later remindings were to examples that were similar on the surface, irrespective of whether the principles matched. Experts in a domain are more likely than novices to retrieve structurally similar examples, but even experts retrieve some examples that are similar only on the surface. However, as demonstrated by Novick in 1988, experts reject spurious remindings more quickly than do novices. Thus, especially for novices, there is an unfortunate dissociation: while accuracy of transfer depends critically on the degree of structural match, memory retrieval depends largely on surface similarity between objects and contexts.

Analogical encoding in learning

In the late twentieth century, researchers began exploring a new technique, called analogical encoding, that can help overcome the inert knowledge problem. Instead of studying cases separately, learners are asked to compare analogous cases and describe their similarities. This fosters the formation of a common schema, which in turn facilitates transfer to a further problem. For example, in 1999 J. Loewenstein, L. Thompson & D. Gentner found that graduate management students who compared two analogical cases were nearly three times more likely to transfer the common strategy into a subsequent negotiation task than were students who analyzed the same two cases separately.

Implications for education

Analogies can be of immense educational value. They permit rapid learning of a new domain by transferring knowledge from a known domain, and they promote noticing and abstracting principles across domains. Analogies are most successful, however, if their pitfalls are understood. In analogical mapping, it is important to ensure that the base domain is understood well, that the correspondences are clear, and that differences and potentially incorrect inferences are clearly flagged. When teaching for transfer, it is important to recognize that learners tend to rely on surface features. One solution is to minimize surface features by using simple objects. Another is to induce analogical encoding by asking learners to explicitly compare cases. The better educators understand analogical processes, the better they can harness them for teaching.

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