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ANALOGICAL DISTANCE AND PURPOSE IN CREATIVE THOUGHT: MENTAL LEAPS VERSUS MENTAL HOPS

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When people apply existing knowledge to new tasks, the circumstances surrounding that application can vary enormously from one situation to the next. Potentially important variations include the purposes to which the old information is put, the conceptual distance between the old source and the new target domain, and the person's state of knowledge regarding the target. Considering some of these variations can help to provide a broader context for the research I will present and for thinking about knowledge transfer more generally.

Knowledge from a familiar source can be used for the purpose of reasoning about, explaining, or otherwise coming to understand a less familiar target domain, or it can be used to supply the starting point or structuring information needed for the design of novel products, inventions or other tangible artifacts. As a short-hand, these different uses of existing knowledge can be referred to as **explanatory** and **inventive**, respectively.

In terms of conceptual distance, the source and target can come from the same conceptual domain, from related, though nonidentical domains, or from wildly discrepant domains, (e.g., Dunbar, 1997; Vosniadou & Ortony, 1989). For ease of reference, those continuous variations can be labeled loosely with the dichotomous terms **near** and **distant**.

Finally, individuals seeking to apply source knowledge to a target situation may know a great deal or next to nothing about the target. As discussed below, initial knowledge about the structure of the target should be richer in the explanatory than in the inventive case.

A PARTITIONING OF CASES

The explanatory/inventive and near/distant distinctions can be used to partition knowledge transfer situations into several types. For example, classic instances of real-world analogies, particularly those involved in scientific discovery, are typically characterized by the use of a well-known, but conceptually distant source domain to explain or understand a relatively less familiar target domain. An oft noted instance of this type of **distant/explanatory** analogy is Rutherford's comparison between the familiar structure of a solar system and the (then) relatively unknown structure of the atom. Another less noted, but equally striking instance is Kepler's analogy between the properties of light and a hypothetical motive power of the sun which he invoked to try to explain planetary motion (Gentner, Brem, Ferguson, Wolff, Markman, & Forbus, 1997).

Distant sources are also reported to serve the purpose of envisioning, designing, and producing novel inventions. A frequently cited instance of this type of **distant/inventive** analogy is the role of burrs in the invention of velcro. According to the story, when velcro's inventor, George de Mestral, used a microscope to examine burrs that had attached to his clothing, he noticed that they were collections of

miniature "hooks" that had locked into the "eyes" in the cloth of his pants and socks. Mestral used that knowledge to design a similar system of miniature hooks-and-eyes that could be used as a fastener.

Recent observations of the activities of molecular biology laboratory groups have also identified a preponderance of **near/explanatory** analogies, which involve the use information from either the same domain in a different context, or a closely related source domain to understand the target domain (e.g., Dunbar, 1997). Instances of these types of analogies identified by Dunbar include a mapping from how HIV operates in an in vivo context to how it works in an in vitro context, and a mapping between the Ebola and Herpes viruses.

To complete the set, the world is replete with instances of **near/inventive** analogies in which individuals stay within a domain, but push its boundaries by envisioning and bringing to fruition novel exemplars of that domain.. The term "inventive" here is not used to restrict these types of analogies to the acts associated with producing patentable inventions, but rather to contrast them with those analogies designed primarily to explain or understand a phenomenon. Thus, when an engineer designs a new gear, a novelist crafts a new unlikely hero, or a country singer pens a new ballad, their creative activities can all be seen as instances of near/inventive analogy use. Examples of this type of activity abound, and they include specific cases of invention, such as Thomas Edison's patterning of his electric light distribution system after the existing gas light distribution system of his day (Friedel & Israel, 1979), and Eli Whitney's use of the existing charka as the basis for his cotton gin (Basala, 1978). They also include more generic tendencies, such as science fiction writers' reliance on Earth animals as the bases for their imaginary extraterrestrials (Ward, 1994), and architects' reliance on specific instances of prior buildings to accomplish particular goals in the design of new buildings (see e.g., Kolodner, 1997).

MENTAL LEAPS, MENTAL HOPS, MAPPING AND ACCESS

Considerable research has focused on the use of analogy in reasoning and explanation, and, at least from the examples that have been described most often, much attention has been given to distant analogies. In contrast, the current presentation will focus primarily on the sorts of products that emanate from near/inventive uses of existing knowledge, with a particular emphasis on the retrieval of highly representative domain exemplars as sources of information. However, it will also briefly attempt draw out connections to more distant and explanatory types of transfer, and to delineate some of the potential variations in goals and outcomes across the situations. To what extent is the transfer of old knowledge to new situations governed by similar principles across the range of conceptual distances and purposes?

As one possible difference across situations, it is reasonable to postulate that distant analogies are more likely to be associated with extraordinary forms of creativity, whereas near analogies are more likely to be associated with everyday, relatively small creative increments. If distant analogies are seen as creative "mental leaps" (e.g., Holyoak & Thagard, 1995), intra-domain conceptual extensions might be better seen as creative "mental hops," with less deviation from the source and more attributes preserved. That is, because the objects from distant domains will differ greatly in their superficial properties while at the same time participating in comparable relations, only the latter will tend to be mapped (Gentner, 1989) across distant domains.

In contrast, because instances from the same or close conceptual domains will share superficial as well as deeper similarities, those surface properties are more likely to be preserved in the near than in the distant case. Put differently, the new concept that results from the analogy process will generally diverge less from the old ones in near than in far analogies. Near analogies reflect more of a literal similarity between the source and target (e.g., Gentner, 1989), they may

represent smaller conceptual changes between the old and new ideas, and thus may be seen as less dramatically creative.

Having linked near analogies to smaller creative advances, however, I hasten to add that this in no way diminishes their importance. Human progress is certainly much indebted to the basic propensity to innovative in small incremental steps that diverge only slightly from what has come before (see e.g., Basala, 1978).

It is important, too, to distinguish the conceptual distance between old and new ideas from the broader impact of those new ideas. For instance, Edison's lightbulb differed only slightly in basic form from several less successful patented versions that preceded it. Yet, the end result of widely available electric light had a dramatic effect on society. Thus, it represented a small hop from what had come before conceptually, but a giant leap in terms of its impact on the world.

Another difference across the types of situations is that the inventive case seems to imply less initial knowledge about the structure of the target, and consequently, a more limited role for an initial mapping between the source and target. Unlike the case of explanatory analogies that presumably arise because there are observations and some amount of knowledge about a target domain that call for further explanation, the "targets" or products of inventive analogies often do not exist until they are created via the projection of structure from the source.

For example, observations about planetary motion existed before Kepler applied knowledge about light to explain or understand those phenomena, whereas the concept of velcro did not exist, even in rudimentary form prior to de Mestral realizing that the structure of burrs could be adapted to produce a reusable fastener. Results from experiments on specific disease processes existed to be explained by near analogies to other known disease processes (Dunbar, 1997), whereas the cotton gin, as a specific product, did not exist until Whitney applied knowledge from its immediate predecessor, the charka, to develop it.

Because the target, **perse**, tends to come into being in the inventive case as a result of the analogical process, determining the mapping between source and target domains is somewhat simplified relative to the explanatory case in which the relational structures of the source and target must be structurally aligned to produce an effective analogy (e.g., Gentner & Markman, 1997). This is not to say that the goals or desirable properties of inventions, story lines, villains, buildings, and so on are not specified in advance or that they play no role in adapting the structure of the source knowledge, but simply that mapping between domains is minimized and projection is emphasized. Inventive analogies seem to reflect, not so much a process of comparison of structures as they do a process of projecting or instantiating a known structure in a novel way.

Although mapping may be minimized, a crucial issue for inventive analogies (as well as explanatory ones) is to characterized how people **access** the source information. What factors determine the retrieval of the information that will serve as the basis for the structure of the novel product? Here too, there may be differences across situations.

Similarity of surface level and structural properties between the target and source is widely acknowledged as being crucial to retrieving sources in explanatory analogical reasoning (see e.g., Dunbar, 1997; Gentner, 1989; Holyoak & Thagard, 1989; 1997; Ross, 1989). However, in the inventive case, the target only exists after the fact, and similarity to the source may be better seen as the **consequence** rather than the **cause** of retrieving a particular source. Alternatively, if the goals for the novel product are well-enough specified, and the person's knowledge is indexed in a way to allows access to previous cases that have satisfied those goals, goal-relatedness might drive retrieval in the inventive case (see, e.g., Kolodner, 1997).

Beyond similarity to the target and the capacity to satisfy the goals for the target, retrieval of source information may well be determined primarily by the properties of the source domain itself as well as more general conceptual

processing tendencies, such as a reliance on the basic level of categorization. Without a rich target representation driving the retrieval of a highly similar source, properties of the source domain itself may take on special importance in determining what gets retrieved and used in the inventive case. In the next sections I describe a series of experiments concerned with the near/inventive use of existing knowledge, and I discuss one particular model that highlights the role of the graded structure of source domains and the retrieval of highly representative instances from those domains.

NEAR/INVENTIVE ANALOGICAL PROJECTION

Because the products of near/inventive creative endeavors are direct outgrowths of the concepts that have come before, they can be expected to share important properties with previous exemplars of those concepts. This is true of real-world accomplishments, such as inventions, art, music, writing, and science (e.g., Basala, 1988; Friedel & Israel, 1986; Weisberg, 1986), as well as laboratory-based performance observed in a variety of generative tasks (e.g., Ward, 1994; Ward & Sifonis, 1997).

As an illustration of a laboratory-based study concerned with the role of existing knowledge in near/inventive, creative generation, Ward (1994) asked college students to imagine, draw, and describe animals that might live on other planets. Despite the fact that the planets were described as being completely different from Earth, Ward found that the students' creations tended to be strongly **analogous** to Earth animals in many respects. At the level of superficial similarity of component elements, they were very likely to possess standard sensory organs, such as eyes, and standard appendages, such as legs that were highly similar in appearance to their counterparts in Earth animals.

At a somewhat deeper level, it is also obvious from the participants' drawings and descriptions that the form of these imagined animals was influenced by the kinds of relational structures that connect the separate elements of Earth animals. That is, the senses and appendages were not simply scattered about randomly, but rather were organized into symmetric wholes within bounded solid forms. Likewise, the component elements of the creations showed a kind of one-to-one correspondence with those of Earth animals in that the individual sense organs and appendages tended to correspond to single matching organs and appendages of Earth animals. Eyes matched eyes and tended to serve only the single function of extracting visual information. Legs matched legs, and tended to serve mobility only.

In addition, although participants did not often state it explicitly, their creations also showed a kind of systematicity. That is, clusters of symmetrically placed elements seemed to play complementary roles within broader goal systems. For example, the eyes serve to collect information about prey, the legs allow an approach to the prey, and the claws provide the capacity to grasp it.

It is important to note, however, that despite their obvious similarity to Earth animals, the imagined animals were only rarely direct replicas of any one specific Earth animal. Thus, they possessed some degree of novelty, while still preserving much of the structure of the source domain of Earth animals.

Although with hindsight, these results are not terribly surprising, it is important to note that living things on other planets could conceivably take any of an infinite variety of forms. There is no reason, in principle, why they would have to resemble Earth animals in their surface form. Nevertheless, people projected many of the characteristic properties of Earth animals onto their imagined extraterrestrials. Similar results have been found with other conceptual domains, such as faces (Bredart, Ward, & Marczewski, in press), and with other age groups, such as young children (Cacciari, Levorato, & Cicogna, 1997).

Taking the properties of the novel creations collectively, they seem to reflect an instance of analogical projection from a well-known source domain (Earth animals), to a relatively unknown target domain (extraterrestrials from

planets different from Earth). That is, they were structured by component elements that were projected in way that preserved **structural consistency** or **isomorphism**, as well as a high level of **sytematicity**, which have been identified as important ingredients of analogies (e.g., Gentner, 1989; Gentner & Markman, 1997; Holyoak & Thagard, 1989; 1997).

THE PATH-OF-LEAST-RESISTANCE

To account for the structuring of new ideas by old information, Ward and his collaborators have proposed the path-of-least-resistance model (Ward, 1994; 1995; Ward et al., 1997). According to this model, when people approach the task of developing a new idea, their thinking carries them down paths-of-least-resistance in their conceptual representation of the most relevant knowledge domains. They are assumed to gravitate toward fairly specific (basic level) exemplars of the concept, and to project the properties of those instances onto the novel ideas they are developing. For example, in developing imaginary extraterrestrial animals, rather than remaining at the broad level of "animal" people tend to gravitate toward more specific categories within that domain, and to highly **representative** instances, such as dogs rather than less representative ones, such as iguanas.

Although there are many different measures of representativeness (Barsalou, 1985), the one Ward et al. hypothesized to be most predictive was **Output Dominance**, a measure of how readily instances come to mind. The idea is that the category exemplars that come to mind most readily are the ones most likely to be used as starting points in formulating novel ideas. The rationale is that generating new ideas is cognitively demanding, and people tend to simplify the task by pursuing ideas that come readily to mind.

Ward et al. (1997) have recently provided support for the path-of-least-resistance model. They first determined which exemplars were most representative of the domains of animals, tools, and fruit by having college students list the first 20 items that came to mind for each of those categories. The students' responses were then tabulated to derive Output Dominance scores for each exemplar, that is, the number of students listing each exemplar.

The prediction from the path-of-least-resistance model was that the items that were found to be highest in Output Dominance would be the ones most likely to be used as the basis for novel ideas in tasks of imagination. To test the prediction, Ward et al. (1997) then had different groups of college students imagine animals, tools, and fruit that might exist on other planets. In addition to drawing and describing their creations, the students listed all of the factors they could think of that influenced them during the creation process. Those statements were then examined for references to specific exemplars from those domains (e.g., dogs, hammers, apples, and so on), and across the domains, roughly two-thirds of the participants mentioned relying on such specific exemplars.

References to each exemplar were then tabulated to derive a measure termed **Imagination Frequency**, which is an indicator of the likelihood of any given exemplar being used as a starting point for a novel creation. For instance, of the college students who developed imaginary animals, seven mentioned that they based their creations on dogs, which resulted in dog receiving an Imagination Frequency score of 7. Across all three domains and several procedural manipulations, Imagination Frequency scores were found to be significantly positively correlated (in the .60 range) with Output Dominance scores. That is, the students tended to rely most heavily on those category exemplars that come to mind most readily.

THE UNCONSTRAINED CASE

Although, the global findings reveal that many people retrieve and use specific category instances, and that those instances tend to be highly representative ones, considering variations in the task conditions used by Ward et al. (1997) can provide additional insight into the factors that do and do not affect what people

retrieve from the source domains. In the first experiment, participants imagined animals that might live on other planets, but they were given little information about the planets, other than the fact that they were very different from Earth. Participants were free to imagine any creature they could, with no constraints on what it could look like, in what type of environment it might need to survive, and so on. Consequently, it is possible that they gravitated toward specific, highly representative Earth animals in this unconstrained case largely because those animals provided an easy solution to the task at hand; they were quickly retrieved from memory, and they did not violate any specified constraints. But what happens to retrieval when various constraints are imposed or when additional information about the target is given?

DESIGN CONSTRAINTS

In the second experiment of Ward et al. (1997), participants imagined novel tools that might be used by a species of intelligent extraterrestrials. Some participants were given no design constraints, whereas others were asked to imagine tools that could meet the needs of an alien species very unlike humans in that they had no appendages. The idea was that, because manipulation by way of hands is a central property of standard tools, constraining participants to consider such a creature might encourage them to move away from Earth tool exemplars. Alternatively however, the tendency to rely on highly retrievable exemplars of the domain may be strong enough that it remains even when those exemplars would need to be heavily modified to meet task constraints. By this latter view, participants facing the constraint may be just as likely as unconstrained participants to rely on Earth tool models, and they will simply modify those exemplars to meet the needs of the species.

The latter view clearly won out in this particular experiment. Those participants who were constrained to design tools for creatures that had no appendages were just as likely as those who faced no design constraints to retrieve specific instances of Earth tools as starting points, and those retrieved tools were no less likely to be predominantly high in Output dominance. Thus, the relative accessibility of category exemplars can play a powerful role even when other situational constraints are operative. The path-of-least-resistance appears to be a seductive and slippery one.

RETRIEVAL CUES FROM THE TARGET

It is important to note, however, that the representativeness of instances within a domain is flexible rather than rigid (e.g., Barsalou, 1987) Consequently it ought to be possible to bias people to retrieve and make use of particular types of instances. Ward (1994) explored this possibility by providing participants with additional information about the properties of the target. Specifically, different groups of participants were told that the creature to be imagined had feathers, scales, or fur, or they were given no information about its attributes.

The subjects in the "feather" condition were significantly more likely to include wings and beaks as additional features, whereas those in the "scales" condition were significantly more likely to include fins and gills, relative to those in the "fur" or control conditions. More importantly for present purposes, self-reports indicated that participants tended to base their creations on particular instances of known birds, fish, or mammals, in the feather, scales, and fur conditions, respectively. Thus, the different cues provided about the target led to the retrieval of different instances from the source domain of Earth animals, whose properties were then mapped onto the novel entities.

In a subsequent experiment, Ward (1994) examined the interactive effects of two types of information about the target domain on the retrieval and use of specific instances: one was general information about the environment on the creature's planet, and the other was specific attributes of the imagined creature itself. Some participants were told that the planet was composed mostly of molten rock with only a

few islands of solid land. To obtain enough food, creatures on the planet needed to be able to travel from one island to the next. Consequently, being able to fly over the molten rock would be an adaptive trait and participants creations were expected to be highly likely to fly.

Other participants were told that the planet had violent winds blowing all around it, from just a couple feet above the surface all the way up to the upper reaches of the atmosphere. Flight on such a planet might be expected to be maladaptive and few flying creatures were expected.

In each planet condition, some participants were given a specific detail about the target creature, namely that it had feathers. Others were told that it had fur.

The most important findings were that a) participants in the Molten-Feather and Molten-Fur conditions were highly likely to design flying extraterrestrials, thus showing a sensitivity to the design constraints in the task, but that b) they appeared to have arrived at those creations by different paths. Participants in the former group were more likely than those in the latter group to produce creatures that were classified as birdlike, and to report basing their creations on specific instances of Earth animals. A plausible account of the findings is that the presence of the cue "feathers" led participants to retrieve exemplars of birds which would have been compatible with the environmental constraints of the Molten planet (i.e., safe travel over the molten areas from one island to the next). In contrast, the cue of "fur" may have led participants to initially retrieve mammalian exemplars which, with the exception of bats, would not possess the desired attribute of flight. Consequently, those exemplars would have been rejected in favor of a different starting point. However, because the cue of "fur" also would have reduced the likelihood retrieving birds, birdlike exemplars would have been unlikely to serve as that next starting point. Such conflicts between retrieved exemplars and desired properties of the target may ultimately have led participants to construct flying creatures on the basis of more general information about flight rather than on the basis of specific known exemplars. Thus, the end-product would be less likely to resemble a bird.

Participants in the Windy conditions were less like to produce flying creatures and less likely than those in the Molten-Feather condition to report a reliance on specific Earth animals. Presumably, those in the Windy-Feather condition might also initially have retrieved birdlike exemplars, but would have rejected or drastically modified them because of their incompatibility with the environmental conditions on the Windy planet.

In general then, the findings suggest that information about the known properties of targets (e.g., feathers) and about other task constraints can interact to determine the probability that people will make use of particular instances from the source domain. Target cues can increase the likelihood of retrieving source instances that have properties that match the cue. When other salient properties of those retrieved exemplars are compatible with the task constraints, people tend to rely heavily on those specific exemplars. When those other properties conflict with task constraints, reliance on specific exemplars can be reduced.

CONSTRAINTS FROM PERCEIVED TASK DEMANDS

It may seem odd that people would gravitate toward highly representative instances when they are trying to be creative. Why not shift to more exotic exemplars, or try to avoid them entirely? One reason that people may not do so in these laboratory tasks is that they perceive the demands of the tasks differently from what we intended. Perhaps they think that they are supposed to use representative exemplars or that highly original products would not be valued.

To examine the role of expectations, Ward et al. (1997) had participants design imaginary fruit under different instructional conditions. Some were told to be creative and others were given no special instructions. The results were straightforward; participants who were given

the creativity instructions were just as likely as control participants to rely on highly representative instances of Earth fruit in designing their own creations. Thus, the heavy use of highly representative instances is not due exclusively to perceived demand characteristics. More generally, although expectations will surely matter in some real-world and laboratory situations, category structures may often be powerful enough to produce large effects in spite of those expectations.

ACCESS TO SPECIFIC INSTANCES AND LIMITATIONS ON CREATIVE FUNCTIONING

A particularly intriguing finding is that those participants who report that they base their creations on specific exemplars from the source categories design imaginary products that are rated as showing less originality than those produced by participants who report other types of approaches (Ward, 1994; Ward et al., 1997). That is, their creations diverge less from the characteristic properties of known instances from the source domains. Having brought specific instances to mind, the participants tended to project the properties of those retrieved instances onto their novel creations, with the consequence that those creations showed less innovation than ones produced by participants who adopted different approaches to the task. Thus, it appears that one of the major constraints on generative or creative functioning lies in our natural tendency to rely on previous examples when thinking of novel concepts or ideas. More original products can be expected to result when people avoid the tendency to apply the first available representation to a problem (Ward & Sifonis, 1997).

STRATEGIES AND POPULATION EFFECTS

Relying on specific, highly representative exemplars of a known concept and projecting properties from those exemplars onto novel creations should be seen as strategic choices. More creative individuals may be expected to be more flexible in the use of their conceptual knowledge, better able to avoid reliance on representative instances, and less likely to project characteristic properties from specific exemplars. To examine this possibility we have recently observed the performance of gifted adolescents (who can be hypothesized to possess that cluster of conceptual abilities) in the imaginary fruit task (Ward, Saunders, & Dodds, in press).

The gifted participants showed a balance between flexibility and rigidity in the way they approached the design task. That is, they were less likely than our typical college student samples to rely on specific types of Earth fruit. However, when they did so, they were just as likely to gravitate to the items that come to mind most readily, that is, that are highest in output dominance. The correlations between Imagination Frequency and Output Dominance scores for Earth fruit were nearly identical to those found for college students.

ABSTRACTION AND CONCEPTUAL DISTANCE

The path-of-least-resistance model implies that people should be able to develop more creative ideas by moving back up the path in the conceptual hierarchy to more abstract levels. Properties from any level will be projected onto the novel entity being constructed, but they will be less specific, and thus less constraining at more abstract levels. For example, patterning of a novel creature after a dog might lead to the projection of two eyes placed symmetrically in the head, whereas projection from "living thing" might lead to the projection of "taking in information about the environment," a less constraining property that could be instantiated in an indefinite number of ways.

Moving back up the path might be thought of as enhancing originality by shifting the case from a near analogy to a far one. At a specific level, such as "dog," if the person imports information from yet another source to bolster the originality of the creation, it is likely to be a

source in the same superordinate, such as a "cat." The higher the level, the broader the superordinate is and the more distant that other source can be. At a very broad level, such as "living thing," the immediate superordinate might be as broad as "physical entity" which could open the possibility of importing information from a quite distant domain, such as "nonliving thing" (e.g., wheels for appendages). In so doing, the length of the mental hop can be increased so that it more approximates a mental leap.

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