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Meta-Analogical Transfer: Transfer between Episodes of Analogical Reasoning

Bruce D. Burns

University of California, Los Angeles

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Address: Bruce Burns
Department of Psychology
University of California, Los Angeles
Los Angeles, California, 90095-1563

Abstract

Meta-analogical transfer (i.e., transfer due to forming an analogy between analogies) was demonstrated in four experiments. Results suggested that the basis of meta-analogical transfer was transfer of predicate mappings (mappings of the concepts used to represent analogies) between separate episodes of analogical reasoning. Episodes of letter-string analogy problem solving of the form, “If **abc** was changed into **abd**, how would you change **kji** in the same way?” were used. These analogy problems are well-constrained and have multiple plausible solutions. In Experiment 1 participants generated solutions in two separate analogical reasoning episodes. Order of presentation effects provided evidence of meta-analogical transfer based on transfer of predicate mappings (e.g., "successor to successor"). Experiments 2a and 2b reinforced these findings, demonstrating transfer when mappings for the first analogy were directly manipulated by having participants justify an answer to the first analogy. Experiment 3 demonstrated that a mapping of non-identical predicates ("successor to predecessor") can also be transferred.

Meta-Analogical Transfer: Transfer between Episodes of Analogical Reasoning

Analogical reasoning is based on transferring information from a known situation (the *source* domain) to a situation requiring explaining (the *target* domain) by finding a similar system of relations that holds among the elements in each situation (Vosnaidou & Ortony, 1989). Such analogical reasoning has been suggested to underlie human thinking within domains as diverse as science (Oppenheimer, 1956), management (Isenberg, 1986), poetry (Holyoak, 1982), football recruiting, international relations (Gilovich, 1981), military command, chess, and fire fighting (Klein, 1986). One might ask, for example, whether a potential conflict involving the USA is another "Vietnam War" or another "World War II." Or in 1981, when Nancy Reagan was the "first lady" of the United States, who was the "first lady" of England? As Hofstadter (1985) pointed out, this question could have multiple answers: the Queen? Margaret Thatcher (at that time, the Prime Minister of the England)? Dennis Thatcher, who was Margaret Thatcher's husband? Hofstadter points out that Dennis Thatcher seems the most analogous answer because Nancy Reagan and Dennis Thatcher had the same relationship to political power.

The ability of people to form abstract analogies is impressive (Gentner & Gentner, 1983; Gick & Holyoak, 1980, 1983; Keane, 1988). But once an *episode* of analogical reasoning is over, do the representations formed simply evaporate? Or, could the result of one episode of analogical reasoning be transferred to a new episode of analogical reasoning? Hofstadter (1995, p. 317) suggested that people can form *meta-analogies*, that is, analogies *between* analogies. He illustrated this concept with the following analogy:

> *Doug:* The Germans call a tortoise a *Schildkröte* — literally, "shield-toad".
>
> *Carol:* "Shield-toad"?! Come on! That's like calling an eagle a "feather-cow"! (Hofstadter, 1995, p. 304)

In this meta-analogy, Doug points out that the German language suggests an analogy between a tortoise and a "shield-toad". Carol then ridicules this terminology, by drawing a new analogy between an eagle and a "feather-cow". In forming this new analogy Carol is transferring the analogical relationship between tortoise and "shield-toad" ("shield" has a good analogical correspondence to the shell that

covers a tortoise, but "toad" has a poor correspondence to its body) and using those correspondences to form a new analogy ("feathers" are what cover an eagle, but "cow" has little correspondence to an eagle's body). Another such meta-analogy can be illustrated using the previous example, that is, the analogy that Nancy Reagan was to America what Dennis Thatcher was to England. One might ask, who is to France as Albert Einstein is to Germany? In seeing Dennis Thatcher as analogous to Nancy Reagan the concept of "woman" in the source domain (i.e., Nancy Reagan being the first lady of America) is placed into correspondence with the concept of "man" in the target domain (i.e., Dennis Thatcher being the "first lady" of England). Such a correspondence can be described as a *mapping* of "woman to man" (in this paper the mapping of two concepts, X and Y, will be denoted as "X to Y"), which implies the mapping of "man to woman" as well. Accordingly, if people form a meta-analogy between the analogy that "Dennis Thatcher is the first lady of England" and the analogy problem "Who is the Albert Einstein of France", then they may transfer the mapping of "man to women". Thus people may be more likely to answer "Marie Curie". In a sense, meta-analogies are a form of learning from analogy, in that the mappings formed in one episode of analogical reasoning may assist with analogical reasoning in a new episode.

A different form of learning from analogical reasoning was identified by Gick and Holyoak (1983), who found that making an analogy between two dissimilar stories (e.g., "The General" and "The Fire Chief", see Gick & Holyoak, 1983) resulted in the formation of an abstract schema that distilled the essence of the two stories (i.e., using converging weak forces in place of a single large force). People who formed such an abstract schema were better at solving a subsequent problem (i.e., The radiation problem of Duncker, 1945) that was analogous to both of the original stories, than if they had been given one analogue alone. Other studies have found similar advantages of forming a schema (Catrambone & Holyoak, 1989; Novick & Holyoak, 1991; Ross & Kennedy, 1990). But note that all the situations used in these experiments, including the source stories used to form the schema and the target problem, were analogous to each other. Individually, "The General" story is analogous to the radiation problem, as is the "Fire Chief" story. This design contrasts with meta-analogical transfer (i.e., transfer of elements of the first analogy to the second analogy through the formation of a meta-analogy).

In meta-analogical transfer, rather than all situations being analogous to each other, an analogy is found between the *analogical relationships* within each pair of situations comprising an analogical reasoning episode. Thus saying that "Nancy Reagan is the first lady of America" corresponds in no meaningful way to saying that "Einstein is the greatest physicist of Germany". The learning demonstrated in schema induction is learning of a refined source domain (i.e., the schema), rather than learning of a set of mappings that can potentially be applied to new analogies.

Predicate Mappings as the Medium of Meta-Analogical Transfer

Predicates represent the meaningful concepts (e.g., "man", "husband", "opposite-in") in a situation and are organized into *propositions* which consist of a predicate with a set of arguments (e.g., "man [Ronald Reagan]; "husband [Ronald Reagan, Nancy Reagan]"; "opposite-in [man, women, gender]"). Unless an argument to a predicate is itself a predicate, such arguments are referred to as *objects*. These propositions represent the structure of a situation by describing the relationship between parts of the situation. Thus *predicate mappings* are mappings between predicates in the source and target domains. For example, in the "Dennis Thatcher" analogy, mappings may be made of "husband to wife", "man to woman", and "opposite-in to opposite-in".

Halford (1987) provides a useful taxonomy for the degree of complexity of predicate mappings: *Element mappings* (or attribute mappings, in the terminology of Gentner, 1983) map predicates that take one argument, such as, the proposition LAST(i) when describing the string of letters "kji". *Relational mappings* map predicates that have two arguments, such as, SUCCESSOR(k, j). *System mappings* involve predicates that have three arguments, such as, SEQUENCE(k, j, i). In this terminology an *object mapping* would be a mapping of two arguments of predicates, for example, mapping the letter *i* to some letter in another letter string. But transfer based on object mappings alone in the absence of predicate mappings would not be called analogical.

This paper proposes that the medium of meta-analogical transfer is predicate mappings. This hypothesis is based on theories of analogical reasoning such as those of Gentner (1983) and Holyoak and Thagard (1989), which claim that people form coherent mappings between predicates in the source and target domains. For example, Gentner (1983) defines an analogy as an assertion that the relational

structure that normally applies in one domain can be applied in another domain. That is, the relations (which are represented by predicates) can be mapped between the domains.

The emphasis on predicate mappings in models of analogical reasoning such as those of Gentner (1983) and Holyoak and Thagard (1989) accounts for our ability to form analogies when little semantic similarity exists between the source and target domains. In these models the mapping is assumed to be constrained by a pressure to maintain structural consistency. This constraint requires that mapped elements should play similar roles in both the source and target domains, and tend to map to only a single element in the other domain. To meet this requirement, a set of mutually constraining, coherent mappings are formed. As Holyoak and Thagard (1989, p. 295) state: "At the core of analogical thinking lies the process of *mapping*: the construction of orderly correspondences between elements of a source analog and those of a target." The flexibility of predicate mappings — allowing mappings of predicates with no semantic similarity — accounts for the power of analogical reasoning. In Genter's and Holyoak and Thagard's theories the analogy *is* a set of mappings. Thus if meta-analogical transfer occurs, these theories imply that the predicate mappings formed in the first analogical reasoning episode will be transferred to the second.

There is little direct evidence concerning whether predicate mappings could be the basis for meta-analogical transfer. Some results obtained by Novick and Holyoak (1991) could be interpreted as evidence against the necessity of predicate mappings for analogical reasoning. Novick and Holyoak told participants the predicate mappings between the source and the target. They found that such a predicate-mapping hint resulted in no improvement in transfer of the analogical solution, when compared to a hint that simply referred back to the appropriate problem. Both types of hints were better than no hint, but worse than an object-mapping hint (e.g., saying that the number 5 in one problem maps to the number 6 in the new problem). However, this result may demonstrate the usefulness of object mappings, rather than that predicate mappings are irrelevant. Furthermore, if people derive predicate mappings spontaneously, then that would obviate their usefulness as hints.

The present paper proposes that predicate mappings may be transferred between analogies, providing the basis for transfer effects between episodes of analogical reasoning. To investigate the

existence of meta-analogical transfer effects it was necessary to examine people's performance when involved in multiple episodes of analogical reasoning (each in itself requiring a mapping of source to target). The aims of the experiments reported here were to investigate whether meta-analogical transfer occurs and, if so, to test whether predicate mapping provide the basis of such transfer.

Letter-String Analogy Problems

A constrained task was used to investigate predicate mappings and their role in transfer: letter-string analogy problems of the type modeled in the computer program *Copycat* (Hofstadter, 1985; Hofstadter & Mitchell, 1994; Mitchell, 1993). Copycat is a computer program that creates analogical inferences in a single domain, a micro-world consisting of the 26 letters of the alphabet and associated concepts. The program solves analogies such as: "Given that **abc** changes to **abd**, how would you change **kji** in the same way?" Or " ... how would you change **mrrjjj** in the same way?" (Note that the convention in this paper will be to present the string to be changed in **bold-face**, while strings that are possible answers will be in *italics*.) Mitchell (1993, p. 16) claimed that analogy-making can be broadly characterized as distilling the essence of one situation and adapting it via "conceptual slippage" (essentially, mapping of non-identical predicates) to fit another situation. The letter-string analogies isolate what Mitchell and Hofstadter consider to be the key to such analogy making for both people and machines: constructing a coherently structured representation of a situation at an appropriate level of abstraction.

Examples of Letter-String Problems

Copycat is intended to be one instantiation of a theory of both human and machine analogical reasoning (see Hofstadter, 1995; Mitchell, 1993); the way in which Copycat solves letter-string analogies provided the basis for initial hypotheses about how people might solve these analogies.

Consider the analogy problem **abc:abd::kji:?** (this notation signifies the problem of how to change the string **kji** in the same way as **abc** is changed into **abd**, which will be referred to as the '**kji** analogy"). This analogy appears to have at least three reasonable answers: *kjj*, *kjh*, and *lji*. When given this analogy, these were the three most common answers that Copycat produced. Each answer depends on building a different representation of the analogy. In order to derive the *kjj* answer it is necessary to

form a representation in which *c* (last element of the string **abc**) is mapped to *i* (last element of the string **kji**) and the successor relationship between *c* and *d* is mapped to a successor relationship between *i* and *j*. Thus this mapping is based on the predicate mapping of "successor to successor". To produce the *kjh* answer, however, requires representing the fact that the **abc** string is a sequence (ascending) and so is the **kji** string (a descending sequence). Thus, *b* is the successor of *a* and *c* is the successor of *b*, as well as *j* being the predecessor of *k* and *i* being the predecessor of *j*. These successor relationships in the **abc** string are then mapped to the predecessor relationships in the **kji** string. To maintain consistency, the predicate mapping of "successor to predecessor" is made, allowing the successor relationship between *c* and *d* to map to the predecessor relationship between *i* and *h*. Thus the *kjh* answer is based on the predicate mapping of "successor to predecessor", as well as a predicate mapping of "sequence to sequence". Similarly, to generate the *lji* answer the "sequence to sequence" mapping is still made between the **abc** and **kji** letter-strings, but now the predicate mapping of "right to left" is made. The "successor to successor" predicate mapping can then be used, resulting in the successor relation between *c* and *d* mapping to another successor relation, that between *k* and *l*.

When Copycat is given the analogy problem **abc:abd::mrrjjj:?** (which will be referred to as the "**mrrjjj** analogy"), it produces two common answers, namely *mrrjjk* and *mrrkkk*. Both answers involve the "successor to successor" mapping, equating the successor relationship between the *c* and *d* in **abc:abd** to the successor relationship between *j* and *k*. The two answers differ in the underlying representation of the analogy: Either the string **mrrjjj** represents a set of six letters and the relation of last letter (*c*) is mapped to last letter (*j*), or the **mrrjjj** string is represented as three groups (**m**, **rr**, and **jjj**) and the relation of last letter (*c*) is mapped to last group (*jjj*).

Insert Figures 1 and 2 about here

Possible representations of the two analogies are illustrated in Figures 1 and 2. Figure 1 shows a representation of the *kjh* answer to the **kji** analogy. As can be seen, each string has an internal structure made up of predicates, which map to the predicates of the string in the other half of the

analogy. The "successor" predicate links from left-to-right in **abc:abd** map to the "predecessor" predicate links from left-to-right in **kji:***kjh*. Therefore, a mapping linking predicates (i.e., "successor to predecessor") can link the predicates in the representation of the **abc:abd** strings to every predicate in the representation of the **kji:***kjh* strings. In contrast, little structure can be built for the **mrrjjj** analogy. Figure 2 shows a representation of the *mrrkkk* answer to the **mrrjjj** analogy. As can be seen, little internal structure can be formed for the *mrrkkk* answer, as no predicates link its components. Consequently, few predicate mappings can be formed between the **abc:abd** and **mrrjjj:***mrrkkk* parts of the analogy.

Letter-String Analogies as a Task for Studying Meta-Analogies

On the surface, letter-string analogies resemble four-term "proportional" analogies of the form A:B::C:?? (e.g., Red is to Stop, as Green is to ??), which have been used extensively to study analogical reasoning (for a review see Sternberg, 1977). They thus differ from the types of analogies that have been used in many studies of analogical reasoning as it occurs in the context of problem solving (e.g., Gick & Holyoak, 1980, 1983). Such work investigates analogical transfer of the solution of an old problem to a new problem via the formation of an analogy between the two problems, even when the new problem could in principle be solved without drawing an analogy to the first problem (e.g., the radiation problem of Duncker, 1945; see Gick & Holyoak, 1980, 1983). In such problem-solving tasks the reasoning may or may not be analogical.

In four-term proportional analogies, on the other hand, the problem fundamentally is an analogy, so analogical reasoning almost certainly will be used to find a solution. As Gick and Holyoak (1983) pointed out, four-term analogies obviate the need for people to spontaneously notice that an analogy could be formed, which is a prerequisite for successful transfer to the new problem. Consequently, four-term analogies can only be used to investigate the types of mappings people form in analogical transfer, not the conditions under which analogical transfer will occur at all. But once people realize that an analogy can be formed, the nature of the analogical reasoning used to solve a problem should follow the same principles, whatever the type of problem. As Gentner (1983) pointed out, the four-term analogy "3:6::2:4" relies on the fact that the relationship between 3 and 6 is the same as relationship

between 2 and 4. The same predicate – "twice as great as" – applies to both. Structural consistency holds between the two situations (i.e., 3:6 and 2:4), just as it should for any analogy according to the theories of Gentner (1983) and Holyoak and Thagard (1989).

For investigating meta-analogies it is unimportant whether the analogical transfer used to form the analogy in the first episode of analogical reasoning was spontaneous; rather, the issue is whether the mappings formed in the first episode can be meta-analogically transferred to the second episode. Failure to solve each episode by using an analogy would rule out meta-analogical transfer of mappings, which makes it desirable to maximize the probability of participants solving each episode by analogy. Four-term analogies are therefore well-suited for investigating meta-analogies.

Four-term analogies can be more difficult than "Red:Stop::Green:?". Letter-string analogy problems are quite complex because they can have a large amount of internal structure that can be represented as propositions (e.g., successor[C, D]). Further, the structure can have competing interpretations (e.g., should the **kji** string be represented as an alphabetic sequence, or just a spatial ordering of unrelated letters?), leading to different answers. It is the mapping formed between the predicates describing the internal structures of each string that is critical to producing any coherent answer to these analogies (as is the case for all types of analogies).

There are several complementary arguments for using letter-string analogies experimentally. First, they are truly ambiguous, in that there is no externally validated correct answer. Different answers will reflect different representations. The lack of an objectively correct answer may allow more subtle transfer effects to be observed than when transfer is determined simply by whether a person produces the "correct" solution. Second, despite the ambiguity and artificiality of letter-string analogies, Mitchell (1993) showed that people can produce satisfying answers. Third, solving letter-string analogies requires the construction of a set of predicate mappings, which allows the nature of such mappings to be investigated, as well as their possible transfer between different analogical reasoning episodes. Fourth, these analogies have complex internal structure, so that the predicate mappings formed should usually be at least at the level of relational mappings. Fifth, the clarity of the mappings that underlie most answers

makes letter-string analogies a good task with which to investigate transfer of predicate mappings between episodes.

For these reasons, letter-string analogies appear to be useful for addressing the questions raised earlier about analogy: Does meta-analogical transfer occur? If so, can the predicate mappings formed in one episode of analogical reasoning be transferred to new episodes of analogical reasoning? If meta-analogical transfer causes predicate mappings to be transferred, then when peoples are involved in consecutive episodes of analogical reasoning, the mappings formed during the first episode should be more likely to be repeated and form the basis of the analogy in the second episode. The following experiments tested these ideas by presenting participants with multiple episodes of letter-string analogy problem-solving. Transfer was investigated by altering the nature of the first episode and observing the effects on the second episode.

Experiment 1

To investigate meta-analogies, in Experiment 1 participants were presented with two episodes of analogical reasoning. In one episode they solved the **kji** analogy problem, stated as: "Suppose that the letter string **abc** was changed to **abd**; how would you change the letter string **kji** in the same way?" The other episode presented them with the **mrrjjj** analogy, stated in the same way but with **mrrjjj** as the string to be changed. The **kji** and **mrrjjj** analogies were chosen because they are not isomorphic and because no single answer dominated the responses produced by Copycat; thus they are ambiguous in that different predicate mappings yield different answers. This ambiguity should make these analogies sensitive to transfer effects, as previous analogical reasoning episodes could bias the use of the different representations.

For the **kji** analogy there should be three common answers: *kjh*, *kjj*, and *lji*. Each of these answers reflect different predicate mappings. As discussed previously, the *kjh* answer should be based on the mappings of "successor to predecessor" and "sequence to sequence"; the *kjj* answer should be based on mapping "successor to successor"; and the *lji* answer should be based on the mappings of "left to right" and "sequence to sequence". Little structure can be built to represent the **mrrjjj** analogy, so the most common answers should be *mrrjjk* and *mrrkkk*, both of which are the result of the predicate

mapping "successor to successor". These two different answers could result from constructing different representations of the problem with regard to what constitutes the "last element": either the last letter or last group of letters.

Giving participants both analogies and manipulating the order of presentation should affect solutions to the second episode of analogical reasoning if meta-analogical transfer occurs. Approximately half the participants received the **kji** analogy first and half received the **mrrjjj** analogy first, after which each participant received the other analogy problem. If the predicate mapping of "successor to successor" is often formed when solving the **mrrjjj** analogy, and it can be transferred, then there should be a clear order effect on the **kji** analogy. When the **kji** analogy is solved after the **mrrjjj** analogy, the *kjj* answer to the **kji** analogy should be more common than when the **kji** analogy is solved first, and the alternative mapping "successor to predecessor" required by the *kjh* answer should become less common. It is unlikely that such straightforward order effects could be observed from the **kji** analogy to the **mrrjjj** analogy, as most plausible answers to the **mrrjjj** analogy appear to involve the predicate mapping of "successor to successor;" thus it was not possible to predict a priori what should be transferred from the **mrrjjj** analogy.

Method

Participants. A total of 140 participants from the introductory psychology subject pool at the University of California, Los Angeles (UCLA) attempted the analogy problems.

Procedure. Either during or after participating in another experiment, participants were given a two-page booklet. On one page was written, "Suppose that the letter string **abc** was changed to **abd**; how would you change the letter string **kji** in the same way?" The same question was written on the other page, but with the string "**mrrjjj**" substituted for "**kji**". For half the participants the **kji** analogy appeared first and for the other half the **mrrjjj** analogy appeared first. For each analogy participants were given as long as they wanted to complete the task. Participants were also instructed that if they wrote down more than one answer they were to circle the one they thought the best. At the bottom of the first page participants were instructed not to turn the page until they had completed the problem and that they

were not to turn back to the first page. These instructions were intended to discourage participants from attempting the second analogy before completing the first.

Results and Discussion

Only the answer that participants indicated was the best was recorded. Some participants wrote down additional solutions, but these were not analyzed. Participants who did not write down additional solutions may have considered other solutions, but the instructions did not demand that participants produce more than one answer. As participants who chose to write down additional answers may constitute a biased sample, it would be hard to draw conclusions from an analysis of additional answers.

Sixty-six participants solved the **kji** analogy first and 74 solved the **mrrjjj** analogy first. Table 1 reports the proportion of participants generating the most common responses to the **kji** analogy, when the analogy was solved first or second. Twenty different answers were generated, so for reasons of space, all responses produced by two or fewer participants (across both conditions) are grouped together into the category 'other'. A record of all responses is presented in the Appendix.

Insert Table 1 about here

If meta-analogical transfer occurs from one episode to the next, the distribution of answers to the **kji** analogy problem should be affected by the order in which the two analogies were presented. Strong order effects were found by comparing the frequencies of responses to the same analogy when solved second instead of first. As Table 1 shows, for the **kji** analogy the most common answer, *kjh*, became less common, $X^2(1) = 11.34$, $p < .001$ (an alpha level of .05 is used throughout this paper), when the analogy was solved second. The *kjj* answer became the most common answer when the **kji** analogy was solved second, and it was more frequently generated than when the **kji** analogy was solved first, $X^2(1) = 19.67$, $p < .0005$. This finding supports the prediction that the use of a "successor to successor" mapping, necessary for the *kjj* answer, will be used more often after the **mrrjjj** analogy is solved (an analogy which should require the "successor to successor" mapping), while the "successor to predecessor" mapping required for the *kjh* answer becomes less common.

Table 2 reports the frequency of responses to the **mrrjjj** analogy when an answer to the **mrrjjj** analogy was generated first or second. Again, because participants generated a total of forty-seven different answers, all responses produced by only two or fewer participants (across both conditions) were included in the category 'other', as were cases in which no solution was given. A record of all responses can be found in the Appendix.

Insert Table 2 about here

As was the case for the **kji** analogy, if meta-analogical transfer occurs to the **mrrjjj** analogy, then the distribution of answers to the **mrrjjj** analogy should vary depending on the order of presentation of the two analogies. For the **mrrjjj** analogy the most common answer, *mrrkkk*, was generated less often when the **mrrjjj** analogy was solved second, $X^2(1) = 13.71$, $p < .0005$. The second most common answer, *mrrjjk*, was also generated less often, but not significantly so, $X^2(1) = 1.83$, $p > .10$. This decline in simple application of the predicate mapping "successor to successor" was consistent with the fact that 36% of the participants solving the **mrrjjj** analogy second had just solved the **kji** analogy with the answer *kjh*, which requires the mapping of "successor to predecessor."

When the **mrrjjj** analogy was solved second a greater variety of answers to this analogy was generated. A total of 21 different solutions were generated by participants solving the **mrrjjj** analogy first, but 33 different solutions were generated when this analogy was solved second. This greater variety was reflected in a significant increase in the number of participants in the 'other' category, $X^2(1) = 26.51$, $p < .0005$. ('Other' solutions are those produced by two or fewer participants, or when no solution is given.) This order effect suggested that transfer also occurred from the **kji** analogy to the **mrrjjj** analogy, but that this transfer was less likely to conform to a single pattern. This finding contrasts with the transfer found to the **kji** analogy from the **mrrjjj** analogy, which was highly uniform. If participants build the types of representations postulated in the Introduction, then it should be hard to fit the representation of their answer to the **kji** analogy to the **mrrjjj** analogy. If participants tried to make the mappings for the **kji** analogy fit the **mrrjjj** analogy when there was no simple way to do so, this

could explain the greater variety of answers to the **mrrjjj** analogy when it was solved second. A clear example of participants trying to fit their mappings for the **kji** analogy to the **mrrjjj** analogy was provided by the six participants who generated answers based on the mapping of "successor to predecessor", *mrriii* (4 participants) and *mrrjji* (2 participants), answers never produced except when the **mrrjjj** analogy was solved second. All except one of these six participants had previously given the *kjh* answer to the **kji** analogy, an answer requiring a "successor to predecessor" mapping. Only one participant who solved the **mrrjjj** analogy first produced an answer that might be based on a "successor to predecessor" mapping (*mqqjjj*). In contrast to the difficulty of transferring from the **kji** analogy, participants who solved the **mrrjjj** analogy first appear to have encountered relatively little difficulty in transferring the mappings formed to represent the **mrrjjj** analogy to the **kji** analogy, which may account for why there was no increase in the generation of 'other' answers to the **kji** analogy when it was solved second.

An important aspect of the results was that the meta-analogical transfer appeared to be asymmetrical in that there was clearer evidence of transfer from the **mrrjjj** analogy to the **kji** analogy than vice versa. If transfer between the two analogies was symmetrical, then for any given pair of answers to the two analogies (e.g., the *kjj* answer to the **kji** analogy and the *mrrkkk* answer to the **mrrjjj** problem), then the order of presentation should not affect the proportion of participants producing a member of this pair as their solution to the second analogy, after producing the other member of the pair as their answer to the first analogy. For example, the proportion of participants who gave the *mrrkkk* answer to the second analogy (the **mrrjjj** analogy in this case) after giving the *kjj* answer to the first analogy (the **kji** analogy), should equal the proportion of participants who gave the *kjj* answer to their second analogy after they had produced the *mrrkkk* answer to their first analogy.

An examination of common pairs of answer revealed that the above criteria was violated, suggesting that asymmetry of transfer occurred. Of the 34 participants who produced *mrrkkk* when solving the **mrrjjj** analogy first, 23 subsequently answered *kjj* to the **kji** analogy. However, of the 14 participants answering *kjj* when they were given the **kji** analogy first, only two then answered *mrrkkk*. These two proportions (.68 vs. .14) were significantly different by a test of the association of which analogy was

solved first with the answer to the second analogy (i.e., whether the second answer was a member of the pair), given that a member of this pair was generated as the answer to the first analogy, $X^2(1) = 11.3$, $p < .001$. Similarly, of the 11 participants answering *mrrjjk* to the **mrrjjj** analogy first, 10 subsequently answered *kjj* to the **kji** analogy, but of the 14 answering *kjj* when the **kji** analogy was first only three later gave *mrrjjk* as their answer to the **mrrjjj** analogy. Again, these proportions (.91 vs. .21) were significantly different, $X^2(1) = 11.91$, $p < .001$, thus if a member of the *kjj/mrrjjk* pair was generated as the answer to the first analogy, which analogy problem had been solved affected the likelihood that the second member of the pair would be generated. Crosstables for all participants' responses to the two analogies for each analogy order are given in the Appendix. This asymmetry is especially surprising for transfer from the *kjj* answer to the **kji** analogy as it would appear that this answer is based on an idea that can easily be applied to the **mrrjjj** analogy: simply change the last element (however one defined it) to its successor. The observed asymmetry suggests that the representation of the *kjj* answer may involve more than the "successor to successor" mapping.

The asymmetry effects strongly supported the claim that some type of transfer is occurring. Participants did not simply answer in a certain way because they have a propensity to favor "successor" answers; otherwise, the order in which they received the analogies would not have changed the frequency of pairs of answers such as *kjj/mrrjjk*. The asymmetries further suggested that participants represent and transfer more than the change to be made to one letter. They may map the concept that the letters **abc** are a sequence to the concept that the letters **kji** are also a sequence, and subsequently try to use this predicate mapping in forming their representation of the **mrrjjj** analogy; however, there is no easy way to apply this "sequence to sequence" mapping to the **mrrjjj** analogy.

Experiment 1 demonstrated that people can produce coherent answers to letter-string analogy problems, and that the ambiguity of these analogies leads people to generate a variety of answers that reflect different predicate mappings. More importantly, meta-analogical transfer was demonstrated: the order of presentation of episodes of analogical reasoning affected the solution of the episodes. The results supported the claim that predicate mappings were formed during analogical reasoning episodes, and that these mappings were the medium of meta-analogical transfer between analogical reasoning

episodes. The way in which the first episode of analogical reasoning was solved systematically affected the second episode. The clearest example of transfer of predicate mappings was the finding that an answer to the **kji** analogy requiring the "successor to successor" mapping (*kjj*) became more common after solving the **mrrjjj** analogy (an analogy that promotes such a mapping), while an answer requiring the "successor to predecessor" mapping (*kjh*) became rarer.

An alternative basis of transfer between episodes could be transfer of a simple rule, for example, "change last element into its successor." However, it is difficult for transfer of such a simple rule alone to explain the asymmetry of the transfer results. Almost every participant who generated *mrrjjk* as their answer when they solved the **mrrjjj** analogy first, subsequently produced *kjj* as their answer to the **kji** analogy, which would appear to be simple transfer of a rule. But few participants who generated *kjj* as their answer when they solved the **kji** analogy first subsequently generated *mrrjjk* as an answer to the **mrrjjj** analogy, even though *mrrjjk* would appear to be a straightforward application of the rule "change last into successor". It is even harder for a rule-based explanation to account for the transfer effects from the **kji** analogy to the **mrrjjj** analogy. If the result of generating an answer to the **kji** analogy when it is solved first is a simple rule, such as "change last into predecessor" (for the *kjh* answer), then more people would be expected to apply such rules to the **mrrjjj** analogy than did so. Furthermore, usually if a rule cannot be applied it has no effect; thus participants who solved the **mrrjjj** analogy second should have been unaffected by the first analogy if they could not apply the rule derived from the first analogy. But instead participants generated an increased variety of answers, indicating that something was still being transferred even when the rule did not fit.

Experiment 2a

Experiment 1 clearly demonstrated an effect of the order in which the analogy problems were solved. Further, there appeared to be a systematic relationship between how participants solved their first analogy and how they solved their second analogy. These results suggest that through meta-analogical transfer, specific mappings are transferred from one analogy problem to a new one. However, there may be alternative explanations for the apparent relationship. In Experiment 1, any attempt to relate a participant's answer in the first episode of analogical reasoning to his or her answers in the second

episode is vulnerable to the criticism that how participants solved the first analogy was not constrained. This lack of control of the mappings formed in the first episode may introduce unknown biases. For example, the most dramatic order effect in Experiment 1 was the failure of participants who generated a *kjj* answer to the **kji** analogy to subsequently generate *mrrjjk* or *mrrkkk* answers to the **mrrjjj** analogy when it was solved second, despite almost all *mrrjjk* answers leading to *kjj* answers to the **kji** analogy when the **mrrjjj** analogy was solved first. But perhaps participants generating *kjj* as their answer to the **kji** analogy when it was given first were simply unmotivated, so that little can be concluded from their solutions to the second analogy. Similar ad hoc explanations of other specific transfer effects (though not the overall order effect) could be raised because what participants' did on the their first analogy was uncontrolled. To rule out such alternative explanations, in Experiment 2a a direct manipulation was made of how participants solved the first analogy. Participants were given an answer to the **kji** analogy and asked to justify why someone might think it was a good answer. Participants then solved the **mrrjjj** analogy. By manipulating the answer to the **kji** analogy that participants justified, it should be possible to alter the likelihood of participants producing a particular answer to the second analogy. If participants indeed exhibit meta-analogical transfer, this direct manipulation should replicate the results for the **kji** analogy first condition of Experiment 1.

The answer to the **kji** analogy that was provided to participants was either *kjj* or *kjh*. Given that the *kjj* answer emphasizes the mapping of "successor to successor", first justifying the *kjj* answer to the **kji** analogy should lead to more *mrrjjk* answers to the **mrrjjj** analogy than should first justifying the *kjh* answer. The *mrrjjk* answer is a clear application of the "successor to successor" mapping, but one that can ignore other aspects of the structure of the string, as does the *kjj* answer to the **kji** analogy. Similarly, the *mrrkkk* answer should also become more common for participants in the justify-*kjj* condition, because the *mrrkkk* answer is still based on making the "successor to successor" mapping, even though it is a more structured answer to the **mrrjjj** analogy. Because the *kjh* answer to the **kji** analogy involves mappings that are difficult to transfer to the **mrrjjj** analogy, trying to transfer a set of mappings from the *kjh* answer that has no simple fit should yield a variety of answers. Therefore, an

increase in rare answers (defined, as in Experiment 1, as those produced by two or fewer participants in Experiment 1) should be observed when the *kjh* answer was justified.

Method

Participants. There were 146 participants, 101 from the UCLA subject pool and 45 from the University of Texas, Austin subject pool. All received partial course credit for participating.

Materials and Procedure. Participants were given a two-page booklet. The **kji** analogy, stated in the same way as in Experiment 1, was presented on the first page. But instead of then being instructed to write down an answer to the **kji** analogy, participants were given the following instructions:

> There are a number of possible answers to this problem. One answer that many people think is a good answer to this problem is:
>
> **kjj**
>
> Try to explain why someone could think that **kjj** is a good answer to this problem.

The above wording is for the justify-*kjj* condition. For the justify-*kjh* condition the string "kjh" was substituted for "kjj". The instructions were followed with ruled lines on which participants were to write down their justification.

On the second page of the booklet the **mrrjjj** analogy was presented in the identical manner as that in Experiment 1.

Results and Discussion

The justifications that participants gave for the *kjh* or *kjj* answer were evaluated. Almost all participants gave answers supportive of the given answer. In the justify-*kjh* condition only 2 out of 73 participants, and in the justify-*kjj* condition only 4 out of 73, gave justifications that were not supportive of the given answer. There was no evidence of differences in the amount of effort participants put into justifying each answer. This conclusion was supported by a simple count of the number of lines of text participants wrote, which showed that the mean number of lines used was not significantly different for the justify-*kjh* (M = 5.0, SD = 1.99) and justify-*kjj* (M = 4.4, SD = 2.29) conditions, $t(144) = 1.77$, p

> .05. Thus the manipulation appeared to be effective at inducing participants to think about the basis for the given answer.

Insert Table 3 about here

The answer to the **mrrjjj** analogy that participants produced was recorded in the same way as in Experiment 1. Table 3 is organized in a similar way to Table 2 in Experiment 1, in that it shows the proportion of participants producing the answers that were common in Experiment 1. Only one answer not listed in Table 3 was produced by more than two participants: *mrrhhh*, which was generated by four participants who justified *kjh*. For comparison, Table 3 also lists the proportions of those participants who solved the **mrrjjj** analogy second in Experiment 1 who generated each answer to the **mrrjjj** analogy, depending on whether they had generated the *kjj* or *kjh* answer to the **kji** analogy first. Table 3 allows a direct comparison between transfer after generating the answer *kjj* or *kjh*, and transfer after justifying the *kjj* or *kjh* answers, respectively. Comparisons between Experiments 1 and 2a found no statistically significant differences in the proportions of participants who generated the *kjj* or *kjh* answers to the **kji** analogy in Experiment 1 and the Experiment 2a participants who justified the same answer (for *kjh*: $X^2[7] = 3.01$, $p > .5$; for *kjj*: $X^2[7] = 13.11$, $p > .05$; all cells in Table 3 were included in the analysis except *jjjmrr*, an answer nobody gave in this experiment). Thus, having participants justify an answer appears to have a similar effect as that observed for participants who generated that answer on their own, though the small number of Experiment 1 participants who can be used in this comparison makes it hard to draw a definitive conclusion.

As predicted, the proportion of *mrrjjk* answers produced for the **mrrjjj** analogy was greater for the justify-*kjj* than for the justify-*kjh* condition, $X^2(1) = 5.84$, $p < .02$. However, the prediction that the proportion of *mrrkkk* answers would be greater was not supported, $X^2(1) = .53$, $p > .5$. However, support was found for the prediction that the proportion of 'other' answers (consisting of the same

answers as those in the 'other' category in Experiment 1) would be much greater for the justify-*kjh* group than for the justify-*kjj* condition, $X^2(1) = 6.66$, $p < .01$.

Experiment 2a showed that there was a strong influence on the **mrrjjj** analogy of which answer was justified for the **kji** analogy. The simplest application of the "successor to successor" mapping to the **mrrjjj** analogy, the *mrrjjk* answer, was generated more often after such a mapping was encouraged by first justifying the *kjj* answer to the **kji** analogy.

Although justifying the *kjj* answer to the **kji** analogy clearly affected participants' answers to the **mrrjjj** analogy, many justify-*kjj* participants (43%) produced answers other than *mrrjjk* or *mrrkkk* to the **mrrjjj** analogy, just as did participants in Experiment 1 who answered *kjj* to the **kji** analogy when they solved it first. This finding suggested that the participants in Experiment 1 who generated *kjj* as their answer to the **kji** analogy but subsequently did not generate *mrrjjk* as their answer to the **mrrjjj** analogy were not just unusual participants. This result therefore supports the interpretation that it is difficulty of transferring predicate mappings that accounts for the asymmetrical transfer effects in Experiment 1. Both the *mrrjjk* and *kjj* answers are based on the mapping of "successor to successor", but the *mrrjjk* answer appears to involve no other meaningful mappings. Accordingly, this mapping can easily be transferred to the **kji** analogy, as the results of Experiment 1 suggested. In contrast, the *kjj* answer may involve other mappings which can not be easily transferred to the **mrrjjj** analogy, leading to many answers being generated other than the *mrrjjk* or *mrrkkk* answers.

The *kjh* answer to the **kji** analogy is based on mappings such as "successor to predecessor" and "sequence to sequence", which can not be easily applied to the **mrrjjj** analogy. As predicted, justifying *kjh* as an answer to the **kji** analogy resulted in a greater variety of answers to the **mrrjjj** analogy than did justifying *kjj*.

In summary, the results of Experiment 2a lend support to the claim that predicate mappings are transferred and that they account for meta-analogical transfer.

Experiment 2b

If the order effects on the **kji** analogy in Experiment 1 were due to transfer from the answers participants produced to the **mrrjjj** analogy, then it should be possible to change the distribution of

participants' answers to the **kji** analogy by having them justify a particular answer to the **mrrjjj** analogy. For Experiment 2b a similar procedure was used as in Experiment 2a; participants justified an answer to the **mrrjjj** analogy that embodied a certain mapping, and then they had to generate an answer to the **kji** analogy. However, both of the most common answers to the **mrrjjj** analogy — *mrrjjk* and *mrrkkk* — would predict the same result: an increase in the frequency of *kjj* answers. Therefore, other answers to the **mrrjjj** analogy were used as well. One answer that should produce a greater number of answers based on a "sequence to sequence" mapping than would the *mrrjjk* or *mrrkkk* answers, is the *mrrjjjj* answer. This was produced by only one participant in Experiment 1, but Mitchell (1993) argues that it may be the most elegant answer because it requires a sequence mapping. The *mrrjjjj* answer maps a sequence of letters (as in **abc:abd**) to a sequence of numbers describing the group sizes (**1-2-3 : 1-2-4**).

One potential objection to comparing *mrrjjjj* to the *mrrjjk* and *mrrkkk* answers is that *mrrjjjj* is perhaps the best answer to the **mrrjjj** analogy. Perhaps a good answer to the **mrrjjj** analogy will lead to better answers to the **kji** analogy by somehow encouraging good answers to the **kji** analogy, irrespective of the mappings involved. To provide evidence that not only good answers to the **mrrjjj** analogy reduce the frequency of *kjj* answer to the **kji** analogy, a fourth answer to the **mrrjjj** analogy was also used: *mrrjjd*. This answer appears to be a poor one as it is based on a superficial element mapping of "*d* to *d*", and it was never generated in Experiment 1 (though one participant in Experiment 2a generated *mrdjjd*). However, if mappings are transferred between the analogy problems, then justifying *mrrjjd* should be less likely than justifying *mrrjjk* or *mrrkkk* to lead to a *kjj* answer to the **kji** analogy, as *mrrjjd* does not involve a mapping of "successor to successor".

Altogether, Experiment 2b had four conditions: justify-*mrrjjjj*, justify-*mrrkkk*, justify-*mrrjjk*, and justify-*mrrjjd*. If predicate mappings are being transferred then the justify-*mrrjjk* and justify-*mrrkkk* conditions should lead to more *kjj* answers to the **kji** analogy than either the justify-*mrrjjjj* or justify-*mrrjjd* conditions. If the predicate mapping of "sequence to sequence" can be transferred from the *mrrjjjj* answer, then the justify-*mrrjjjj* answer should lead to more *kjh* and *lji* answers (both of which require a mapping of "sequence to sequence") to the **kji** analogy than any of the other three conditions. Although only one participant gave the answer *kjd* to the **kji** analogy in Experiment 1, if the object

mapping of "*d* to *d*" can be transferred then there should be a large number of *kjd* answers to the **kji** analogy in the justify-*mrrjjd* condition. Novick and Holyoak's (1991) study suggested that an object mapping should be strongly transferred.

Method

Participants. Three hundred and forty-three participants from the UCLA subject pool participated for partial course credit.

Materials and Procedure. Participants were given identical materials and instructions as those in Experiment 2a, modified only to reflect the different analogies given in Experiment 2b. For the justify-*mrrjjjj*, justify-*mrrkkk*, justify-*mrrjjk*, and justify-*mrrjjd* conditions, participants first justified the relevant answer to the **mrrjjj** analogy. All participants then generated an answer to the **kji** analogy.

Results and Discussion

The proportions of participants producing each answer to the **kji** analogy for each justification condition are presented in Table 4. The categories of answers to the **kji** analogy presented are the most common answers given to this analogy in Experiment 1 — *kjh*, *kjj*, and *lji* — as well as the *kjd* answer that was expected to arise in the justify-*mrrjjd* condition. The 'other' category contains all other responses, no single one of which was produced by more than three participants, except for the answer *kjjiii* that was produced by five justify-*mrrjjjj* participants.

Table 4 also compares participants in Experiment 1 who generated the *mrrjjk* or *mrrkkk* answers when they did the **mrrjjj** analogy first, to participants in Experiment 2b who justified the *mrrjjk* or *mrrkkk* answers. Comparisons revealed no significant differences between participants in the two experiments (for *mrrkkk*: $X^2[3] = 1.18$, $p > .5$; for *mrrjjk*: $X^2[3] = 3.18$, $p > .25$; all relevant cells in Table 4 were included in the analysis except those for *kjd*, an answer nobody gave in these conditions).

Insert Table 4 about here

There was no theoretical reason to differentiate the justify-*mrrjjk* and justify-*mrrkkk* conditions. If justifying one of these two answers led to different transfer effects from justifying the other, then the

distribution of answers to the **kji** analogy should vary between the two conditions. There was no difference between the justify-*mrrjjk* and justify-*mrrkkk* conditions in the proportions of participants producing answers in each of the categories (excluding *kjd*) in Table 4 for the **kji** analogy, $X^2(3) = 3.92$, $p > .25$. Accordingly, for further analyses these two conditions were combined.

If the "successor to successor" mapping was transferred from the **mrrjjj** analogy to the **kji** analogy, then the proportion of *kjj* answers (which require the "successor to successor" mapping) to the **kji** problem should be greater after justifying the *mrrkkk* or *mrrjjk* answer (answers which also require the "successor to successor" mapping) to the **mrrjjj** analogy, than after justifying either of the other two answers. This prediction was supported as the proportion of justify-*mrrkkk*/justify-*mrrjjk* participants generating the *kjj* answer to the **kji** analogy was greater than the proportions generating the *kjj* answer in the justify-*mrrjjjj* condition, $X^2(1) = 45.1$, $p < .0001$, or in the justify-*mrrjjd* condition, $X^2(1) = 41.2$, $p < .0001$.

If the "sequence to sequence" mapping can be transferred, then the number of *kjh* answers to the **kji** problem should be greatest in the justify-*mrrjjjj* condition, as both the *kjh* and *mrrjjjj* answers require that mapping. The proportion of participants producing the *kjh* answer to the **kji** analogy was greater in the justify-*mrrjjjj* condition than in either the combination of justify-*mrrkkk*/justify-*mrrjjk* conditions, $X^2(1) = 8.28$, $p < .005$, or in the justify-*mrrjjd* condition, $X^2(1) = 4.27$, $p < .05$. Similarly, the proportion of participants producing the *lji* answer was greater for the justify-*mrrjjjj* condition than for the combination of the justify-*mrrkkk*/justify-*mrrjjk* conditions, $X^2(1) = 5.59$, $p < .02$, though the difference did not reach significance for the comparison between the justify-*mrrjjjj* and justify-*mrrjjd* conditions, $X^2(1) = 3.09$, $p < .10$. The results thus suggested that the "sequence to sequence" mapping was transferred most often in the justify-*mrrjjjj* condition, or at least that this condition interferes the least with forming this mapping.

While more participants in the justify-*mrrjjjj* condition than other conditions gave answers based on representations of the **kji** letter string as an alphabetic sequence, the justify-*mrrjjjj* condition also resulted in a greater variety of answers being produced. A larger proportion of justify-*mrrjjjj* participants produced 'other' answers than did those in the justify-*mrrkkk*/justify-*mrrjjk* conditions,

$X^2(1) = 19.2$, $p < .0005$. This finding suggested that it was harder to transfer the system mapping of "sequence to sequence" than the relational mapping of "successor to successor" to the **kji** analogy.

The large number of *kjd* answers produced by the justify-*mrrjjd* group illustrates the point made by Novick and Holyoak (1991), that encouraging element mappings can strongly affect analogical reasoning. More generally, the results of Experiment 2b add to the evidence that predicate mappings are transferred in meta-analogies.

Experiment 3

The previous experiments have shown that transfer of predicate mappings occurred, but all the mapping transfers that have so far been demonstrated have been mappings of identical predicates (specifically, "successor to successor", "sequence to sequence"). In order to establish the generality of transfer of predicate mappings in meta-analogies, it is necessary to demonstrate transfer of mappings of non-identical predicates. Experiment 3 examined transfer of the mapping of the non-identical predicates "successor to predecessor", the basis of the *kjh* answer to the **kji** analogy.

Testing for transfer of the predicate mapping "successor to predecessor" required an analogy other than the **kji** analogy that had a frequent solution based on a "successor to predecessor" mapping. Such an analogy is the **xyz** analogy: "If **abc** becomes **abd**, how would you change **xyz** in the same way?" Mitchell (1993, pp. 82-83) reported giving the **xyz** analogy to participants and finding that virtually all participants gave the solution *xya*, which assumes that the alphabet can be considered circular (an assumption that Copycat does not make). When then asked to generate another solution, the most common answers were *xyz*, *xyy*, and *xyd*. Burns (1994, Exp. 4) gave participants the **xyz** analogy (with the *xya* answer prohibited) and found that the most common answers were *wyz* (19% of participants), *xyd* (15%) and *wxz* (8%), when the **xyz** analogy was solved before any other. The *wyz* answer appears to be based on a "successor to predecessor" mapping as well as mapping "first to last". The *xyd* answer appears to be based on participants making an object mapping, "*d* to *d*", probably because they find no other solution satisfactory. The **xyz** analogy therefore appears to have exactly the properties required to look for transfer of a "successor to predecessor" mapping, as this mapping is the basis of plausible answers, yet the **xyz** analogy is otherwise quite different from the **kji** analogy.

One difficulty with using the **xyz** analogy is that the variety of answers generated in Burns (1994, Exp. 4) was large and even the most common answer (*wyz*) was only produced by 19% of participants. This diffusion of the frequency of answers raised issues regarding how to group the answers together as representatives of a given mapping. To avoid the necessity to arbitrarily group answers, it was decided to use a rating task for this analogy, rather than a generate task. A rating task is similar to the generate task used in Experiment 1 in that the analogy is described in the same way: "If **abc** was changed into **abd** how would you change **kji** in the same way?" But rather than generating an answer to the analogy, participants rate how good they think is each member of a set of answers. Burns (1994, Exp. 3) had participants rate how good the answers *kjj* and *kjh* were as answers to the **kji** problem, either before or after they had generated an answer to the **mrrjjj** analogy. The ratings showed the same reversal of preferences for answers to the **kji** analogy as when answers were generated for the **kji** analogy in Experiment 1. That is, when answers to the **kji** analogy were rated first, the *kjh* answer was rated more highly (M = 4.75, on a seven point scale) than the *kjj* answer (M = 3.49), but when answers to the **kji** analogy were rated after an answer to the **mrrjjj** analogy had been generated, the *kjj* answer (M = 5.01) was rated more highly than the *kjh* answer (M = 3.71). The similarity of the pattern of results for the two tasks suggested that it is legitimate to generalize from a rating task to a generate task. In addition, the rating task offers the advantage that the range of participants' answers can be restricted.

In Experiment 3 participants rated *wyz* and *xyd* as answers to the **xyz** analogy, or rated *kjj* and *kjh* as answers to the **kji** analogy. These two pairs were chosen because each member of each pair was among the most common answers to their analogies, yet they embody quite different mappings. However, one of each pair involved a "successor to predecessor" mapping. Before rating a pair of answers to either the **xyz** or **kji** analogies, participants justified an answer to the other analogy problem as they had done in Experiments 2a and 2b; this answer either would or would not provide the basis for the potential transfer of the "successor to predecessor" mapping. If they were to rate the answers to the **xyz** analogy, then they first justified the *kjh* or *kjj* answer to the **kji** analogy. If they were to rate the answers to the **kji** analogy, then they first justified the *wyz* or *xyd* answer to the **xyz** analogy. A control condition was included in which participants completed no justification, but instead rated first the two

answers to the **kji** analogy and then the two answers to the **xyz** analogy, or vice versa. If there is transfer of the "successor to predecessor" mapping, then the *wyz* answer to the **xyz** analogy should be rated more highly after justifying *kjh* than after *kjj* is justified as an answer to the **kji** analogy. Similarly, the *kjh* answer to the **kji** analogy should be rated more highly after justifying *wyz* than after justifying *xyd* as an answer to the **xyz** analogy.

Method

Participants. There were 497 participants, 447 from the UCLA subject pool and 50 from the University of Texas, Austin subject pool.

Materials and Procedure. Participants were given a two-page booklet consisting of a justification task on the first page and a rating task on the second page. Each participant received both the **kji** and **xyz** analogies, one as a justification task, and one as a rating task. The justification task was identical in format to the justification task used in Experiments 2a and 2b, in that participants were asked to write down a justification for one of the two answers to either the **kji** (*kjh* or *kjj*) or the **xyz** (*wyz* or *xyd*) analogy. The **xyz** analogy description explicitly excluded the *xya* answer as the instructions stated, "Do not assume that the alphabet is circular, therefore the answer *xya* would make no sense." For the rating tasks on the second page of the booklet, participants rated the goodness of the two answers to either the **kji** (*kjh* and *kjj*) or **xyz** analogy (*wyz* or *kjd*). For the **kji** analogy there appeared on the page the following instructions:

> Below you are presented with two possible answers to the following question:
>
> Suppose that the letter string **abc** was changed to **abd**; how would you change the letter string **kji** in "the same way"?
>
> Please consider the listed answers and rate each by circling a number on the seven-point scale below it. Your rating should correspond to how good you think the answer is. On the scale the higher the rating, the better an answer you consider that string to be.

The two possible answers for the **kji** analogy (*kjh*, *kjj*) were then presented below each other, each with a seven-point scale next to it. The *kjj* answer was always on top and it was then followed by the *kjh* answer (Burns, 1994, found no effect of the order of answers). The description of the rating task was similar, except that the answers *xyd* and *wyz* were rated as answers to the **xyz** analogy, with the *xyd* answer always on top.

In the control conditions participants rated answers to either the **xyz** or **kji** analogy on the first page, and then rated the answers to the other analogy on the second page. (No analysis of the second ratings will be presented as results could only be correlational) Thus there were six conditions in all.

Participants were given the booklet as part of a packet of short experiments and surveys. Each participant randomly received a booklet for one of the six conditions.

Results and Discussion

Three participants were excluded from the analysis because they did not rate all of the answers.

The mean ratings given by participants for answers to the **xyz** analogy (*wyz* and *xyd*) for the justify-*kjh* group (83 participants), the justify-*kjj* group (80 participants) or the no-justification group (80 participants) are presented in Table 5. If there is transfer from the *kjh* answer for the **kji** analogy, then the ratings for the *wyz* answer to the **xyz** analogy should be highest in the justify-*kjh* condition. For *wyz* ratings, a one-way ANOVA found a significant difference between justification groups, $F(2,246) = 3.90$, $p < .05$ ($MS_e = 4.11$). A Newman-Keuls post-hoc test showed that the *wyz* ratings for the justify-*kjh* group were significantly higher than those for the justify-*kjj* groups. As predicted, justifying the *kjh* answer led to higher ratings of the *wyz* answer which uses the same "successor to predecessor" mapping. Neither justification group produced ratings significantly different from those of the no-justification group.

For *xyd* ratings a one-way ANOVA found no significant difference between justification groups, $F(2,246) = .445$ ($MS_e = 4.94$). This lack of an effect on the *xyd* rating may be because neither justifying the *kjh* nor the *kjj* answers to the **kji** analogy involved making an object mapping that could be transferred to the *xyd* answer.

Insert Tables 5 and 6 about here

Table 6 gives the mean ratings by participants of answers to the **kji** analogy (*kjh* and *kjj*) for the justify-*wyz* group (81 participants), the justify-*xyd* group (84 participants), or the no-justification group (86 participants). If there is transfer from the *wyz* answer for the **xyz** analogy, then the ratings for the *kjh* answer to the **kji** analogy should be highest in the justify-*wyz* condition. For the *kjh* ratings a one-way ANOVA found a significant difference between justification groups, $F(2,242) = 3.78$, $p < .05$ ($MS_e = 3.97$). A Newman-Keuls post-hoc test showed that the *kjh* ratings for the justify-*wyz* group were significantly higher than those for either the justify-*xyd* or no-justification groups. Again, as predicted, justifying an answer that used the "successor to predecessor" mapping (*wyz*) resulted in higher ratings of an answer that used the same mapping (*kjh*) than when an answer was justified that did not require this mapping (*xyd*).

For *kjj* ratings a one-way ANOVA also revealed a significant difference between justification groups, $F(2,242) = 3.04$, $p < .05$ ($MS_e = 4.13$). A Newman-Keuls post-hoc test showed that the no-justification group gave higher ratings to the *kjj* answer than did the justify-*wyz* group, although not significantly greater than the justify-*xyd* group. Thus it appears that justifying either answer to the **xyz** analogy suppressed *kjj* ratings. This result is in contrast to those obtained with the **mrrjjj** analogy in Experiments 1 and 2b, which when solved first promoted subsequent *kjj* answers to the **kji** analogy. The increased favorability of the *kjj* answer to the **kji** analogy in earlier experiments was thus not simply a product of doing just any analogy first; rather, it only occurred when the first analogy was likely to promote the formation of the mapping of "successor to successor".

The results of Experiment 3 supported the claim that mapping of non-identical predicates ("successor to predecessor") can be transferred. Ratings of answers based on this mapping — *kjh* or *wyz* for the relevant analogy — were increased by having participants justify an answer that used the "successor to predecessor" mapping. It might be suggested that some other mapping is being transferred between the *wyz* and *kjh* answers, as they have another common mapping, "ascending (sequence) to descending (sequence)". However, this is also a mapping of non-identical predicates.

Thus whichever mapping or mappings are being transferred, the results support the claim that non-identical mappings can be transferred between analogical reasoning episodes.

General Discussion

These experiments demonstrated the existence of meta-analogical transfer, as the analogical relationship formed in solving one problem can itself be transferred to a new episode of analogical reasoning. The experiments reported here provided strong evidence that the medium of meta-analogical transfer is the predicate mappings made during the first episode of analogical reasoning, These predicate mappings were transferred to a second episode of analogical reasoning in which they were used to solve a new analogy problem. A form of learning thus results from solving analogies.

Clear transfer phenomena were observed. Experiment 1 provided evidence of more uniform transfer from one analogy problem (**mrrjjj**) to a more structured analogy problem (**kji**), than when the order of presentation was reversed. When answers to the **kji** analogy were generated, *kjh* was generally preferred over *kjj* as an answer; this pattern was reversed if the **kji** analogy was solved after the **mrrjjj** analogy had been solved. Thus there appeared to be transfer of the mappings of "successor to successor", which should be part of most answers to the **mrrjjj** analogy as well as the *kjj* answer to the **kji** analogy. Transfer also appeared to occur from the **kji** analogy to the **mrrjjj** analogy, but the transfer was less uniform in that the diversity of answers increased when the **mrrjjj** analogy was solved second. Experiments 2a and 2b reinforced these findings by showing that transfer also occurred when participants' mappings were directly manipulated by having participants justify a pre-determined answer to the first analogy. Experiment 3 demonstrated that mappings of non-identical predicates such as "successor to predecessor" can be transferred. These experiments do not provide direct evidence that participants were transferring mappings (for example, no verbal protocols were collected from participants); however, the consistency of the influence of prior solutions on new problems makes a strong argument that transfer of predicate mappings occurs.

While Experiment 3 generalized the finding of meta-analogical transfer to different predicate mappings and different letter-string analogies, the present study did not demonstrate that these results will generalize to other types of meta-analogies. If meta-analogical transfer occurs it provides evidence

about what kinds of relationships can be transferred. It has been argued that abstract analogical relations cannot be transferred (Detterman, 1993). But the current experiments appear to show that participants are sensitive to abstract similarity, at the level of the similarity of analogical mappings, even when the mappings are of non-identical predicates. In the current experiments, transfer was not tested across different types of situations. For example, no attempt was made to investigate if forming the "Dennis Thatcher" analogy could affect solutions to letter-string analogies. Whether such transfer can occur has been an important issue in analogical reasoning (see Detterman, 1993), so a future challenge is to determine if meta-analogical transfer can occur across different types of situations. Another issue raised by Detterman is whether analogical transfer is spontaneous. Although participants in these experiments were not required to use the solution from the first episode in the second episode, the fact they immediately followed each other makes it unlikely that the transfer was spontaneous. Thus determining whether meta-analogical transfer can be spontaneous is other potential challenge for future research.

While the emphasis of this paper has been on relational predicate mappings, this is not meant to imply that transfer of object mappings does not occur. In fact, these experiments yielded many examples of transfer of element mappings. In particular, strong evidence of transfer of the object mapping "*d* to *d*" was provided by the finding from Experiment 2b of a large number of *kjd* answers to the **kji** analogy after the *mrrjjd* answer to the **mrrjjj** analogy was justified. However, it is disputable whether answers based purely on an object mapping constitute analogy. Gentner (1989) characterizes comparisons between a source and target that are based on object mappings as *mere-appearance matches*. Gentner contrasts such matches with analogies, which are defined as being based on mappings of predicates that express a relation between their arguments. Because answers to letter-string problems based on object mappings may not constitute analogies by some theoretical criterion, it would be problematic to consider transfer based solely on object mappings to be evidence of meta-analogical transfer.

Implication for Computational Models

These demonstrations of transfer of mappings between analogical reasoning episodes indicate that such episodes are not isolated; the solution of future analogy problems can be influenced by a previous analogy problem even when the two sets of problems are not isomorphic. Such meta-analogies are not dealt with by current computational models of analogical mapping, such as Copycat (Mitchell, 1993), ACME (Holyoak & Thagard, 1989) or SME (Falkenhainer, et al. 1989), nor by models of analogical retrieval, such as ARCS (Thagard, Holyoak, Nelson, & Gochfeld, 1990) and MAC/FAC (Gentner, Forbus, & Law, 1995). Broadly, the present experiments offer some support for these models by reinforcing the claim that predicate mappings are being formed when analogies are made. The importance of such mappings is a critical assumption in these models. While the above models currently deal only with single episodes of analogical reasoning, it may be possible to extend them to deal with transfer between multiple episodes. Hofstadter (1995) has recognized this challenge and explicitly sets out the processing of meta-analogies as an aim of future models of analogy that go beyond Copycat. All of the above models in some way propose that mappings are the basis of analogical reasoning; thus transfer could possibly be incorporated into these models by having the mappings produced during the solution of previous analogy problems bias the mappings formed during new episodes. How such biasing could be achieved would depend on the details of each individual model. For example, in ACME either the activations of mappings from previous analogies could become the initial values of corresponding mappings for new analogies, or these mappings could receive external activation during the new analogical reasoning episode.

Implications for Asymmetries of Transfer

Experiment 1 found asymmetrical transfer between the **kji** and **mrrjjj** analogy problem-solving episodes. A number of studies have suggested that asymmetries exist in analogical transfer (Bassok, 1990; Bassok & Holyoak, 1989, 1993; Reed, Ackinclose, & Voss, 1990; Reed, Ernst, & Banerji, 1974; Reed & Evans, 1987), though none deal with meta-analogical transfer. While the current experiments do not reveal why asymmetries in transfer occur, they lead to some hypotheses.

The **kji** and **mrrjjj** analogies differ in a potentially interesting way, as they contrast a relatively unstructured analogy (**mrrjjj**) with a more structured one (**kji**). It is possible to produce highly

structured answers to the **kji** analogy based on mapping the predicate "sequence" from the representation of the **abc** string to the "sequence" predicate in the representation of the **kji** string, which in Halford's (1987) terms is a more complex system mapping than the relational mappings on which most **mrrjjj** answers are based (e.g., "successor to successor" is a relational mapping). But for the **mrrjjj** analogy it is hard to use predicates to link all parts of the strings together. or to use a system mappings used (except for the *mrrjjjj* answer). Because of the greater amount of structure, Copycat produces answers with more structure for the **kji** analogy than for the **mrrjjj** analogy (Mitchell, 1993).

If the **kji** and **mrrjjj** analogies contrast in terms of the amount of structure their answers tend to have, then they will differ in that more predicates will tend to be required to represent answers to the **kji** analogy than to represent answers to the **mrrjjj** analogy. The sheer number of predicates in a representation is almost certainly not the only issue — higher-order predicates are probably particularly important — but how these factors may interact remains unclear. Asymmetries in numbers of predicates may lead to asymmetries of transfer because it may be more important for the source to fit the target, than vice-versa. The problem solver may focus more on using the source knowledge they already have to make inferences about the target they are trying to interpret. That analogies involve using the source to understand a target is illustrated by the comparison, "Some butchers are surgeons", as opposed to "Some surgeons are butchers". As Glucksberg, Gildea, and Bookin (1982) pointed out, the former appears to be saying something nice about the target (butchers), while the later is unflattering to the target (surgeons).

How might the number of predicates lead to asymmetries of transfer? For an analogical solution to be transferred from a source to a target domain an appropriate mapping is required. Yet it is probably rare that only one set of predicate mappings exists between complex domains. Mapping therefore becomes partly a selection problem, as people must settle on one of several alternative mappings. When transferring from a domain with relatively few predicates in its representation, to a domain with a representation requiring a larger number of predicates, there may be only a limited number of ways to fit the source to the target domain, if it is assumed that participants focus on how to fit an already understood source domain to a target domain, rather than vice versa. But when the mapping is many-

to-one, as it is when there are relatively more predicates in the source than the target representation, participants must discard some predicates, even though they may have relatively little basis for how to judge which are the appropriate predicates to focus on and try to map. Hence, different participants will resolve this many-to-one mapping problem in different ways, resulting in some hitting upon the mappings that lead to one solution (which may or may not be correct by some external criteria), whereas others select mappings that lead to other solutions (correct or incorrect). Thus asymmetries in the number of predicates used to represent analogies may lead to asymmetries of transfer. The evidence from letter-string analogies supports this interpretation by demonstrating that even when participants do not produce the common solutions, they still appear to be producing answers to the second problem that are the result of transfer from the first problem. The heterogeneity of the answers is greatest when transferring from the analogy problem with the most structure (the **kji** analogy). As Gentner and Bowdle (1994) point out, unmapped structure can provide the basis for inferences. However, if these inferences are unconstrained then they may lead to a variety of different answers.

Representation and Meta-analogy

To be a good meta-analogy, transfer of more than a single predicate mapping may be necessary. In addition, the relation between mappings may be transferred. Thus Hofstadter's "shield tortoise" to "feather-cow" meta-analogy may be a better meta-analogy than "Dennis Thatcher" to "Marie Curie". The later may only require transfer of the mapping of "man to women", but Hofstadter's meta-analogy requires transferring the relationship between the mappings, that one is good ("shield to tortoise shell") and one is poor ("toad to tortoise body"). In this paper only the transfer of predicate mappings has been clearly demonstrated, but the asymmetries of transfer are suggestive that more than a single mapping is being transferred. It is tempting to speculate that the complete representation of a letter-string analogy includes the relationship between mappings (e.g., that "successor to predecessor" and "ascending to descending" mappings for the *kjh* answer to the **kji** problem are linked by the "opposite" relationship), and that such relationships are transferred.

In general, the results of the present study emphasize the importance of understanding the structures people build to represent analogies in order to understand transfer. Transfer to a new

problem occurred through the first episode biasing the predicate mappings (which constitute the representation) in the second episode. Thus the representation of the analogies were not fixed by their content. The idea that building representations interacts with the way analogies are solved has been advanced recently by others, particularly in Hofstadter and Mitchell's work (e.g., Hofstadter, 1995; Mitchell, 1993). Ross and Bradshaw (1994) have emphasized the importance of representation in analogical reasoning, speculating that reminding, mapping, and transfer, may interact dynamically during encoding. Medin, Goldstone, and Gentner (1993) have argued that similarity comparisons interact with the process of building representations of the objects being compared. The results reported here suggest that participants transfer more than simple rules, even when a simple rule would fit perfectly well. They instead appear to form elaborate representations and they fit such representations to the target domain (explicitly or implicitly), even when the fit is poor or under-constrained. The clarity of the representations of letter-string analogies may make them especially useful for investigating the role of representation in analogical and meta-analogical transfer. In general, these experiments demonstrated that letter-string analogies can be a useful tool for addressing a range of issues in analogical reasoning.

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Correspondence concerning this paper should be addressed to Bruce Burns, Department of Psychology, University of California, Los Angeles, California, 90095-1563, USA. E-mail: burns@psych.ucla.edu.

Table 1.

*Proportion of participants producing each answer to the **kji** analogy for participants receiving the **kji** analogy first then the **mrrjjj** analogy (N=66) or vice versa (N=74).*

	kjh	*kjj*	*lji*	*ijl*	Other
kji then **mrrjjj**	.36	.21	.23	.08	.12
mrrjjj then **kji**	.12	.58	.12	.04	.14

Table 2.

*Proportion of participants producing each answer to the **mrrjjj** analogy, for participants receiving the **kji** analogy first then the **mrrjjj** analogy (N=66) or vice versa (N=74).*

	mrrjjk	*mrrkkk*	*mrriii*	*mrrjjjj*	*jjjmrr*	*mrsjjk*	*mrsjjj*	Other
kji then **mrrjjj**	.08	.17	.06	.05	.01	.05	.05	.55
mrrjjj then **kji**	.15	.46	0	.01	.04	.08	.01	.14

Table 3.

*Proportion of participants producing each answer to the **mrrjjj** analogy, broken down by condition, justify-kjh (N=73) or justify-kjj (N=73). In parentheses for each group are presented the proportion of participants who in Experiment 1 produced each **mrrjjj** answer after generating the kjh (24 participants) or kjj (14 participants) answers to **kji**.*

	mrrjjk	*mrrkkk*	*mrriii*	*mrrjjjj*	*jjjmrr*	*mrsjjk*	*mrsjjj*	Other
justify-*kjh*	.10	.26	.05	.05	.00	.04	.03	.47[a]
	(.05)	(.20)	(.13)	(.05)	(.00)	(.05)	(.00)	(.54)
justify-*kjj*	.25	.32	.03	.03	.00	.12	.01	.25[b]
	(.21)	(.14)	(.00)	(.00)	(.00)	(.14)	(.21)	(.29)

[a]Nine participants gave no answer; four participants gave each of the following answers: *mrrjkk, mrriii*; two participants gave each of the following: *mrsjjj, mrrjjjkkkk, mrrbbb, mrrhhh*. Single participants gave each of the following: *jjjmr, jjjmyy, mmrrkkk, mrk, mrqjjj, mrrjjm, mrrkkkk, mrrppp, mrrtttt, mrrvvvv, mrsjj, mrsjkl, mrskkk, mxxjjj, nrrbbb*.

[b]Three participants gave no answer; two participants gave each of the following answers: *mrriii*; *mrrhhh, mrrkkkk, mssjjj*. Single participants gave each of the following: *mrdjjd, mrkkk, mrrjji, mrrsss, mrrzzzz, mrsjjj, mrsjkl, mstkln, nsskkk*.

Table 4.

*Proportion of participants producing each answer to the **kji** analogy, broken down by condition, justify-mrrjjjj (N=89), justify-mrrkkk (N=90), justify-mrrjjk (N=85), or justify-mrrjjd (N=79). In parentheses for the relevant groups are presented the proportion of participants who in Experiment 1 produced each kji answer after generating the mrrkkk (34 participants) or mrrjjk (11 participants) answers to the **mrrjjj** analogy.*

	kjh	*kjj*	*lji*	*kjd*	Other
justify-*mrrjjjj*	.20	.27	.25	0	$.28_a$
justify-*mrrkkk*	.04	.74	.14	0	$.07_b$
	(.08)	(.68)	(.18)	(.00)	(.06)
justify-*mrrjjk*	.12	.67	.12	0	$.09_c$
	(.00)	(.91)	(.09)	(.00)	(.00)
justify-*mrrjjd*	.09	.28	.14	.32	$.18_d$

[a]Three participants gave no answer; five participants gave *kjjiiii*; three participants gave *kjii*; two participants gave each of the following: *ijk, ijl, jik, kjg.* Single participants gave each of the following: *kji, kjih, kjij, kjl, ijk, lki.*

[b]Single participants gave each of the following answers: *jjl, jkl, khj, kja, kjk, mji*.

[c]Three participants gave *ijl*; two participants gave *kjk*. Single participants gave each of the following: *kjl, kju, kki.*

[d]One participant gave no answer; two participants gave each of the following answers: *dji, ijl, kjk, kjl.* Single participants gave each of the following: *jik, kji, kjig, kjil, kjl, mji.*

Table 5.

*Mean ratings of answers to **xyz** analogy for groups asked to justify the kjh or the kjj answer to the **kji** analogy, or who made no justification (standard deviations in parentheses).*

	wyz rating	*xyd* rating
Justify-*kjh* (N = 83)	4.47 (2.02)	3.43 (2.29)
Justify-*kjj* (N = 80)	3.59 (2.11)	3.76 (2.32)
No-justification (N=86)	3.95 (1.96)	3.59 (2.06)

Table 6.

*Mean ratings of answers to **kji** analogy for groups asked to justify the wyz or the xyd answer to the **wyz** analogy, or who gave no justification (standard deviations in parentheses).*

	kjh rating	*kjj* rating
Justify-*wyz* (N=81)	5.33 (1.77)	2.35 (1.93)
Justify-*xyd* (N=84)	4.54 (2.04)	2.60 (1.79)
No justification (N=80)	4.66 (2.15)	3.11 (2.30)

Appendix

Listing of all answers given to the first analogy problem given in Experiment 1 crossed with the answers given to the second analogy problem.

Table A. Number of responses to **mrrjjj** analogy when it is completed first, crossed with responses to the **kji** analogy completed subsequently.

	kjh	*kjj*	*ijl*	*lji*	*jig*	*lkj*	*kjl*	*qji*	*kjk*	*ijk*	*klj*	*kjp*	none	total
mrrjjk		10		1										11
mrrkkk	3	23	1	6					1					34
mrrkkkk	1		1											2
mrtjjk		1		1										2
mmrrkk		1											1	2
mrrk		1												1
mrrjjjj	1													1
jjmrr			1	1						1				3
msskkk					1									1
mrsjjk		5												5
mrrkk	1													1
mrrsss							1							1
mrrggg	1													1
mqqjjj								1						1
mrsjjj		1												1
jjjrrm						1				1				2
mjjrr	1													1
morij											1			1
mrrzzzz												1		1
mrsjkl		1												1
total	9	43	3	9	1	1	1	1	1	2	1	1	1	74

Table B. Number of responses to **kji** analogy when it is completed first, crossed with responses to the **mrrjjj** analogy completed subsequently.

	kjh	*kjj*	*ijl*	*lji*	*kln*	*kji*	*kli*	*hij*	*kij*	*lkj*	*jkl*	*kjd*	total
mrrjjk	1	3		1									5
mrrkkk	5	2		4									11
jms			1										1
mrriii	3			1									4
mrt					1								1
mrrjjjwwww	1												1
mrrjjjj	1		1	1									3
jjmrr			1										1
mrrjji	2												2
mrrfff	1												1
rjmjrj						1							1
mtrjjj							1						1
mjjjrr	1												1
jjrrmj			1										1
rrmjjj									1				1
mrrjjjkkkk		1											1
mrsjjk	1	2											3
mrruuu	1												1
mrrjjd				1								1	2
mssjjj				1									1
mrrkk		1											1
mrrjkk		1											1
mrrhhh	1												1
jmmrrr				1									1
nrjjjj				1									1
mrsjjj		3											3
jjjmrs				1									1
mrrnnnn	2												2
mrrzbd				1									1
mrrjjj	1	1											2
mrrmmmm				1									1
mrrlll			1										1
none	3			1				1		1	1		7
total	24	14	5	15	1	1	1	1	1	1	1	1	66

Figure Captions

Figure 1. A representation of the answer *kjh* to the letter-string analogy problem: **abc:abd::kji:???** Links between elements from left-to-right in the **abc:abd** strings are labeled with "succ" (successor predicate) and are mapped to links labeled "pred" (predecessor predicate) in the **kji:***kjh* strings.

Figure 2. A representation of the answer *mrrkkk* to the letter-string analogy problem: **abc:abd::mrrjjj:???** Links between elements from left-to-right in the **abc:abd** strings are labeled with "succ" (successor predicate) and are mapped to links labeled "succ" in the **mrrjjj:***mrrkkk* strings.