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CROSS-MAPPED ANALOGIES: PITTING SYSTEMATICITY AGAINST SPURIOUS SIMILARITY

Dedre Gentner & Cecile Toupin
Dept. of Psychology, University of Ill., Champaign, IL 61820
Dept. of Psychology, University of Cal., Berkeley, Berkeley, CA 94720

An analogy can be viewed as a device for conveying that two domains share significant relational structure even though they may not share surface similarity. The value of an analogy lies in its ability to give a causal or explanatory coherence to a new domain through the transference of a mutually-constraining set of relations. In Gentner's (1980, 1982, 1983) structure-mapping theory, this is called the systematicity principle. Intuitively, systematicity reflects people's tacit preference for coherence and deductive power in analogy. Syntactically, systematicity is realized as a preference for mapping relations that are governed by higher-order constraining relations that can themselves be mapped. The use of systematicity appears to be a central aspect of adult competence in comprehending analogies. In this research we investigate two questions concerning the nature of this competence: (1) the role of systematicity in the on-line mapping process and (2) the developmental course of the use of systematic knowledge in analogical mapping.

The first question is exactly how systematicity enters into the mapping process. Is it simply a passive desideratum which conveys the complexity, utility, or aptness of an analogy once it has been correctly interpreted ? In accordance with structure-mapping theory, we suggest that systematicity plays a decisive role in the mapping process itself. More specifically, our aim is to show that the presence of systematic structure in the base domain can help people keep the mapping process on track. Moreover, this affect should be most pronounced for difficult mappings. That is, the less transparent the object correspondences are between base and target, the more important will be the ability to take advantage of systematic structure. Without systematicity, spurious similarities between domains are likely to mislead in the mapping process.

To illustrate these principles, we offer a brief analysis of Rutherford's analogy between the solar system and the hydrogen atom. Consider the case where a person hears the Rutherford analogy for the first time. According to structure-mapping theory, the transference of knowledge from the base domain (e.g. the solar system) to the target domain (e.g., the hydrogen atom) involves a mapping process in which the objects from the base are placed in correspondence with objects in the target, e.g., sun --> nucleus, planet --> electron. Then predicates are mapped from the base to the target according to the following three mapping rules:

(1) The relations between objects in the base tend to be mapped across. For example, the lower-order relations:

i. MORE MASSIVE THAN (sun, planet) -->
MORE MASSIVE THAN (nucleus, electron)
ii. REVOLVE AROUND (planet, sun) -->
REVOLVE AROUND (electron, nucleus)

(2) The particular relations mapped are determined by systematicity, as defined by the existence of higher-order constraining relations which can themselves be mapped. For example,

ii. CAUSE [MORE MASSIVE THAN (sun, planet),
REVOLVE AROUND (planet, sun)] -->
CAUSE [MORE MASSIVE THAN (nucleus, electron),
REVOLVE AROUND (electron, nucleus)].

Note that the lower-order relation HOTTER THAN (sun, planet) is not part of the systematic structure and can be dropped.

3) Attributes of objects are dropped. For example:
iv. [YELLOW (sun)] --/-> [YELLOW (nucleus)]

By applying these principles the appropriate relational similarity between the solar system and atom is obtained, as depicted in Figure 1.

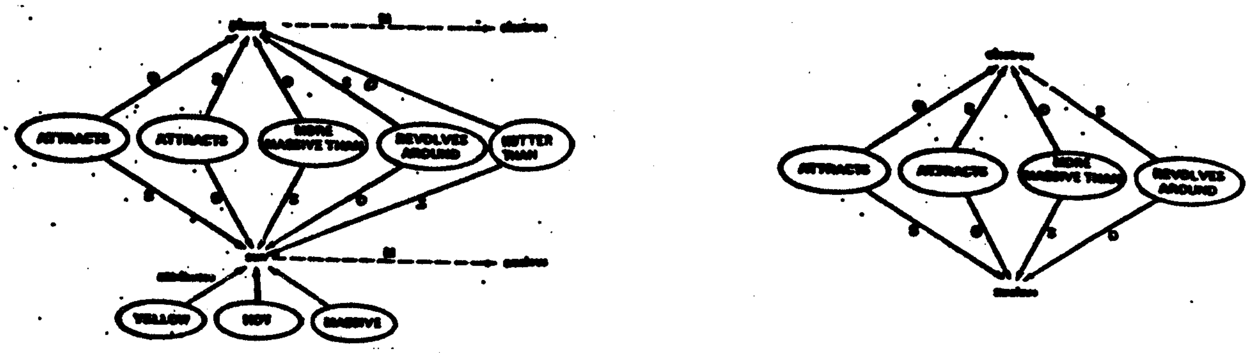
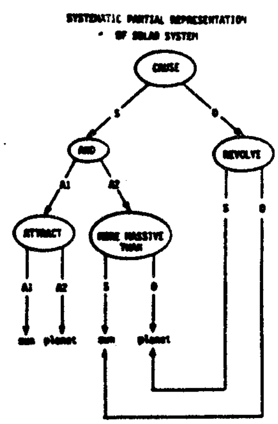


FIG1. Partial depiction of the analogy between solar system and hydrogen atom, showing a person's presumed initial knowledge of the solar system and the mapping of that knowledge to the atom.

By the structure-mapping account, two factors should enter into the success of the mapping process: (1) the transparency of the object correspondences and (2) systematicity. Higher-order relations help to guide the mapping of lower-order relations and provide a check on the correctness of the lower-order mappings. To illustrate how these two factors can interact in the mapping process, we now consider the case where the object correspondences are not wholly transparent, and a mapping error is made. Let us contrast two cases: (1) the systematic case: the learner's initial knowledge of the solar system includes the higher-order relation that there is a causal relation between (a) the fact that the planets revolve around the sun and (b) the fact that the sun is more massive than the planets: and (2) the nonsystematic case: the learner knows facts (a) and (b) but does not know the higher-order relation between them. Figure 2ab depicts a systematic and a nonsystematic representation of the solar system.

- a. Systematic representation



- b Nonsystematic representation.

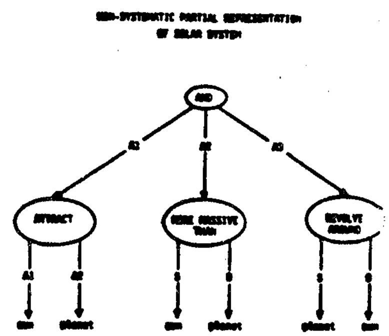


FIG2. More detailed depictions of a person's representations of the solar system

Now lets suppose both learner's are given the solar system/atom analogy, and both make the same error. They become momentarily confused and reverse the object correspondences while mapping the MORE MASSIVE THAN relation, resulting in MORE MASSIVE THAN (electron, nucleus). For the learner who has a systematic model of the base domain, the presense of a higher-order causal relation can be used to spot and correct the spurious mapping of the lower-order relation. In this example, when the predicate structure is transfered from base to target on the basis of the erroneous lower-order relation (proposition 1), as follows,

1. MORE MASSIVE THAN (electron, nucleus)
2. REVOLVE AROUND (electron, nucleus)
3. CAUSE [MORE MASSIVE THAN (electron, nucleus), REVOLVE AROUND (electron,nucleus)]

the learner is in a position to detect a relevant inconsistency. Namely that this chain violates the causal constraint that he knows holds true in the base domain i.e., CAUSE[MORE MASSIVE THAN (sun,planet),REVOLVE AROUND (planet, sun)]. The inconsistency can be resolved by rechecking the object mappings, and reversing the order of objects in the MORE MASSIVE THAN predicate. Thus systematic knowledge of the base domain allows the learner to detect and repair an incorrect local mapping.

In the nonsystematic case, the learner has only two lower-order relations, one of which is erroneous:

1. MORE MASSIVE THAN (electron, nucleus)
2. REVOLVE AROUND (electron, nucleus)

There is nothing is this derived representation of the target domain that can alert him to an error in mapping these relations. Without systematic structure to map from the base domain, the learner simply has an unrestrained set of lower-order predicates. Note that the correct object correspondences - sun/nucleus and planet/electron - are not additionally supported by any salient attribute similarities. Thus unlike the learner who has systematic knowledge, he is unlikely to notice and repair the mapping error.

This line of reasoning leads us to two predictions concerning analogical mapping: 1) systematic knowledge of the base domain leads to more accurate analogical mapping and 2) the affect of systematicity will be strongest when the appropriate object correspondences are least transparent.

The Development of the Use of Systematicity

In this research we investigated the development of the use of systematicity in analogical mapping. We wished to discover when children are able to benefit from the presence of a set of mutually-constraining relations in carrying out an analogy. The method we used was designed to avoid some of the problems that commonly arise when assessing young children's analogical ability e.g., conflating developmental differences in children's ability to reason analogically, with differences in their command of vocabulary, knowledge about domains and pragmatic understanding of when nonliteral comparisons are permissable. The analogical domains in our study consisted of children's stories with simple plot structures. The analogical mapping step involved transferring the story plot from one set of characters to another. In performing this task the child was required only to act out the stories using toy dolls and animals. Thus the success of the child's mapping did not depend upon accessing any privledged information about the base domain, the child's verbal skills, or his/her pragmatic understanding of nonliteral comparisons.

In order to test our predictions concerning the use of systematic structure as a guide to analogical mapping two variables were manipulated: systematicity, and mapping difficulty. In varying the first factor, children were given either systematic or nonsytematic base scenarios to map. Higher-order relational information was embedded in the systematic stories in in two ways. In the systematic stories, the protoganist was attributed a story-relevant habit or relational trait(e.g.,"The chipmunk was very jealous"), whereas in the nonsystematic version a story-irrelevant trait was substituted (e.g."The chipmunk was very good-looking"). The second difference was that a final sentence expressing a moral and linking the protoganist's initial character trait to the story outcome was added only in the systematic story (e.g."The chipmunk realized that he shouldn't be so jealous, because it is better to have more friends). With the exception of these differences, the wording and hence the plot structure of the two scenario types was identical.

The degree of transparency of the object correspondences, or mapping difficulty, was varied using what we called a cross-mapping technique. With this manipulation, the correspondences between the original set of characters (the base set) and the test characters (the target set) could be either very easy with similar-looking characters playing the same roles (S/S) ; or moderately difficult, with different-looking characters playing the story roles (D); or extremely difficult, with characters that looked similar to the original characters but playing different roles than the ones they were assigned in the original story (S/D). An example will help to clarify the differences between these three mapping conditions. Suppose that in the original story the hero was a chipmunk, the hero's friend was a robin and the villain was a horse. Then the roles in the three mapping conditions might be as follows:

	ORIGINAL	S/S	D	S/D
HERO	chipmunk	squirrel	elephant	zebra
FRIEND	robin	bluebird	shark	squirrel
VILLAIN	horse	zebra	cricket	bluebird

The prediction was that the children's accuracy in enacting the target story would be greatest for the S/S mapping condition and lowest in the S/D condition, where the natural object mappings had to be resisted. A further question was which of the two experimental variables - systematicity or object-mapping - would show up earlier developmentally. Our expectation was that effects of mapping condition would show up before effects of systematicity. A more interesting question, from our theoretical perspective, was whether systematicity would interact with mapping difficulty. For if the presense of systematic higher-order relations helps the child preserve the relational structure she is trying to map, then the more difficult the mapping the greater the potential effects of systematicity.

Method

Subjects. The subjects were 72 children, 36 four-to-six-year-olds, and 36 eight- to ten-year-olds, recruited from local preschools in Cambridge, Mass. Approximately equal numbers of males and females were included within each of the two experimental conditions (systematic and nonsystematic), and within each age group.

Materials. Nine short stories were constructed consisting of (1) an introductory section, which introduced two out of the three story characters and their relationship (2-3 sentences) (2) an event sequence, depicting a series of actions with an outcome (10 - 15 sentences) and (3) a moral (in systematic versions only). There were two versions of each story: systematic and nonsystematic. The two story types differed only in their introductory sections and in whether they contained a moral.

Story-telling Stimuli. Sixty-three toy dolls and animals were used to depict the characters. Of these, there were 27 pairs of animals that were independently judged by three judges to be 'similar-looking', and nine animals that were judged to be 'different looking' from one another and from any of the paired animals. A small number of props were additionally used to aid in the story-telling e.g., plastic food, and felt pieces to mark locations.

Systematicity Condition. Subjects in each age group were randomly assigned to either the Systematic or the Nonsystematic Condition so that there were equal numbers in both conditions. Subjects in each of these conditions received all nine stories of either the systematic or nonsystematic type, respectively.

Mapping Conditions. For each base story that the child heard, one of three sets of characters were inserted as the actors in the story. Relative to the 'target' set of characters, which were the same for all subjects, the characters depicted in the base story were either similar-looking characters in the same story roles (S/S); different-looking characters in the story roles (D); or similar-looking characters in different story roles (S/D). We decided to vary the characters in the original base story that the children heard , while keeping the target story to be retold by the subjects the same (instead of vice versa) in order to achieve strict comparability on the test/scoring phase.

Each child received three stories in each of the three mapping conditions, for a total of nine stories. The assignment of stories to mapping condition was counterbalanced across groups of children. The mapping conditions (S/S,D and S/D) were presented in six different orders, according to a Latin Square Design. There were two story-presentation orders; an ordering of all nine stories was presented in a forward or reverse sequence.

Procedure

The experimental procedure was the same for each story and was divided into two parts: the Story Phase and the Test Phase. Prior to beginning the experiment subjects received a practice session to acquaint the subjects with the nature of their task. Once the child demonstrated the ability to perform the transfer task with a four-line story about two characters. without help, the experiment proceeded.

Story Phase. For each story, the experimenter began by introducing each of the three story characters by presenting their toy facsimiles and naming them (e.g., "Here is the moose.") With the characters in view, the base story was then read aloud. and the subjects were instructed to listen very carefully. Then props were introduced and the children were asked to act out the story on their own, verbalizing as much as possible. Any omissions and errors were corrected by the experimenter during this phase. The Test Phase began once the subject demonstrated the ability to act out the story correctly without help.

The Test Phase . The experimenter then asked the subject to act out the story again, but with three new characters. The three original story characters were removed from view and the new test characters were introduced and named. The experimenter then read aloud the introductory section of the story just read . substituting the names of the new 'target' characters for the names of the original story characters, thereby identifying the relationship between and character traits of two of the three characters. This introductory section was repeated if desired. Then the subject was told to tell the rest of the story. During the test phase, the experimenter did not provide the subject with any information regarding mapping assignments, omissions or errors.

The Story and Test Phases were carried out in the same way for each story. Children were given three stories in a test session, with a two-minute play task between stories. Each child participated in three test sessions, spaced at least a day apart.

Scoring. For each story, the sentences were grouped into six core propositions representing the major events and the outcome. These six did not include the moral in the systematic stories. Thus the same six propositions were scored for the systematic and nonsystematic conditions. In scoring, propositions were treated as wholes. A proposition was scored as correct if the child either verbally or nonverbally depicted the correct actor(s) and action(s) contained in the proposition. Two types of errors were scored: omissions and incorrect answers. A proposition was scored as an omission if the child both verbally omitted any actor or action contained in the proposition AND failed to convey the information through nonverbal actions. Similarly, a proposition was scored as incorrect if any actor(s) or action(s) contained in that proposition was incorrectly identified both verbally AND through nonverbal actions.

Results

The results are shown in Figure 3. All of our expectations were confirmed: (1) the object-mapping condition had strong effects on the transfer accuracy for both age groups. (2) systematicity benefited only the older group and (3) the benefits of systematicity were strongest in the most difficult mapping condition.

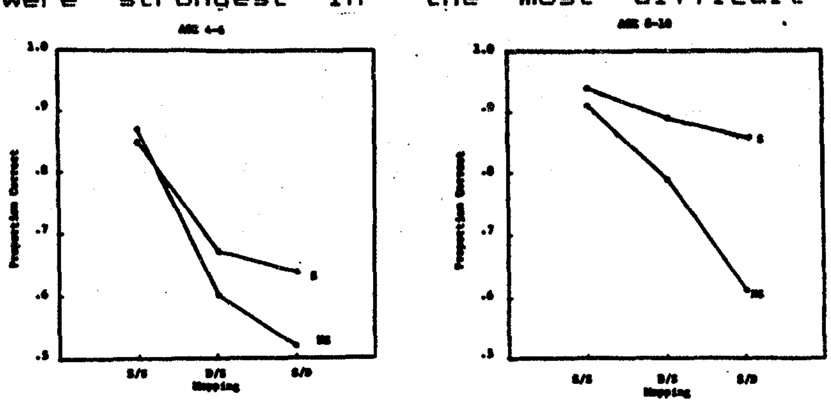


FIG 3. Results: Proportion of statements in the target stories correctly enacted under different kinds of mapping conditions given systematic versus nonsystematic versions of the original story, for four-to-six year-olds and eight-to-ten year-olds

A 2x2x3 mixed-measures analysis of variance of Age (Between) x Systematicity (Between) x Mapping Condition (Within) showed main effects of Age $[F(1,68)=14.93, p < .01]$, Systematicity

[F(1,68)=6.28, p < .05], and Mapping Condition [F,(2,136)= 29.01, p < .000001]. There was also the predicted interaction between Systematicity and Mapping Condition [F(2,136)=3.89, p <.05]. Although both Mapping Condition and Systematicity show main effects, their developmental patterns differ. Planned comparisons confirmed that Mapping Condition had significant effects on both age groups. As predicted children performed best with the easy S/S mapping, intermediate with the D mapping, and worst with the misleading S/D mapping. In contrast, Systematicity showed significant effects only in the older group. For the older children, performance was significantly better on systematic stories [t(34)=2.48, p < .01]. This was not true for the younger children; they derived no significant advantage for systematic plot structure [t(34) = 1.08, NS]. Moreover, planned comparisons within the older group revealed that systematicity was significant only in the S/D condition. This confirmed our third prediction that systematicity should have its greatest effects on the most difficult mappings. This suggests that systematicity indeed plays a role in the mapping process: children (at least by the age of eight) can use higher-order constraints to help keep the lower-order predicates straight. We found informal support for this claim in the self-corrections that the older children occasionally made. A child would begin to make an error, acting out an event with the wrong character, and then stop herself with a remark like "No wait, it's the greedy one who got stuck in the well, because he ate too much." Here the child is using higher-order causal relations to check the correctness of a lower-order predicate.

Discussion

In this research we found effects of both systematicity and object-mapping difficulty on the accuracy of children's analogical mappings. These results have implications both for theories of analogical processing and for accounts of the development of analogy and metaphor. While the principle of systematicity has become increasingly prominent in computational approaches to analogy , there has been little evidence about how systematicity enters into the analogical process. Structure-mapping theory , and the results of this research , suggest that both systematicity and the naturalness of object correspondences contribute to the correctness of the mapping process. Two developmental questions were posed here: (1) whether there are developmental differences in the effects of difficult object correspondences in analogical mapping and (2) whether children develop in their ability to profit from systematic relational structure in dealing with difficult object mappings. One rather nice aspect of our methodology is that it allows an indirect measure of the child's ability to use systematicity. Research on the development of metaphor has shown repeatedly that children do not articulate their interpretation of metaphors in the same manner as adults. However, it is unclear what conclusions should be drawn from these results concerning children's ability to perform metaphorical and analogical transfer. In the present methodology, children simply acted out stories with a new set of characters. Thus, although they were not required to verbalize the relational structure they were carrying across, their ability to make the transfer was clear from the accuracy of their reenactment. Given that the child can act out the original story (which was in all cases true), we found (1) children of both ages were affected by the naturalness of the object mappings (2) systematicity benefited only the older children and (3) systematicity had its greatest effect when the object mappings were most difficult.

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