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Pragmatics in Analogical Mapping

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Theories of analogical reasoning differ in the roles they ascribe to pragmatic factors as a source of constraints on analogical mappings. The multiconstraint theory as instantiated in the ACME model (Holyoak & Thagard, 1989a) claims that pragmatic constraints interact with structural and semantic constraints within the mapping stage itself, in addition to influencing pre-mapping and post-mapping stages. Participants in three experiments were asked to generate mappings between non-isomorphic analogs for which mappings for some elements were ambiguous on structural grounds. In all experiments, manipulations of participants' processing goals influenced their preferred mappings. At the same time, goal-irrelevant information contributed to many-to-one mappings (Experiments 1 and 2) and to the resolution of mappings that were ambiguous on the basis of goal-relevant information alone (Experiment 3). The qualitative pattern of results was successfully simulated using the ACME model, implementing the impact of processing goals as an inhibitory process of selective attention.

A crucial requirement for purposeful thinking is ensuring that inferences are *relevant* to the goals of the reasoner. Often a problem situation will cue an enormous range of associated knowledge stored in long-term memory, most of which will be irrelevant to achieving a solution. Selective information

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processing helps to ensure that out of the infinitely large pool of potential inductive inferences that could be generated on the basis of current knowledge (most of which would be useless), people will tend to generate inferences that are plausible and goal-relevant (Holland, Holyoak, Nisbett, & Thagard, 1986). At the same time, an overly restrictive ''filter'' runs the risk of impeding problem solving by prematurely excising information that might somehow later prove useful. Goal-directed thinking therefore seems to involve a delicate trade-off: It should protect the system from being swamped by irrelevancies, yet at the same time it should allow a degree of openness to serendipitous insights.

CONSTRAINTS ON ANALOGICAL MAPPING

An important form of inductive inference in which this trade-off arises is reasoning by analogy (Holyoak, 1984, 1985). Analogical reasoning typically involves using a comparatively well-understood *source* domain as the basis for drawing inferences about a less well-understood *target* domain. An analogy may be drawn to help achieve a variety of different goals, such as solving a problem that has arisen in the target domain, predicting what is likely to happen if various alternative actions are taken, or generating an explanation of why the target domain behaves as it does (Holyoak & Thagard, 1995). One of the reasons why analogy is a particularly interesting type of induction is that analogical inferences are often made on the basis of a single initial case (i.e., the source), rather than relying on a large number of examples. On some occasions, analogy yields a wealth of inferences on the basis of a paucity of evidence. If analogy is to be useful, strong constraints must ensure that analogical inferences will be both plausible and relevant. At the same time, analogy can sometimes trigger creative insights (Holyoak & Thagard, 1995); hence the constraints must not be so rigid as to preclude the generation of unexpected inferences.

Analogy use can be broken into a number of component processes (e.g., Carbonell, 1983; Gentner, 1989; Gick & Holyoak, 1980; Hall, 1989; Keane, 1988; Novick & Holyoak, 1991). For the purposes of the present paper the major distinction is between the process of *mapping*—that is, identifying a set of orderly correspondences between the elements of the source and target analogs—and other processes that either precede or follow mapping. Premapping processes select a source analog such that the goal-relevant aspects of the source and target are likely to map well; post-mapping processes use the set of correspondences established by the mapping process to generate plausible inferences about the target. Within this overall framework the mapping process is thus viewed as pivotal, and hence has been the major focus of theory and research (e.g., Falkenhainer, Forbus, & Gentner, 1989; Gentner, 1983; Holyoak & Thagard, 1989a; Keane, Ledgeway, & Duff, 1994).

Although researchers generally agree that analogical mapping is guided by constraints of some sort, the exact nature of these constraints and their opera-

tion has been controversial. Most computational models of analogical inference postulate (although do not necessarily implement) some mechanism by which a reasoner's purpose for using the analogy can influence the process of analogical transfer (e.g., Anderson & Thompson, 1989; Burstein, 1986; Carbonell, 1983, 1986; Falkenhainer, 1990; Falkenhainer et al., 1989; Forbus & Oblinger, 1991; Holyoak & Thagard, 1989a, 1989b; Kedar-Cabelli, 1985; Winston, 1980). (An exception is the Copycat model of Hofstadter & Mitchell, 1988, 1994, which does not posit any influence of goals external to the process of analogical reasoning itself.)

But although most theorists acknowledge that analogical inference is somehow influenced by goals and context, theories of analogy differ in their assumptions about whether such pragmatic constraints directly enter into the mapping process. The clearest contrast has been offered by two general theories of analogical mapping: Gentner's structure-mapping theory (1983, 1989) and Holyoak and Thagard's multiconstraint theory (Holyoak, 1985; Holyoak & Thagard, 1989a, 1995). The structure-mapping theory, with its computational implementation SME (Structure-Mapping Engine; Falkenhainer et al., 1989),[1] postulates that the mapping process is purely syntactic and is not directly influenced by pragmatic constraints. ''[P]lans and goals and other aspects of current context influence the analogy process *before* and *after* the analogy engine but not during its operation'' (Gentner, 1989, p. 215; italics in original).[2]

In contrast, the multiconstraint theory (Holyoak, 1984, 1985; Holyoak & Thagard, 1989a, 1995) postulates that goals and context affect every stage of analogical inference, including the mapping stage, yielding the prediction that ''Differing goals can lead to different mappings for what is putatively the 'same' analogy . . .'' (Holyoak, 1985, p. 76).[3] In the multiconstraint theory, which is embodied in a computational model called ACME (Analogical Con-

[1] The SME program can be configured with a variety of different mapping rules. All references to the ''SME model'' in the present paper denote the SME program as it operates when running structure-mapping rules.

[2] Nonetheless, a variant of the SME model does admit a role for pragmatics (Forbus & Oblinger, 1990).

[3] Gentner (1989, p. 218) criticizes Holyoak's (1985) position as one in which ''. . . structural principles played no role; matching was governed entirely by the relevance of the predicates to the current goals of the problem solver.'' This characterization reflects an apparent misunderstanding. In fact, Holyoak (1985, pp. 70–76) stressed that mapping between problems is controlled by multiple constraints that guide the construction of an approximation to an isomorphism between the source and target representations. The concept of isomorphism has a clear definition in terms of structural correspondences between representations, which has been developed in formal model theory (Tarski, 1954) and applied to the theory of mental representation (e.g., Palmer, 1978). Thus, whereas structure-mapping theory postulates that mapping is based on purely syntactic constraints, the multiconstraint theory has maintained—in agreement with Gentner (1989)—that ''. . . a good case can be made for the need to augment structural considerations with goal-relevant considerations . . .'' (p. 219; italics in original).

straint Mapping Engine; Holyoak & Thagard, 1989a), pragmatic and other constraints are assumed to interact during the mapping process to generate correspondences by parallel constraint satisfaction. The multiconstraint theory claims that analogical coherence emerges from the interaction of three constraints: (1) The structural constraint of *isomorphism* yields a preference for mappings that are (a) *one-to-one* and (b) *structurally consistent.* Structural consistency requires that if a source proposition maps to a certain target proposition, then the predicate and argument(s) of the former should also map to the respective predicate and argument(s) of the latter. (2) The constraint of *semantic similarity* yields a preference for mappings between predicates that are similar in meaning (e.g., identical, or sharing a common superordinate). (3) Finally, *pragmatic centrality* yields a preference for correspondences that are assumed prior to the mapping process, or that link especially important elements. The multiconstraint theory treats all of the above not as strict requirements, but rather as ''soft'' constraints that can potentially be overridden when they conflict with one another. As such conflicts will often arise, the ''best'' mapping is likely to satisfy each constraint only imperfectly.

In the present paper we report the results of three experiments that test the multiconstraint theory's prediction that different goals of the analogist can lead to different mappings for the same analogy (Holyoak, 1985), and that goals actively interact with other types of constraints during the mapping process. In addition, we explore the possibility that the mechanism by which goals influence mapping is based on inhibitory processes for selective attention.

PREREQUISITES FOR IDENTIFYING PRAGMATIC CONSTRAINTS ON MAPPING

In order to resolve the issue empirically, we need to differentiate specifically pragmatic constraints on mapping from both (a) other types of constraints on mapping and (b) pragmatic constraints on pre- and post-mapping processes. These are difficult requirements to meet. As a consequence, few, if any, previous studies have provided evidence that directly bears upon the theoretical issue. We will point out several prerequisites for identifying pragmatic constraints on mapping, the difficulties these create for interpreting previous research that might seem relevant to this issue, and their methodological implications for the present study.

1. The Pragmatic Constraints Must Not Be Reducible to Other General Constraints

To identify specifically pragmatic constraints on mapping it is necessary to distinguish two roles that goals can play in analogical thinking, which can be respectively termed their *static* and *processing* roles. In the static role, a goal simply forms part of the representation that serves as input to the analogical comparison process. That is, a goal will itself provide part of the structure

of the analog. For example, in creating a mapping between World War II and the Persian Gulf War of 1991 (Spellman & Holyoak, 1992), part of the representation of the former might be that Hitler had the goal of taking over more countries (i.e., all of Europe) and of the latter that Saddam had the goal of taking over more countries (perhaps all of the Arabian peninsula). In its role as a static representational component, the impact of goals may most parsimoniously be interpreted as a special case of the operation of structural and/or semantic constraints, rather than as a separate type of pragmatic constraint. In other words, a shared goal might have the same effect on mapping as any other shared representational component (Gentner, 1989). In fact, several studies have shown that people's ability to transfer a solution from a source to a target analog is impaired if the two problems have different goals or different constraints on possible solutions (e.g., Gick & Holyoak, 1980, Exp. II; Holyoak & Koh, 1987). However, such studies have only varied goals as static components of the representations of the analogs; hence, such findings cannot provide unambiguous evidence for a pragmatic influence independent of the impact of differences in structural and semantic overlap.

Goals, however, can provide more than static representational components; they can also guide processing. It is the processing role of goals that can potentially provide a distinct pragmatic constraint on analogical comparisons. A person may map two analogs in order to achieve some goal, even though that goal does not form part of the initial representation of the analogs. For example, in order to spur military intervention by the United States during the Persian Gulf Crisis of 1991 (an external goal), the Bush administration encouraged a mapping between the Persian Gulf Crisis and World War II (and, in particular, between Saddam and Hitler). The present experiments were all designed to identify influences of variations in such external processing goals on preferred mappings.

2. The Pragmatic Effects Should Not Be Attributable to Post-mapping Processes

In order to show that goals influence mapping, it is necessary to show that the locus of pragmatic effects is not restricted to post-mapping processes such as inference generation and evaluation. Most studies of analogical inference have not directly examined people's mappings; rather, conclusions about the mapping process have been based on dependent measures such as frequencies of generating an analogous solution to a target problem (e.g., Gentner & Gentner, 1983; Gick & Holyoak, 1980, 1983; Holyoak & Koh, 1987; Keane, 1988; Ross, 1987, 1989) or filling in missing information about the target (Gentner & Toupin, 1986). Because these transfer tasks clearly require post-mapping processes, differences in such dependent measures may reflect the operation of processing stages that *follow* the mapping stage, rather than the operation of the mapping stage itself. Asking participants to generate correspondences for particular elements of an analog would seem to provide the most direct evidence about the immediate

output of the mapping process itself, namely, a set of preferred mappings (Keane et al., 1994; Markman & Gentner, 1993; Novick & Holyoak, 1991; Reed, 1987; Spellman & Holyoak, 1992). In order to more directly implicate the mapping process as the locus of any observed effects of manipulating processing goals, the primary dependent variable in the present experiments is based on participants' answers to questions about source-target correspondences. Participants were also asked to make decisions and generate inferences; however, these tasks were prior to the mappings and served to manipulate participants' external processing goals in order to determine whether such manipulations would influence their preferred mappings.

3. The Pragmatic Effects Should Not Be Attributable to Pre-mapping Processes

As we noted, the structure-mapping theory permits pragmatic constraints to influence such pre-mapping processes as encoding the source analog in long-term memory, retrieving the source analog, and selecting subsets of the source as inputs to the mapping engine (Gentner, 1989). Accordingly, although studies have shown that manipulating participants' encodings of analogs—including their encodings of goal structure—can have a dramatic influence on analogical transfer (e.g., Brown & Kane, 1988; Brown, Kane & Echols, 1986; Catrambone & Holyoak, 1989; Zook & Di Vesta, 1991), such findings do not clearly implicate the mapping stage as the locus of pragmatic effects. Similarly, although experimental studies of case-based reasoning indicate that goals can influence access to source analogs (e.g., Faries & Reiser, 1988; Seifert, McKoon, Abelson, & Ratcliff, 1986; see Seifert, 1994, for a review), the apparent locus of such influences is prior to mapping. In order to eliminate potential explanations for our results based on pre-mapping retrieval processes, the source and target were always directly presented to participants for mapping, eliminating any need to retrieve the source.

The filter and filter-attenuation hypotheses. Even more subtly, as Gentner (1989) has cogently argued, goal-directed pre-mapping processes may select only the relevant subsets of the source and target analogs as input to the mapping process. For instance, in the above example of people trying to use a source analog to make a decision about intervention in the Persian Gulf, it might be that all non-military aspects of the source are ''screened out'' of the working-memory representation on which mapping is performed. Thus, although the external goal would indeed guide people's mappings, it would have exerted its entire influence in selecting the precise input to the mapping process, rather than by guiding the mapping process directly. In other words, rather than amplifying the impact of relevant aspects of the source and target during mapping, as postulated by the multiconstraint theory, goals might be used to eliminate aspects of the analogs that are *not* goal-relevant before mapping even begins.

By analogy to Broadbent's (1958) model of selective attention, we will

refer to the hypothesis that pragmatics entirely screens out goal-irrelevant information prior to mapping as the ''filter'' hypothesis, and by analogy to Treisman's (1964) alternative to Broadbent's model we will refer to the hypothesis that pragmatics de-emphasizes goal-irrelevant information without necessarily screening it out entirely as the ''filter-attenuation'' hypothesis. Note that if selective attention is viewed as an inhibitory process, then complete filtering is the logical extreme of a filter-attenuation mechanism in which the de-emphasized information is fully suppressed. The multiconstraint theory, which treats pragmatic importance as a continuum, is compatible with the filter-attenuation hypothesis. More specifically, the ACME model can make use of goal-directed inhibition to provide a mechanism for encouraging relevance without altogether blocking information that is not directly related to the goal (Spellman & Holyoak, 1993). The filter-attenuation hypothesis is consistent with other previous evidence that goal-irrelevant information at least sometimes influences mapping (Ross, 1987, 1989).

Paradoxically, demonstrating that goals influence the mapping process itself, rather than solely acting as a pre-mapping filter on inputs, requires simultaneously demonstrating a secondary influence of goal-irrelevant aspects of the analogs on the mapping process. In our experiments, we sought converging evidence that the processing goal does not completely screen out goal-irrelevant aspects of the source prior to mapping. We attempted to show that even though processing goals affect people's preferred correspondences, at the same time other correspondences based on goal-irrelevant aspects of the analogs are also reliably generated by participants, thus indicating that the latter type of information was also passed to the mapping mechanism.

The role of homomorphic mappings. One potential source of evidence for an influence of goal-irrelevant information on mapping can potentially be provided by homomorphic (i.e., either one-to-many or many-to-one) mappings. Suppose that the processing goal supports one mapping for an ambiguous element, whereas other, less pragmatically central relations, support a different mapping. If participants sometimes map *both* possibilities either to or from such an ambiguous element, this would imply that they did not entirely screen out goal-irrelevant information prior to mapping. It is not obvious people will actually generate homomorphic mappings, as both the structure-mapping and the multiconstraint theories posit that the mapping process is guided by a one-to-one constraint. However, the multiconstraint theory's soft version of the isomorphism constraint implies that competing pressures can sometimes lead to cases in which people will generate (and presumably report) mappings that systematically violate one-to-one mapping. The structure-mapping theory (and the SME model) treats one-to-one mapping as a ''hard'' constraint[4] that individuals will not violate when they *generate*

[4] As noted by Markman and Gentner (1993, p. 463), ''SME differs from other competing models in its adherence to structural consistency—one-to-one mapping and connectivity—as strict constraints on mapping.''

a mapping. However, according to structure-mapping theory, it is still possible for individuals to *report* non-isomorphic mappings. In finding the best analogy, SME computes multiple sets of consistent mappings, or ''Gmaps''; although each Gmap is based on a strict one-to-one mapping, it is possible that people might sometimes report mappings based on multiple Gmaps, thus overtly producing homomorphic mappings. Another possibility, consistent with both theories, is that many-to-one or one-to-many mappings may sometimes arise because people recode multiple objects into a group prior to mapping; after computing a unique mapping for the group, people may revert to a representation in terms of multiple objects for the purpose of reporting the mapping.

There is some empirical evidence that people produce homomorphic mappings. Spellman and Holyoak (1992) asked participants to generate mappings between the leaders and countries involved in the Persian Gulf War of 1991 and those involved in World War II. For the country of Kuwait (the victim of Iraqi aggression in the Gulf War), about 9% of participants gave as their mapping two or more of Austria, Czechoslovakia, and Poland (all of which were victims of Nazi Germany prior to and/or during World War II). Such one-to-many mappings, although relatively infrequent, were clearly systematic, reflecting conflicting pressures created by overlap of a target object with the roles of multiple source objects. A few other subjects mapped Kuwait to things like ''the countries Hitler invaded early in the war''—thus recoding multiple items into a group. The overall rarity of one-to-many and many-to-one responses may be due to experimental demands. Studies that involve potentially ambiguous mappings (e.g., ''cross'' mappings in which attribute similarity supports one match for an element while relational similarity supports another) have typically used question formats that tend to preclude one-to-many mappings. For example, Markman and Gentner (1993) asked their participants to draw a line from one figure to the ''best match'' (singular). Studies that ask for mappings to be written typically provide one line next to each source element on which participants are to write the analogous target element(s). Such task demands may deter participants from reporting one-to-many matches.

Experiments 1 and 2 assess the effect of external processing goals on mapping and examine homomorphic mappings as a potential means of finding evidence favoring the filter-attenuation hypothesis. Experiment 3 uses potentially ambiguous mappings to rule out alternative explanations of our data based on premapping processes. In the latter experiment, we attempted to show that even correspondences involving goal-relevant elements can be influenced to some extent by goal-irrelevant aspects of the analogs.

EXPERIMENT 1

The role of pragmatic constraints on mapping was examined by manipulating participants' external processing goals and measuring changes in their

responses to mapping questions based on structurally ambiguous analogies. If participants are asked to map structurally-ambiguous elements of analogs, and they are guided by their processing goals, then they should favor goal-relevant over goal-irrelevant mappings. In addition, if goal-irrelevant information is not totally excluded from the mapping stage (as the filter-attenuation model suggests), then participants may sometimes generate homomorphic mappings for structurally ambiguous elements.

Method

Materials, Design, and Procedure

The present methodology is an extension of that used by Spellman and Holyoak (1992, Experiment 3). Participants read science-fiction stories that included descriptions of countries and their leaders, made judgments designed to manipulate their processing goals, then answered a series of mapping questions. Participants were given booklets containing instructions and story materials. On the first page participants read about ''Captain Krick'' of the Federation, who had just returned from exploring two new planets, and who knew that he was going to have to recommend that the Federation take some action towards the countries on those planets.

In the Trade condition, Krick knew that he would have to recommend whether to begin trading with the countries on those planets. The instructions stated that the important qualities for a trading partner were that it had things the Federation wanted and that it wanted things the Federation had. (Trading partners were not judged on humanitarian values, as it was assumed that increased contact with the Federation would have a positive effect on other societies.) In the Membership condition, Krick knew that he would have to recommend whether to invite the countries on those planets to become trial members of the Federation. The most important qualities for a member of the Federation were that it was receptive to new foreign ideas and that it respected all forms of life. In the Control condition, Krick knew that he would have to make both kinds of recommendations, and the instructions provided descriptions of both important qualities.

Participants then read Captain Krick's descriptions of three countries located on two planets. First they read about Anthar, the country on Antares II, which was big and prosperous and had made many medical advances, but was somewhat technologically underdeveloped. The country had just elected a President who seemed compassionate in his dealings with another, less prosperous ''winter'' country. The President nominated an Ambassador to meet with the representatives of the Federation.

Participants then read about the two countries on the planet Zenoba III. Minutus was a small, poor country, lacking in resources. The ruler of Minutus was a benevolent King. The King promised to improve farming techniques and develop culture. He seemed humane in his dealings with a hurricane-torn tropical island country on Zenoba III, and he appointed a Consul to confer with the Federation. Grandus was a large, technologically advanced country, rich in natural resources, but which occasionally experienced food shortages. The ruler of Grandus was an evil Emperor who restricted communications within his country and was hostile to the island country. He appointed a Minister to negotiate with the Federation. The order of the descriptions of the countries on Zenoba III was counterbalanced across participants.

Immediately after reading the description of each country, participants were asked to evaluate one or two questions about it, using a 7-point rating scale ranging from ''definitely not'' to ''definitely yes.'' Then they were asked to justify their answer. In the Trade condition the question was whether the country should be selected as a trading partner; in the Membership condition the question was whether the country should be admitted to trial membership in the Federation. In the Control condition participants were asked both questions; the order was counterbalanced between participants.

For all participants, the final page of the booklet contained a matching task. Participants were told that Captain Krick was asked to describe the similarities between the situations on Antares II and Zenoba III, and were asked what they thought Krick would respond. They were instructed as follows:

> For each of the people or countries listed below from Antares II, please write down the most natural match or matches from the planet Zenoba III. If you think there is no good match, write ''none.''

Participants were told that they were allowed to look back at the descriptions on the previous pages. Five people and countries from Antares II (the source analog) were listed on the left side of the page: winter country, Anthar, President's wife, President, and Ambassador. For half of the participants the items in the mapping task were presented in the above order, and for the other half the serial positions of Anthar and President were switched. To the right of each name was a blank line on which participants were to write their match or matches.

Participants

A total of 116 students from the University of California, Los Angeles (UCLA), participated in the experiment. The data from 12 participants were discarded because (in 9 cases) they mapped only to countries (i.e., only to Minutus, Grandus, or ''none,'' including mapping people to countries); in one case mapped only to ''technology'' or ''none''; in one case mapped only to ''Antares III'' or ''Zenoba II''; and in one case mapped only to ''none.'' Of the remaining 104 participants, 47 were from an upper-division psychology elective course (Psychology and Law) and were run in one large group, and 57 were from an introductory psychology course and served as participants in partial fulfillment of a course requirement. The latter participants were run individually or in groups of up to 8 and received this task along with other short experiments. Participants from the two pools were distributed approximately equally across the conditions.

Results and Discussion

All statistical tests are reported with respect to the two experimental conditions (Trade versus Membership); descriptive data for the Control condition is presented in the tables for calibration purposes only. Reported results differ in number of participants because not all participants answered all five mapping questions.

Evaluation Task

To check that our pragmatic manipulation focused participants' attention on the relevant similarities between the countries, we first examined participants' responses in the evaluation task for the Trade and Membership conditions. Mean ratings are shown in Table 1. The various conditions did elicit the expected evaluations. For both questions, participants ratings differed across the three countries (Trade, $F(2, 72) = 21.45$, $p < .001$; Membership $F(2, 64) = 176.94$, $p < .001$). For the Trade question, a Newman-Keuls test revealed that all three means differed from each other, with Anthar being rated as the best candidate for a trading partner, followed by Grandus and then Minutus. Participants' ratings thus indicated that Anthar was more similar to Grandus than to Minutus with respect to their suitability as trading partners for the Federation. For the Membership question, a Newman-Keuls test revealed no

TABLE 1
Mean Ratings for Countries in the Evaluation Task of Experiment 1 ($N = 104$)

	Membership question			Trade question		
Condition	Anthar	Grandus	Minutus	Anthar	Grandus	Minutus
Trade ($N = 37$)	*	*	*	1.59	.38	−1.14
				(2.19)	(3.96)	(2.95)
Membership ($N = 33$)	2.03	−2.12	1.88	*	*	*
	(1.34)	(1.67)	(1.42)			
Control ($N = 34$)	1.85	−1.94	1.68	2.21	.71	−.47
	(1.24)	(1.82)	(1.63)	(.87)	(3.97)	(3.07)

Note. Questions were: Do you think we should admit ⟨country⟩ to trial membership in the Federation? Do you think we should open trade with ⟨country⟩? Rating scale ranged from −3 (definitely not) through 0 (undecided) to +3 (definitely yes). Numbers in parentheses are unbiased variances.

difference between the ratings for Anthar and Minutus, both of which received positive ratings as potential members, with Grandus receiving a negative rating that was significantly lower than those for the other two countries. Thus participants' ratings indicated that Anthar was more similar to Minutus than to Grandus with respect to their suitability as potential Federation members. This reversal of the relative similarity of Anthar to Grandus versus Minutus as a function of the processing goal establishes that our cover stories achieved their intended effect.

Mapping Task

The most important result concerns the mapping for the ambiguous country Anthar. If participants' processing goals can guide their mappings, then participants in the Trade condition should tend to map Anthar to the prosperous country Grandus more often than to the poor country Minutus. In contrast, participants in the Membership condition, who were led to focus on humanitarian values, should tend to map Anthar to the benevolent Minutus rather than to the evil and repressed Grandus. As shown by the boldface numbers in Table 2, participants in the Trade condition were indeed more likely to map Anthar to Grandus rather than Minutus (54% vs 19% of participants), whereas the favored mapping reversed for participants in the Membership condition (21% vs 58%), $\chi^2(1, N = 53) = 11.78$, $p < .001$. This result thus supports the prediction of the multiconstraint theory, which claims that processing goals can serve to guide analogical mapping.

Most participants in all conditions mapped the President to the King (78 out of the 100 who gave any mapping at all for the President). The mappings for the Ambassador and the President were highly associated, $\chi^2(1, N = 83) = 15.95$, $p < .001$. Across all conditions, participants who mapped the Presi-

TABLE 2
Percentages of Participants Who Made Various Mappings for Anthar in Each Condition of Experiment 1 ($N = 104$)

Condition	Mapping for Anthar		
	Grandus	Minutus	None/other
Trade ($N = 37$)	**54**	**19**	27
Membership ($N = 33$)	**21**	**58**	21
Control ($N = 34$)	50	35	15

Note. Boldface percentages reflect reversal of preference for mapping Anthar to Grandus vs Minutus as a function of processing goal (Trade vs Membership).

dent to the King were far more likely to map the Ambassador to the Consul ($N = 61$) than to the Minister ($N = 9$), whereas participants who mapped the President to the Emperor were slightly *less* likely to map the Ambassador to the Consul ($N = 5$) than to the Minister ($N = 8$). Since the only thing participants were told about the Consul and the Ambassador is by which leader they were appointed, this pattern of association indicates that structural consistency controlled the selection of mappings in the absence of other pressures.

Very few participants (23%) gave mappings for the President's wife. The most common mapping (12 participants) was to map the wife to the King. Since these participants all also mapped the President to the King, such responses demonstrated many-to-one mappings. Seven participants mapped the President's wife to the Consul or the Minister; one mapped her to the Emperor; one mapped her to the (non-described but cleverly invented) ''Queen''; and the three remaining participants mapped her to other elements. These mappings were scattered equally across the three conditions.

Eighty percent of participants mapped the winter country (the minor country in the source analog) to either Grandus, Minutus, or the tropical island country in the target analog. For these participants, the relative frequency of the three alternative mappings varied significantly across the two experimental conditions, $\chi^2(2, N = 55) = 6.82$, $p < .05$. The main difference across conditions is that participants in the Trade condition were much more likely to map the winter county to Grandus (31%) than were participants in the Membership condition (4%). This difference may reflect the possibility that both the winter country and Grandus could be viewed as viable trading partners (the winter country had ingredients for medicine, which the Federation might need), whereas the winter country (like Minutus but unlike Grandus) would likely be considered a viable candidate for membership in the Federation.

For a considerable number of participants, the mapping for the winter country formed part of a many-to-one mapping. Overall, 19 participants

mapped the winter country and Anthar to the same element (either Grandus or Minutus). Which many-to-one mapping they made varied by condition, $\chi^2(1, N = 14) = 6.87$, $p < .01$: In the Trade condition 3 participants mapped both the winter country and Anthar to Grandus and 2 participants mapped them both to Minutus; in the Membership condition 0 participants mapped both to Grandus and 9 mapped them both to Minutus. Again, these choices seem to be driven by the processing goals.

In summary, the participants' mappings for a structurally ambiguous element differed depending on the pragmatic focus imposed by their orientation task. The results of Experiment 1 thus provide support for the prediction that processing goals can guide analogical mapping.

EXPERIMENT 2

Although the goals provided in Experiment 1 seem to have guided participants' mappings, it could be questioned whether the manipulation of goals had its influence directly on the mapping stage, or whether the manipulation merely caused the exclusion of the goal-irrelevant aspects of the analogs in the pre-mapping stage, as the filter hypothesis would suggest. The fact that participants sometimes provided many-to-one mappings (e.g., mapping both Anthar and the winter country to Minutus) suggests that participants mapped on the basis of information that might violate strict isomorphism. However, the results of Experiment 1 did not clearly show that both trade-related and membership-related information were jointly used (with differential emphasis) during the mapping process. For example, only one participant (in the Control condition) mapped the ambiguous country Anthar to *both* Grandus and Minutus (the former mapping supported by trade relations, the latter by membership relations).

Notice, however, that one-to-many mappings such as the above may have been discouraged by the format used in the mapping task. Although participants were instructed that they could write more than one answer in the space provided, they may have felt that it was more appropriate to write down (at most) a single response for each question. The violations of strict isomorphism observed in Experiment 1 almost all involved mapping each of two source elements to a single target element (e.g., both Anthar and the winter country to Grandus). Such many-to-one mappings, unlike one-to-many mappings, can be generated even if participants limit themselves to a single response for each mapping question. Accordingly, in Experiment 2 we varied the direction of the mapping so that the crucial ambiguous element would potentially trigger either one-to-many or many-to-one mappings. We suspected that due to task demands subjects would be more likely to report homomorphic mappings in the many-to-one direction. Such mappings would yield converging evidence that goal-irrelevant as well as goal-relevant information influences the mapping process.

Experiment 2 also varied the focus of the pragmatic manipulation. In Exper-

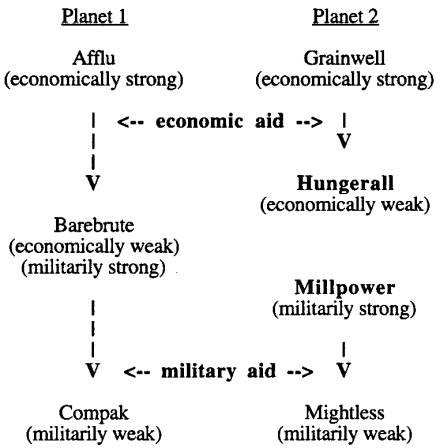

FIG. 1. Schematic diagram of Experiment 2. Vertical arrows represent ''aid'' relations (military or economic). Boldface represents relations and objects that were made pragmatically important in different conditions of the experiment.

iment 1, participants' processing goals were manipulated by questions that directed attention to particular relations in the analogs. The multiconstraint theory predicts that processing goals can also be influenced by questions that direct attention to particular objects, rather than particular relations. Accordingly, in Experiment 2 different groups of participants were exposed to manipulations of the importance of either relations or objects.

Method

Materials, Design, and Procedure

A new set of science-fiction materials, illustrated in Fig. 1, was constructed. In these materials Captain Krick was described as visiting two planets, one with three countries and one with four countries. On the planet with three countries, Afflu was strong economically and gave economic aid to Barebrute; Barebrute was weak economically but strong militarily and gave military aid to Compak; and Compak was weak militarily. On the planet with four countries, Grainwell was strong economically and gave economic aid to the economically weak Hungerall; Millpower was strong militarily and gave military aid to the militarily weak Mightless. Thus, Afflu and Grainwell are obviously analogous, as are Compak and Mightless. The crucial ambiguous country is Barebrute, which shares similarities with both Hungerall (receiving economic aid) and Millpower (giving military aid). The question is, then, whether participants' mappings for Barebrute could be biased by pragmatic influences. The processing goals of participants were manipulated by emphasizing either one of two sets of relations (economic or military) or one of two possible objects (either Hungerall or Millpower). Emphasis on either economic relations or on Hungerall should encourage participants to map Barebrute to Hungerall; emphasis on either military relations or on Millpower should encourage them to map Barebrute to Millpower.

Participants served in one of five conditions: Military, Economic, Millpower, Hungerall, or Control, which differed solely in the orienting tasks that were used to set the participants' processing goals. Each participant received a booklet consisting of four pages and was given as

much time as needed to read and respond to the questions in it. On the first page participants were told about Captain Krick, who was going out on a mission to explore two newly discovered planets. In the Millpower, Hungerall, and Control conditions, participants were told that the Federation was interested in both the military and economic situations on the planets; in the Military and Economic conditions they were only told that the Federation was interested in the corresponding situation (either military or economic).

Participants then read descriptions of the countries on the two planets. On the first page they read about the planet with three countries: Afflu, Barebrute, and Compak. At the bottom of the page participants were asked what actions regarding each country they thought Krick would recommend to the Federation. Participants in the Millpower, Hungerall, and Control conditions were asked to make both military and economic recommendations; participants in the Military and Economic conditions were asked to make only the corresponding recommendation. All participants were told that the Federation wanted to make alliances with countries that are (militarily or economically) strong and give aid to countries that are (militarily or economically) weak. Under the heading ''Military'' and/or ''Economic'' were listed the three countries and the four possible actions: aid, alliance, neither, unsure. Participants were instructed to circle one of those actions for each country and each type of recommendation.

On the second page participants read about the four countries on the second planet: Grainwell, Hungerall, Millpower and Mightless. Half of the participants read about the four planets in the order listed above; the other half read about them in the order Millpower, Mightless, Grainwell, Hungerall.

On the third page participants were asked to make military and/or economic recommendations about some or all of the countries on the second planet. In the Millpower and Hungerall conditions, participants were asked to make both military and economic recommendations for only Millpower or Hungerall. In the Military and Economic conditions, participants were asked to make either military or economic recommendations for all four countries. In the Control condition, participants made both military and economic recommendations for all four countries. As on the first page, the countries and possible actions were listed and participants were instructed to circle one action for each country and each type of recommendation.

The fourth page contained the mapping and rating task. Participants were told that Captain Krick was asked about the similarities between the situations and countries on the two planets. Half of the participants were instructed as follows:

> For each of the countries listed below from Planet 1, please write down the most natural match or matches from Planet 2. If you think there is no good match, write ''none.'' After you have written down the match or matches, please rate how happy you are with your answer by writing a number from 1 to 7 on the line to the right of your answer.

For these participants the names of the three countries of Planet 1 appeared down the left side of the page in one of two orders: either Afflu, Barebrute, Compak or Compak, Barebrute, Afflu. These participants were in the ''1 → 2'' condition, mapping from one ambiguous element (Barebrute) to two possible correspondences (Hungerall, Millpower, or both)

The other half of the participants were asked to make mappings from Planet 2 to Planet 1. For these participants the names of the four countries of Planet 2 were listed down the left side of the page in one of two orders: either Grainwell, Hungerall, Millpower, Mightless or Millpower, Mightless, Grainwell, Hungerall. These participants were in the ''2 → 1'' condition, mapping each of the two possible correspondences to a set of possibilities including the ambiguous element. If participants consider both military and economic relations, even when only one set of relations is goal-relevant, they may provide many-to-one mappings in the 2 → 1 condition.

To the right of each name was a blank line for participants to write their match(es) on; to the right of that was a line for the rating. A 7-point scale was shown with 1 = extremely unhappy, 4 = neutral, 7 = extremely happy, and with all interval markers labeled. Participants were told

TABLE 3
Percentages of Participants in Each Condition of Experiment 2 Who Made the Same Recommendations for Barebrute and Hungerall/Millpower (N = 158)

	Same Recommendation as for Barebrute			
	Economic		Military	
Condition	Hungerall	Millpower	Hungerall	Millpower
Military (N = 31)	*	*	13	77
Economic (N = 35)	69	17	*	*
Millpower (N = 31)	*	3	*	81
Hungerall (N = 33)[a]	70	*	9	*
Control (N = 28)	71	21	11	82
Overall	71[b]	14	11	80[c]

[a] The recommendations for one participant in the Hungerall condition were lost.
[b] Of participants making the same economic recommendation for Barebrute and Hungerall, 94% recommended aid.
[c] Of participants making the same military recommendation for Barebrute and Millpower, 94% recommended alliance.

to write ''N/A'' on the rating line if they had written ''none'' for the match and were told they were allowed to look back at the descriptions on the previous pages.

Participants

The 165 participants were UCLA undergraduates who had not been in Experiment 1. The data from 6 participants were discarded because it was clear they had not understood the instructions (most gave answers drawn from the same planet they were supposed to have mapped from; others gave mappings to Earth). Of the remaining 159 participants, 91 were from an upper-division psychology course and participated in one large group as part of a class demonstration; 68 were from an introductory psychology course who participated in groups of up to 8 and who completed the present experiment along with other short experiments in partial fulfillment of a course requirement. Participants from the two populations were distributed approximately equally across all the conditions.

Results and Discussion

Recommendation Task

To check that our pragmatic manipulation focused participants' attention on the relevant similarities between the countries, we first examined participants' responses in the recommendation task. We looked at each participant's economic and military recommendations for Barebrute and compared them to the participant's economic and military recommendations for Hungerall and Millpower. (Recall that as described in the Method, the particular recommendations participants were asked to make differed across conditions.) As shown in Table 3, the economic recommendations for Barebrute were much more

TABLE 4
Percentages of Participants Who Made Various Mappings for the Ambiguous Country Barebrute in Each Condition of Experiment 2 ($N = 159$)

	Preferred mapping for Barebrute			
Condition	Hungerall	Millpower	Equal	Other/none
Military ($N = 31$)	**29**	**65**	0	6
Economic ($N = 35$)	**43**	**35**	17	6
Millpower ($N = 31$)	**16**	**61**	10	13
Hungerall ($N = 34$)	**44**	**38**	3	15
Control ($N = 28$)	36	43	18	4

Note. Boldface percentages reflect reversal or preference for mapping Barebrute to Hungerall vs Millpower as a function of conditions that manipulated processing goal (Military vs Economic; Millpower vs Hungerall).

similar to those for Hungerall than for Millpower, $\chi^2(1, N = 81) = 37.34$, $p < .001$, whereas the military recommendations for Barebrute were much more similar to those for Millpower than for Hungerall, $\chi^2(1, N = 82) = 46.88$, $p < .001$. These results confirm the effectiveness of our pragmatic manipulation.

Mappings for Ambiguous Country

The most important results center on the mappings for the ambiguous country, Barebrute, which was both a military power and an economic weakling. The key question concerned the influence of participants' processing goals in their generation and evaluation of mappings. The main analysis used participants' preferred mappings as a dependent variable. These data are shown in Table 4. Because we were interested in the strongest mappings for Barebrute, the data from the participants who were in the $2 \rightarrow 1$ condition was treated somewhat differently from the data from the participants who mapped in the other direction. In the $2 \rightarrow 1$ direction, in which participants gave mappings for both Hungerall and Millpower, participants often mapped both to Barebrute (as we will describe in detail below). In cases of such many-to-one mappings we treated the mapping with the higher rating as the preferred mapping for Barebrute. Thus the preferred mapping was either the sole correspondent for Barebrute, or the one of two that received the higher rating. The percentages of participants who rated Hungerall and Millpower as equal, or who mapped Barebrute in some other way (or not at all), are also reported in Table 4.

As can be seen in Table 4, participants were strongly influenced by the manipulation of their processing goals. A 2×2 analysis of the frequency data was performed after collapsing across conditions that encouraged the

same mapping (Military with Millpower because they were both designed to encourage mappings to Millpower; Economic with Hungerall because they both encourage mappings to Hungerall). This analysis revealed an association between the encouraged mapping and the actual mapping (see numbers in boldface in Table 4) such that participants were more likely to make the mapping consistent with their pragmatic focus, $\chi^2(1, N = 108) = 8.85$, $p < .01$. A comparison of the relation (Military and Economic) and object (Millpower and Hungerall) conditions revealed no significant difference in the pattern of associations for the two types of pragmatic manipulations.

In contrast to the ambiguous country of Barebrute, the frequencies of various mappings for the unambiguous countries Afflu and Compak did not differ significantly across either the five goal conditions or direction of mapping. In each of the five conditions, about 90% of participants mapped Afflu with Grainwell and Compak with Mightless.

Many-to-One-Mappings

In order to provide converging evidence that processing goals influenced the mapping stage itself, rather than only pre-mapping processes, we sought evidence that even the goal-irrelevant information in the analogs entered into the mapping process. A potential source of such evidence would be cases in which the same participant mapped more than one country with the ambiguous Barebrute. As in the comparable case of ambiguous Anthar in Experiment 1, one-to-many mappings for Barebrute were rarely produced in the $1 \rightarrow 2$ condition. Only one participant (in the Millpower condition) mapped Barebrute to both Hungerall and Millpower and one participant (in the Economic condition) mapped Barebrute to all three of Hungerall, Millpower, and Mightless.

However, many-to-one mappings were frequently produced in the $2 \rightarrow 1$ condition. In the Control condition, of the 16 participants who mapped in the $2 \rightarrow 1$ direction, 8 (i.e., 50%) mapped both Hungerall and Millpower to Barebrute. Of those 8 participants, 5 rated the two mappings as equally good, 2 preferred the mapping from Hungerall and 1 preferred the mapping from Millpower. Thus, when the cover story did not favor either processing goal, many participants seemed to attend to both.

When collapsed over the four conditions in which a particular mapping was favored by the processing goal (i.e., excluding the Control condition), 32% of the participants mapped both alternatives (Hungerall and Millpower) to Barebrute. Figure 2 depicts the percentages of participants in the $2 \rightarrow 1$ condition who made various alternative mappings for Barebrute. As Fig. 2 indicates, when the many-to-one responses were subdivided as a function of the relative rating given to the pragmatically preferred versus nonpreferred country (greater, equal, or lesser), the relative frequencies of these subtypes differed from each other, and reflected the overall preference for the mapping supported by the pragmatic manipulation, $\chi^2(2, N = 22) = 6.91$, $p < .05$.

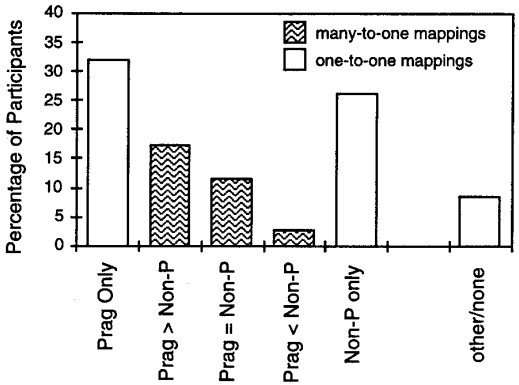

FIG. 2. Percentages of participants making various one-to-one and many-to-one mappings for Barebrute in the 2 → 1 condition of Experiment 2 (N = 68). Prag = mapping supported by pragmatic manipulation; Non-P = mapping not supported by pragmatic manipulation.

Thus, the pattern of many-to-one mappings obtained in the 2 → 1 condition suggests that participants did not entirely screen out goal-irrelevant information prior to mapping. Rather, it appears that many participants used both goal-relevant and goal-irrelevant information to generate mappings, but gave greater weight to the information that was congruent with their processing goals. This pattern thus supports the filter-attenuation hypothesis.

EXPERIMENT 3

Experiment 3 was designed to rule out one possible explanation of the results of Experiments 1 and 2 and thus provide yet stronger evidence that pragmatic constraints interact with structural and semantic constraints in the mapping process itself. In both Experiments 1 and 2, the manipulation of processing goals occurred before the participants first encountered the analogs. Therefore, it is possible that pragmatics influenced the initial representation of the analogs at the pre-mapping stage. In Experiment 3 participants encoded both analogs in a neutral way before any particular processing goal was established, thus ensuring that the initial representations of the analogs were equated across different goal conditions.

Even if the initial representations are equated, however, one cannot rule out the possibility that the analogs will be re-represented at the time the specific processing goal is established. In order to demonstrate that the goal does not solely influence mapping by filtering out goal-irrelevant information prior to the mapping stage, it is necessary to show that even goal-irrelevant information has some influence on participants' mappings. In Experiment 2 we were able to show that many participants generated many-to-one mappings for a structurally ambiguous element based on both goal-relevant and goal-irrelevant information. Experiment 3 was an attempt to supply stronger con-

TABLE 5
Schematic Predicate-Calculus Representation of the Relations between Characters in the Design of Experiment 3

Source	Target	
Bosses (Peter, Mary)	Bosses (Nancy, John)	Bosses (David, Lisa)
Loves (Peter, Mary)	Loves (John, Nancy)	Loves (Lisa, David)
Cheats (Peter, Bill)	Cheats (Nancy, David)	
	Cheats (Lisa, John)	

verging evidence for the interactive character of pragmatic constraints on mapping. The basic design involved analogies in which certain key objects were four-ways ambiguous on structural grounds alone, with two alternative mappings being supported by each of two sets of relations. The processing goal was then manipulated so as to emphasize one of the two sets of relations. If the processing goal were used to filter out all information that was not emphasized by the pragmatic manipulation, then two mappings would remain viable, with no basis for selecting between them. However, goal-irrelevant information was available that could further disambiguate the mapping. Thus, if the processing goal emphasizes the goal-relevant information but does not completely filter out goal-irrelevant information, as the filter-attenuation hypothesis allows, then the goal-relevant and goal-irrelevant information could jointly determine a single optimal mapping for each ambiguous element.

Because the design for Experiment 3 is complex (based on mappings that are four-ways ambiguous), we will first described the essence of the scheme. Table 5 shows several propositions that interconnect a number of characters in a source and target analog using three relations (*bosses, loves,* and *cheats*). The source story involves three main characters (Peter, Mary, and Bill) who are related as illustrated on the left in Table 5. The target story involves four characters (Nancy, John, David, and Lisa),[5] who are related by the same relations as are the characters in the source story. In the target, however, each of the *bosses* and *loves* relations appears twice. In the experimental design, the propositions involving either *bosses* or *loves* will be made important by the pragmatic manipulation; those involving *cheats* will not be.

Suppose, for a moment, that there were no propositions involving *cheats.* In that case Peter could be mapped to any of Nancy, John, David, or Lisa; similarly, Mary could be mapped to any of those same characters. That is, both Peter and Mary are four-ways ambiguous. Now suppose that the propositions involving *bosses* were made ''important'' relative to the *loves* propositions—that is, that the processing goal provided a strong reason to map *bosses* to

[5] In the actual experiment, half of the subjects read about characters with these names while the other half read about identical characters with different names.

bosses and the characters in the *bosses* propositions to each other. Then Peter would map to either Nancy or David and Mary would correspondingly map to either John or Lisa; however, there is still no way to choose between these two alternative mappings (if we ignore gender, which in the experiment will be controlled by counterbalancing). When the *cheats* propositions are added, however, they provide a basis for selecting a unique mapping for Peter and for Mary: Peter maps to Nancy and hence Mary maps to John. If, on the other hand, we were to make the *loves* propositions important (absent *cheats* propositions), then Peter would map to John or Lisa and Mary would correspondingly map to Nancy or David. When the *cheats* propositions are added, Peter maps to Lisa and hence Mary maps to David. Thus, propositions in the source that are not pragmatically manipulated themselves should resolve the mapping ambiguity differently depending on what is made important. The unique final mapping, therefore, would emerge from the joint constraints provided by both goal-relevant and goal-irrelevant propositions. If we can show that participants have a reliable preference for mappings that jointly depend on the information emphasized by their processing goal and on incidental information, we will have strong evidence that goals do not operate solely by excluding incidental information prior to the mapping stage.

Method

Overview

To make the above abstract design concrete, we embedded it in a scenario involving plagiarism of soap opera plots. The materials were slight modifications of those used by Spellman and Holyoak (1993). Participants were told to pretend that they were successful writers of a new soap opera, and that they were in court trying to prove that writers from another soap opera had stolen their ideas. First they were presented with the source—the plot of their own soap opera, called Soap Opera University (SO-U). Characters in SO-U included a professor named Peter who had had a nervous breakdown, Peter's research assistant Mary, who was now running Peter's lab, Peter's brother Bill, and some other minor characters. The three major relations between these characters were: Professional (Peter was Mary's boss); Romantic (Peter was in love with Mary); and Inheritance (Peter cheated Bill out of money the latter should have received from the will of a mutual relative).

The plot of the other soap opera, Soap Opera City (SO City), involved two somewhat distinct sets of characters. The ''lawyer set'' included Nancy, an ex-addict entertainment lawyer, and John, a young lawyer working at her law firm who had often filled in for her. The ''doctor set'' included David, a prominent physician who had become an alcoholic, and Lisa, an intern who was now treating most of David's patients. Nancy and David were half-siblings and John and Lisa were cousins. Both pairs had aging relatives ready to leave them money in a will; in one version of the story Nancy and Lisa (the women) cheat David and John (the men), respectively, out of their shares of the inheritance, and in the other version the men cheat the women out of their shares. In SO City, the three analogous major relations were as follows: Professional (Nancy was John's boss and David was Lisa's boss); Romantic (John was in love with Nancy and Lisa was in love with David); and Inheritance (either Nancy cheats David and Lisa cheats John or vice versa). From this description the object mappings are ambiguous; for example, if the women are the cheaters then Peter seems to map equally to Nancy and Lisa.

The pragmatic manipulation was accomplished using a ''plot-extension'' task. At the end of the description of SO-U, participants were told what happened in the Thursday and Friday

TABLE 6
Optimal Mappings for the Source Characters Based on Pragmatic Manipulation and Gender of Cheater in the Inheritance Relation (Experiment 3).

Professional plot extension				Romantic plot extension		
Gender of cheater					Gender of Cheater	
Male	Female	Role	Source characters	Role	Male	Female
David	Nancy	Boss	PETER	Pursuer	John	Lisa
Lisa	John	Underling	MARY	Pursued	Nancy	David
Nancy	David	Loser to Boss	BILL	Loser to Pursuer	Lisa	John
Aunt Agatha	Aunt Agatha	Victim of Boss	UNCLE UMBERT	Victim of Pursuer	Grandpa Glass	Grandpa Glass

episodes. In one of the episodes, the ''Professional continuation,'' Peter steals the credit for Mary's successes; in the ''Romantic continuation,'' Peter goes to Mary's apartment and tries to persuade her to let him spend the night. After reading the description of the characters on the plagiarized show, SO City, participants were told that a judge had seen a tape of the next SO City episode, that it involved three characters, and that it was ''just like'' either the SO-U Thursday or Friday show.[6] To demonstrate that the writers of SO City were really stealing the ideas of SO-U, participants were asked to describe what they think happened on the tape and which three characters were involved. We assumed that participants would write plot extensions that were analogous to the appropriate subplot continuation; that is, that the pragmatic manipulation should define the choice of continuation used in the plot-extension task. The three characters would include a Peter-analog, a Mary-analog, and an analog of the minor character involved in the relevant continuation.

Participants were then given a mapping task. They were told that the judge wanted them to explicitly state which characters of SO City were like which characters of SO-U because that would provide even more evidence of the plagiarism. Four characters from SO-U were listed and participants were encouraged to match only one character from SO City to each character of SO-U. If goals operate in accord with the filter-attenuation hypothesis, then participants' choices of mappings should reflect both the pragmatic manipulation and the information conveyed by the incidental Inheritance relation.

Table 6 illustrates the predicted mappings for the characters in the source as a function of our

[6] By providing all participants with extensions of the source based on both Professional and Romantic relations, and by counterbalancing which of these extensions became the pragmatic focus, the design made it possible to manipulate processing goals while at the same time controlling for the number of possible inferences that could be produced using mappings based on each of the two sets of primary relations. Some variants of the SME program allow sheer number of potential inferences (independent of their goal relevance) to be a factor that influences selection of preferred mappings. The design of Experiment 3 ensured that any influence of our pragmatic manipulation would not be attributable to differences in the number of potential inferences that could be potentially drawn using the goal-relevant vs the goal-irrelevant relation.

two main manipulations (i.e., which subplot was relevant in the plot-extension task and who cheated whom out of their inheritance). Note that the two main characters in the source—Peter and Mary—may each map to any of four characters from the target, depending on the pragmatic manipulation and the unemphasized Inheritance relation. For both the plot-extension and the mapping tasks, participants' choice of mappings for the two main characters made it possible to diagnose whether they were sensitive to the pragmatic focus (either Professional or Romantic) and/or to the incidental Inheritance relation. For example, consider the possible mappings for Peter summarized in Table 6. Suppose the plot-extension task made Professional relations the pragmatic focus. If participants are sensitive to this manipulation, they should map Peter to either David or Nancy, rather than John or Lisa. Suppose also that the incidental Inheritance relation established that the cheater was female. If participants are sensitive to the Inheritance relation, they should map Peter to either Nancy or Lisa, rather than David or John. Finally, if participants in this example are sensitive to both the pragmatic focus *and* to the incidental relation, they should map Peter to Nancy—the one choice that is supported by both the Professional and the Inheritance relations. The design thus makes it possible to determine whether the impact of the pragmatic manipulation can be attributed to a mechanism that entirely screens out unemphasized relations prior to mapping (the filter hypothesis), or whether the processing goal serves to emphasize the relevant relation without entirely suppressing incidental relations (filter-attenuation hypothesis).

Because the plot-extension task directly required attention to a specific type of relation (either Professional or Romantic), we would expect to find a strong impact of pragmatic focus in the choice of characters to extend the plot of the target soap opera. To the extent that a strong pragmatic focus implies attenuation of goal-irrelevant relations, the impact of the incidental Inheritance relation on character choice would be reduced in the plot-extension task. In contrast, the mapping task does not directly demand that the goal-relevant relation be of exclusive concern; hence the impact of the pragmatic manipulation would be expected to be less extreme. If the attenuation of unemphasized relations is more severe in the plot-extension task than in the mapping task, then the latter task is more likely to provide evidence that goal-relevant and goal-irrelevant relations can jointly guide the choice of mappings for ambiguous characters.

Design and Materials

The complete design had the form of a $2 \times 2 \times 2 \times 2 \times 2 \times 4$ factorial, yielding 128 distinct sets of materials. The design included the counterbalancing factors of name set, order of subplot continuations in the source story, order of doctor/lawyer character sets in target story, gender of the cheater, day of plot-extension, and order in mapping task, as described below. Each participant in the experiment received a five-page booklet containing a unique combination of materials.

Name sets. Names of characters were selected so as to control possible associations between names and ages of characters, a possible source of bias in mappings. Names were selected in the following way. Twenty-eight undergraduates at the University of Texas at Austin were told to write down as many men's and women's names (half in each order) as they could think of in 30 seconds. For the names of the main characters, six men's names were chosen that were listed by at least 5 participants and five women's names were chosen that were listed by at least 3 participants. The names of the two central characters in the source story, SO-U, were Peter and Mary. All of the selected men's names are listed in Kasof's (1993) Appendix B as being ''age-unassociated'' forenames. The name Mary is also considered to be ''age-unassociated.'' Two different sets of names were used in the target SO City scenario. In one set the lawyers were Nancy who bossed John and the doctors were David who bossed Lisa; in the other set the lawyers were Elizabeth who bossed Robert and the doctors were Larry who bossed Susan. Elizabeth and Nancy (alternative names for the boss/pursued lawyer) are listed as ''older adult names,'' while Lisa and Susan (alternatives for the underling/pursuer doctor) are listed as ''younger adult names.'' Half of the participants saw each set of names. Because there were no

differences in results between the two sets, and for ease of exposition, all references will be to the first set of names.

Order of subplot continuations in source story. On the first page of the booklet, participants were told that they were to pretend that they were the writers of a successful new soap opera called ''Soap Opera University'' (SO-U). They were worried that another group of writers had stolen ideas from their show, and they were about to sue these other writers. Participants then read six paragraphs introducing the important characters and describing what had happened on their show so far. The first two paragraphs described Peter, a once-famous professor who is now rather unproductive; Mary, his very bright graduate student; and their professional relationship. Mary's good work had attracted the attention of a scientist named Dr. Grant. The third paragraph described Peter and Mary's Romantic relationship. Peter wanted Mary to date him, but Mary was engaged. The fourth paragraph described how Peter cheated his brother, Bill, out of his inheritance by persuading their old Uncle Umbert to change his will. The fifth and sixth paragraphs were labeled ''In Thursday's episode'' and ''In Friday's episode,'' respectively. One of the paragraphs described the latest professional encounter between Peter and Mary—that Peter took credit for some of Mary's research findings and that Mary appealed to Dr. Grant for help. The other paragraph described the latest Romantic encounter between Peter and Mary—that Peter had gone to Mary's apartment one night when her fiancé was out of town and begged her to let him spend the night, but that Mary had rejected him. Which paragraph appeared in which labeled episode was counterbalanced between participants.

Order of character sets in target story. On the second and third pages, participants read about the plot of the other soap opera, ''Soap Opera City'' (SO-City). The first six paragraphs introduced the two character sets. The ''lawyer set'' consisted of Nancy, a once-successful lawyer who is now somewhat incompetent; John, a recent law school graduate who works for Nancy and is in love with her; Nancy's unnamed husband; and Mr. Rich, a wealthy client who is impressed with John. The ''doctor set'' consisted of David, a once-famous heart specialist who is no longer able to work at his previous level; Lisa, an intern who works for David and is in love with him; David's unnamed wife; and Mr. Hearty, a wealthy patient who is impressed with Lisa. Each set was described in three paragraphs; set order was counterbalanced across participants.

The gender of the cheater. On the second page it is mentioned that Nancy and David are half-siblings and John and Lisa are cousins. The third page describes the battles for inheritances that took place. Nancy and David have an old Aunt Agatha; John and Lisa have an aged Grandpa Glass. Half the participants read about how Nancy rewrote Aunt Agatha's will, disinheriting David, then forced Aunt Agatha into a poorly run nursing home, hastening her death. These same participants also read about how Lisa drugged Grandpa Glass, persuading him to rewrite his will disinheriting John, and then drugged him to death. In the other version of the story, David and John were the cheaters, using the tricks appropriate to their professions to get what they wanted.

Pragmatic manipulation and plot-extension task. The fourth page described what the judge wanted the writers of SO-U to do to prove that the SO-City writers had stolen their ideas. The judge said that a fellow judge had previewed a tape of SO-City episode and had said that it was ''just like'' one of the SO-U episodes from last week. For half the participants the tape was said to be ''just like'' Thursday's episode, for the other half it was said to be ''just like'' Friday's episode. (Thus, for half the participants the tape concerned the Professional subplot and for the other half it concerned the Romantic subplot). The judge told them that the taped episode involved three characters from SO-City and that they should try to figure out which characters they were, remembering that the tape was ''just like'' the particular show from last week and considering all the relationships—Professional, Romantic, and Inheritance—between the characters. Participants were then asked to write down what they thought would happen in the new SO-City episode. They were told that predicting these events successfully would be the strongest possible evidence that the other writers were stealing their ideas.

Mapping task. The fifth page contained the mapping task. The names of four SO-U characters (Peter, Mary, Bill, and Uncle Umbert) were typed down the left side of the page. Participants

were told that the judge wanted them to indicate how the characters of the two soap operas were alike. They were told that for each of the four characters in SO-U they were to write down the name of the single best matching character from SO-City. Above the lines for writing matches, participants read the instructions, ''Before you begin, please read through the entire list of characters.'' There were four different orderings for the SO-U characters, rotated across participants in a Latin-square design.

Participants

The participants were 128 students from the University of Texas at Austin who completed the experiment in partial fulfillment of a course requirement for introductory psychology. They were run individually or in groups of up to 20. They were given as much time as they needed to answer all questions and were allowed to look back at the stories while doing so.

Results and Discussion

For both tasks, the primary focus of the analyses was on answering two questions. First, were participants' mappings primarily guided by the goal-relevant relation (either Professional or Romantic)? Second, were participants' mappings also influenced by the incidental Inheritance relation? All analyses collapse across counterbalancing conditions.

Plot-Extension Task

The pragmatic manipulation was effective: 88% of the participants wrote a story that was analogous to one of the continuations; of those, 97% generated plot extensions with a theme that was appropriate to the pragmatic focus that had been established (either Professional or Romantic). The top panel of Figure 3 depicts the percentages of participants in the plot-extension task who used characters in accord with the goal-relevant relation (either Professional or Romantic) and with the incidental Inheritance relation. The response classified as ''other'' includes the 15 participants who wrote plot extensions that were not analogous to either continuation plus 6 participants who used two sets of characters in the plot-extension task (e.g., Lisa and David and John and Nancy), in which case the influence of Inheritance was indeterminate. Thus, the analyses below are reported on the 84% of the participants not included as ''other.'' An overwhelming majority of those participants wrote an appropriate story (97% vs 3%), $\chi^2(1, N = 107) = 95.33$, $p < .001$, indicating that the pragmatic focus had an effect on the continuation chosen. In this task, however, participants were not affected by the incidental Inheritance relation: 53% mapped in accordance with it, 47% did not, $\chi^2(1, N = 107) = 0.46$, ns. Thus character selection in the plot-extension task was consistent with either the filter hypothesis or with the filter-attenuation hypothesis assuming high inhibition of all goal-irrelevant relations.

Mapping Task

An analysis of character selection similar to that for the plot-extension task was performed using data from the mapping task, which did not so directly

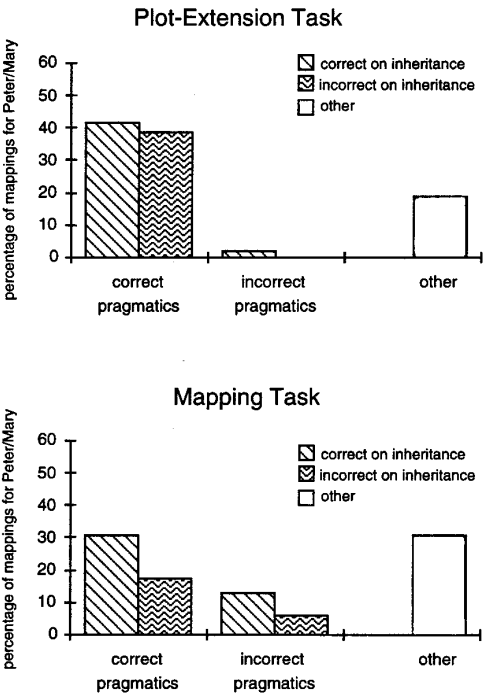

FIG. 3. Top panel: Percentages of participants in the plot-extension task of Experiment 3 who mapped characters in accord with the goal-relevant relation (either Professional or Romantic) and in accord with the incidental Inheritance relation. Other = participants who did not write an analogous plot-extension or whose analogous plot-extension included two sets of characters. Bottom panel: Percentages of participants in the mapping task of Experiment 3 who mapped characters in accord with the goal-relevant relation (either Professional or Romantic) and in accord with the incidental Inheritance relation. Other = participants who did not write an analogous plot-extension, included two sets of characters in the plot-extension, or did not map to a congruous Peter/Mary pair.

demand that participants focus on the goal-relevant relation. Note that the mapping for the major character, Peter, considered in isolation, could be based on either the goal-relevant information, the goal-irrelevant information, or both. Accordingly, whether a participant's mapping was scored as consistent or inconsistent with the goal-relevant information was based on whether Peter *and* Mary were mapped to congruous *pairs* of characters (e.g., Peter = Nancy *and* Mary = John). When the mapping of the Peter/Mary combination is examined, we can determine whether the goal-relevant information and/or the goal-irrelevant information came into play.

The results are depicted in the bottom panel of Fig. 3. The analyses described below are based on the 69% of the participants who were included in the plot-extension task and also made congruous mappings for Peter and

Mary. Unlike in the plot-extension task, participants in the mapping task mapped characters on the basis of *both* the goal-relevant and goal-irrelevant information. Participants exhibited an overall preference for mapping characters on the basis of the Professional rather than the Romantic subplot, 65% vs 35%, $\chi^2(1, N = 88) = 7.68$, $p < .01$. Despite that overall bias, as in the plot-extension task, more participants made mappings consistent with the goal-relevant relation than inconsistent with it (72% vs 28%), $\chi^2(1, N = 88) = 16.41$, $p < .001$. This preference, however, was not as pronounced as in the plot-extension task, as evidenced by the fact that 23 participants mapped on the basis of the goal-relevant relation in the plot-extension but not the mapping task, as compared to just 1 participant who exhibited the opposite pattern, $\chi^2(1, N = 24) = 20.17$, $p < .001$.

The results obtained on the mapping task differed from those obtained on the plot-extension task in that on the mapping task participants were significantly more likely to map in accordance with the goal-irrelevant information rather than opposed to it (65% vs 35%), $\chi^2(1, N = 88) = 7.68$, $p < .01$. The magnitude of this preference did not differ based on whether or not participants mapped according to the goal-relevant information, $\chi^2(1, N = 88) = 0.16$, ns. The impact of the incidental Inheritance relation on mapping was significantly greater in the mapping task than in the plot-extension task, in that 14 participants mapped in accord with the goal-irrelevant relation on the mapping task but not the plot-extension task, as compared to just 4 who exhibited the opposite pattern, $\chi^2(1, N = 18) = 5.56$, $p < .05$.

In summary, the results of Experiment 3 indicate that only the goal-relevant relation had a clear influence on mappings as revealed by character selection in the plot-extension task, whereas both goal-relevant and goal-irrelevant relations guided mappings in the mapping task. Participants' preferences in the mapping task provided clear evidence that both the goal-relevant relation and a non-goal relevant incidental relation were used jointly in the mapping process, supporting the filter-attenuation hypothesis of the multiconstraint theory. Similar results were obtained in the comparable experiment reported by Spellman and Holyoak (1993).

ACME SIMULATIONS

The results obtained in the present study provide support for a core prediction of the multiconstraint theory: that processing goals can directly guide analogical mapping. We have yet to consider possible mechanisms by which pragmatics could yield its observed effects. One general mechanism, which has been incorporated in the ACME model by Spellman and Holyoak (1993), is based on an inhibitory influence of selective attention. We will summarize some simulation results that demonstrate that such a mechanism can yield the central findings observed in our experiments.

In order to test the adequacy of the ACME model as an account of the influence of goals on mapping, we performed simulations of Experiments 1,

2, and the variant of Experiment 3 reported earlier by Spellman and Holyoak (1993). We will refer to the latter experiment as ''Experiment 3*.''[7] These simulations used the ACME model of Holyoak and Thagard (1989a) augmented (for Experiment 3*) by the ''copy with substitution and generation'' (CWSG) transfer algorithm (Holyoak, Novick & Melz, 1994; Melz & Holyoak, 1991).

ACME takes as inputs symbolic representations of the source and target analogs. The algorithm then precedes to execute three steps. First, a connectionist ''mapping network'' is constructed, in which the units represent hypotheses about possible element mappings, and the links represent specific instantiations of the general constraints. Second, an interactive-activation algorithm operates to settle the mapping network in order to identify the set of correspondences that collectively represent the ''optimal'' mapping between the analogs. If the analogs are not entirely isomorphic, some elements may enter into one-to-many or many-to-one correspondences, or simply be left unmapped. In other words, any constraint may be locally violated to establish optimal global coherence. Third, if the model is being used to generate inferences as well as correspondences, CWSG is applied to generate inferences based on the correspondences identified in the second step. In constructing these inferences, previously unmapped predicates in the source are copied over as identical predicates in the target; mapped elements in the target are substituted for their corresponding source elements; and if a source object has no map in the target, then a new target object may be postulated. ACME generates a single set of inferences based solely on the ''optimal'' correspondences after the latter have been determined by constraint satisfaction.

The filter-attenuation account of pragmatic influences was implemented by an extension of ACME that uses inhibition as a mechanism for goal-directed mapping (Spellman & Holyoak, 1993; see Hummel & Holyoak, in press, for a somewhat different approach). This extension avoids computational problems that arise when excitation is used as the sole basis for favoring goal-relevant over irrelevant information (Hummel, Burns, & Holyoak, 1994), and is consistent with empirical evidence implicating inhibition as a mechanism for selective attention in other cognitive tasks (Anderson & Spellman, 1995; Tipper, 1992).

Our simulations were based on predicate-calculus representations of the source and target analogs. Each proposition consists of a predicate followed by a list of its arguments, associated with a proposition name. For example, the fact that Anthar is located on Antares (source story in Experiment 1) was

[7] The design of the experiment of Spellman and Holyoak (1993) was structurally identical to that of the present Experiment 3. Changes were made to the names of the characters and sentences were added to bolster the weaker romantic subplot. In the current discussion, we use the character names from the present Experiment 3.

represented as (*located-on* (*Anthar Antares*) *ac4*). To model the manipulation of processing goals, the propositions in the goal-relevant subset of the target were marked as ''important.'' These propositions, as well as the objects and predicates used in them, were then spared from inhibitory activation that was directed at all other mapping units involving unimportant (i.e., goal-irrelevant) elements of the target.

The solutions that ACME finds depend on the representations provided as inputs, and these involve representational decisions that are to some extent arbitrary. However, we enforced a number of restrictions that sharply limit the ''degrees of freedom'' available to the model. First, all pragmatic manipulations for each experiment were simulated using exactly the same predicate-calculus representations, so that the model's ability to account for differences due to changes in processing goals could not be attributed to shifting representational assumptions. Only the ''importance'' of propositions was allowed to vary in modeling the influence of different goals. Second, the fact that qualitatively similar simulation results were obtained across all three experiments supports the robustness of the basic mechanisms of the model. Third, the model's numerical activation parameters were held constant across all simulations. (See Holyoak & Thagard, 1989a, for a detailed discussion of ACME and its parameters.) These values (except for starting activation, for which a lower value was selected than in previous simulations) were also identical to those used in numerous previous applications of ACME to mappings between large, complex analogs (Holyoak et al., 1994; Spellman & Holyoak, 1992). The major parameter settings were held constant as follows: excitation, .005; inhibition (structural), −.16; similarity of identical predicates, .005; decay, .005; starting activation for all units, .001. Pragmatic inhibition was implemented by a negative weight from the clamped ''pragmatic unit.'' This value was set at −.005 for all simulations of explicit mapping tasks (Experiments 1 and 2 and the mapping task of Experiment 3*), and −.04 in the simulation of the plot-extension task of Experiment 3* (reflecting the assumption that the latter task produced a greater focus on goal-relevant information than did the mapping task). The Grossberg updating rule, with maximum activation of 1 and minimum activation of −.3, was used to settle the network. All simulations were performed using a version of ACME written in *LISP running on a 16000-processor CM2 Connection Machine.

Simulation of Experiment 1

These simulations were based on predicate-calculus representations of the situations Captain Krick encountered on the planets Antares II (source) and Zenoba III (target). The representations included 61 propositions representing the source and 92 propositions representing the target. The resulting constraint network formed by ACME consisted of 3,147 mapping units interconnected by 88,418 links. Three runs were performed to simulate the impact of our pragmatic manipulations in the Trade, Membership, and Control conditions.

TABLE 7
Comparison of Mappings for Ambiguous Country (Anthar) Produced in ACME Simulation with Those Produced by Participants in Experiment 1

			Mappings			
			Anthar = Grandus		Anthar = Minutus	
Condition	# Important propositions	Cycles to settle	ACME	Ss	ACME	Ss
Trade	68	378	**.66**	**54**	**.36**	**19**
Membership	95	472	**.40**	**21**	**.65**	**58**
Control	128	371	.55	50	.54	35

Note. Figures for ACME are asymptotic activation (maximum = 1); those for Ss are percentages of participants producing mapping. Boldface percentages reflect reversal of preference for mapping Anthar to Grandus vs Minutus as a function of processing goal (Trade vs Membership).

Sixty-eight propositions in the two analogs were identified as related to Trade and 95 as related to Membership in the Federation. In the Trade and Membership runs the propositions relevant to the respective goal were marked as ''important''; thus, those propositions were spared from the pragmatic inhibition (weight of −.005) that was received by all other propositions. To simulate the Control condition, both trade-relevant and membership-relevant propositions were treated as important.

The most important empirical result, which was the focus of the simulation effort, was the reversal of the preferred mapping for the ambiguous country of Anthar (which was more similar to Grandus on the basis of trade-relevant propositions, but to Minutus on the basis of membership-relevant propositions). Table 7 presents a comparison of the asymptotic activations of the major rival mappings (Anthar = Grandus and Anthar = Minutus) with the percentages of participants in Experiment 1 who made each mapping, across the three conditions. Only ordinal relationships between ACME's activation values and the human data are theoretically significant. As Table 7 reveals, ACME succeeded in modeling the reversal of the preferred mapping for Anthar that resulted from our pragmatic manipulation.

Simulation of Experiment 2

The simulations of the results of Experiment 2 were based on representations of the situations Captain Krick encountered on the two planets he visited. These representations included 46 propositions representing the source and 49 propositions representing the target. The resulting constraint network formed by ACME consisted of 1,207 mapping units interconnected by 22,271 links. Five runs were performed to simulate the impact of our pragmatic manipulations in the Military, Economic, Millpower, Hungerall, and Control

TABLE 8
Comparison of Mappings for Ambiguous Country (Barebrute) and Unambiguous Countries (Afflu and Compak) Produced in ACME Simulation with Those Produced by Participants in Experiment 2

Condition	# Important propositions	Cycles to settle	Mappings							
			Afflu = Grainwell		Barebrute = Hungerall		Barebrute = Millpower		Compak = Mightless	
			ACME	Ss	ACME	Ss	ACME	Ss	ACME	Ss
Military	48	287	.93	97	**.31**	**29**	**.54**	**65**	.95	94
Economic	50	324	.94	91	**.53**	**43**	**.32**	**35**	.94	86
Millpower	53	330	.86	84	**.28**	**16**	**.57**	**61**	.95	94
Hungerall	53	358	.94	94	**.55**	**44**	**.29**	**38**	.88	85
Control	80	319	.94	86	.46	36	.40	43	.95	89

Note. Figures for ACME are asymptotic activations (maximum = 1); those for Ss are percentages of participants producing mapping. Boldface entries reflect reversal of preference for mapping Barebrute to Hungerall vs Millpower as a function of conditions that manipulated processing goal (Military vs Economic; Millpower vs Hungerall).

conditions. In each of the first four runs the propositions relevant to the respective goal were marked as important (i.e., propositions regarding military ties, economic ties, the country of Millpower, or the country of Hungerall, respectively), and all other propositions received pragmatic inhibition. All propositions that were important to any of the above goals were marked as important in the Control condition. The number of propositions marked as important in each run is shown in Table 8.

Table 8 presents a comparison of the asymptotic activations of the major rival mappings for the ambiguous country of (Barebrute = Hungerall and Barebrute = Millpower) with the percentages of participants in Experiment 2 who made each mapping, across the five conditions. ACME succeeded in modeling the reversal of the preferred mapping for Barebrute that resulted from our pragmatic manipulations, based upon both a shift in the goal-relevant relation (Military vs Economic) and a shift in the goal-relevant object (Millpower vs Hungerall).

As the simulation results in Table 8 indicate, ACME settled with the highest activation given to the preferred mapping for Barebrute, but also with substantial activation given to the participants' secondary mapping (e.g., in the Military condition, the asymptotic activation of Barebrute = Millpower was .54 while that for Barebrute = Hungerall was .31.) These secondary mappings were often the unique mappings provided by participants in the $1 \rightarrow 2$ condition and the secondary mappings provided by participants in the $2 \rightarrow 1$ condition (i.e., when participants mapped both Hungerall and Millpower to Barebrute but gave the two mappings unequal ratings).

Mapping results for the unambiguous countries (Afflu = Grainwell; Compak = Mightless) are also included in Table 8. In all runs, the preferred mappings for the two unambiguous countries emerged as clear winners with activations near the ceiling of 1.0.

*Simulation of Experiment 3**

The simulations performed for Experiment 3* were more elaborate than those required for Experiments 1 and 2 because of the greater complexity of the experimental design (which involved manipulating goal-irrelevant in addition to goal-relevant relations), as well as the introduction of the plot-extension task in addition to a mapping task. The simulations were based on representations of the two soap operas, with 99 propositions representing the source (SO-U) and 136 propositions representing the target (SO City). The SO-U proposition included descriptions of two different episodes (one focusing on Professional relations, one on Romantic relations) that could potentially be used to extend the plot of SO City. In the SO-U representations, we identified 32 propositions in the initial set-up that were causally related to the extension of the Professional plot, and 17 propositions that were causally related to the extension of the Romantic plot. (Note that unlike the simulations of Experiments 1 and 2, in which both source and target propositions were

TABLE 9

Mappings for Central Characters (Peter and Mary) Produced by ACME in Conditions Simulating the Plot-Extension Task (High Inhibition) and the Mapping Task (Low Inhibition) of Experiment 3

Important relation	Attentional inhibition	Cycles to settle	Mapping for Peter	Activation	Mapping for Mary	Activation
Professional	hi (−.04)	331	Nancy	.92	John	.96
	lo (−.005)	361	Nancy	.80	John	.96
Romantic	hi (−.04)	440	Lisa	.95	David	.94
	lo (−.005)	428	Lisa	.88	David	.95

Note. These mappings are produced when the women are the cheaters. If the men were the cheaters, the mappings for Peter would be to David and John while the mappings for Mary would be to Lisa and Nancy (in the Professional and Romantic conditions, respectively); the activations would be identical to those shown. Maximum activation is 1. hi simulates the plot-extension task; lo simulates the mapping task.

marked as important to simulate pragmatic manipulations, the simulations of Experiment 3* only varied the importance of source propositions.) When the Professional propositions were marked as important, the Romantic and Inheritance information was inhibited; whereas when the Romantic propositions were marked as important, the Professional and Inheritance information was inhibited.

To model the difference between the plot-extension and mapping tasks, we assumed that attentional inhibition was higher in the former task. This assumption seems justified by the fact that the requirement to generate an analogous episode based on the SO-U characters directly demanded attention to the goal-relevant subset of the source, whereas the mapping task did not call attention to any particular subset of the source. The sole difference between simulations of the plot-extension and mapping tasks was in the parameter value for attentional inhibition, which was set at either a high (−.04) or low (−.005) value, respectively.

The mapping network for the problem contained 4,037 units interconnected by 146,718 links. In an initial set of four runs (see Table 9) we varied which primary relation was important (Professional or Romantic) and whether attentional inhibition was high or low. In these runs the ''cheater'' in the Inheritance relation was female. (The symmetry of the representations ensures that identical results would be obtained if the gender assignment was reversed.) ACME is implemented as a deterministic model, and the structure of the ambiguous mapping has a ''Necker cube'' quality, such that a single consistent mapping will emerge given even a small initial pressure favoring one mapping over the others (cf. Spellman & Holyoak, 1992). Thus all four basic versions of the problem settled into the optimal consistent mapping for Peter and Mary (i.e., the mapping consistent with both the goal-relevant

relation and the Inheritance relation), with activations of .80 or above, after 331–428 cycles of updating. In modeling performance of the plot-extension task, ACME's CWSG transfer algorithm was used to generate new target propositions describing the required ''new episode.'' In each case ACME successfully generated descriptions of the analogous goal-appropriate plot extension for SO City, using characters consistent with both the goal-relevant relation and the Inheritance relation.

A key empirical result obtained in Experiment 3* and the present Experiment 3 was that the goal-relevant relation had a more pronounced impact on mapping in the plot-extension task than in the explicit mapping task, while the irrelevant Inheritance relation only influenced performance on the latter task. To assess the relative potency of goal-relevant and goal-irrelevant relations on ACME's performance, we tested the robustness of each when it was pitted against a bias toward a contrary mapping. The bias was introduced by adding a link with a small positive weight (.0001) from ACME's pragmatic unit to a non-optimal mapping unit for Peter, the only character in the source involved in all three relations. In mechanistic terms, adding the bias means that in each cycle of updating extra activation was passed to the non-optimal mapping unit; in psychological terms, the bias can be viewed as an approximation to the expected impact of adding variability to the mapping mechanism (which would sometimes favor non-optimal mappings). The greater the impact of a factor, the more it should resist the opposing pressure of the bias.

The bias we added favored a match for Peter that differed from the optimal one only in terms of the Inheritance relation. Thus, for example, when the optimal mapping was from Peter to Nancy (consistent with Professional and Inheritance relations), the bias went to the Peter = David mapping unit (consistent with Professional but not Inheritance relations). When attentional inhibition was high (−.04), simulating the plot-extension task, the bias prevailed, driving the mappings for both Peter and Mary into those contrary to the Inheritance relation. But when inhibition was low (−.005), simulating the mapping task, the Inheritance relation overcame the bias, producing the optimal correspondences for both characters. This pattern was observed both when the Professional and when the Romantic propositions were treated as important. These simulations thus reproduced an important qualitative aspect of participants' mappings: a stronger impact of the Inheritance factor in the mapping task (low inhibition) than in the plot-extension task (high inhibition).

Another set of runs was performed to assess the robustness of the preference for mappings based on the goal-relevant relation (i.e., Professional versus Romantic or vice versa). In these runs a bias was introduced favoring mapping Peter to the person who would be consistent with the alternative relation (as well as the Inheritance factor). For example, when the optimal mapping was from Peter to Nancy (because Professional relations were important), the bias went to the Peter = Lisa mapping unit (which was consistent with Romantic rather than Professional relations). The bias was increased gradually across each set of runs

to determine at what point the impact of the goal-relevant relation would be overcome by the competing bias. When the Professional propositions were treated as important and attentional inhibition was high (simulating the plot-extension task), the mapping for Peter favored by the bias did not prevail until the bias weight reached .005; moreover, no amount of bias for the Peter mapping was able to reverse the preferred mapping for Mary (the other central character). In contrast, when attentional inhibition was low (simulating the mapping task), the mapping for Peter was reversed when the bias reached .0025, and that for Mary was reversed as well when the bias reached .045. Thus the goal-relevant Professional relation was substantially more resistant to an opposing bias when attentional inhibition was high rather than low.

Comparable runs in which the Romantic propositions were treated as important produced a weaker pattern. When attentional inhibition was high, the mappings for both Peter and Mary were reversed when the bias reached .0025. When attentional inhibition was low, the same reversal occurred at a slightly lower level of bias, .002. Although the effect was thus much weaker when the Romantic rather than the Professional propositions were important, in both cases the goal-relevant relation proved more potent when attentional inhibition was high than when it was low, just as participants showed a stronger preference for mappings based on the goal-relevant relation in the plot-extension than in the mapping task. Overall, the lesser potency of the Romantic than the Professional relation in the simulations (resulting from the smaller number of propositions based on the former relation) had its counterpart in participants' strong overall preference in Experiment 3* (also observed to a lesser degree in Experiment 3) for mappings based on the Professional relation in the explicit mapping task.

In summary, the simulation results support our claim that ACME's pragmatic inhibition allows the model to act as a filter-attenuation mechanism (when inhibition is relatively low, as in the simulations of the explicit mapping task), with total filtering emerging as an extreme special case (when inhibition is high, as in the simulations of the plot-extension task).

GENERAL DISCUSSION

The present studies demonstrate the influence of processing goals on analogical mapping. Different goals can indeed yield different mappings for the same source and target analogs. The ACME model with its inhibitory mechanism for attentional control is able to simulate the major qualitative results of three experiments. These simulation results extend previous work in which the model has been used to simulate mappings between large and complex naturalistic analogies (e.g., the Persian Gulf War and World War II in Spellman & Holyoak, 1992), and mappings and transfer patterns for non-isomorphic mathematical analogs (Holyoak et al., 1994) as well as for complex letter-string analogy problems (Burns & Holyoak, 1994). In addition, interactive-activation models based on similar soft constraints have been successfully

used to model analog retrieval (Thagard, Holyoak, Nelson, & Gochfeld, 1990) and relationally complex similarity judgments (Goldstone & Medin, 1994).

Some of the present results may be accounted for by some combination of pre-mapping and post-mapping processes (thereby leaving pragmatics out of the mapping process). For example, in Experiments 1 and 2 it is possible that, as a result of the pragmatic manipulation at the time of encoding, participants might have elaborated upon the goal-relevant information. To illustrate, suppose that while reading the source analog, participants in the Trade condition in Experiment 1 generated propositions such as: *Material goods, food, and technology are best for trade. Anthar has a surplus of food; therefore, Anthar has items that are good for trade.* Similar propositions may have been generated while reading the target analogs. Such elaboration would have the effect of making the goal-relevant interpretation a better match because that interpretation would have more associated propositions to be mapped. Another alternative account of these data involves post-mapping selection. Suppose a participant generates and considers two equally strong potential mappings (e.g., Anthar to Grandus or to Minutus). The participant might then recall that one of the mappings is consistent with the earlier pragmatic manipulation, and therefore report only the consistent mapping.

On the other hand, participants in these experiments frequently did report many-to-one mappings, including (in Experiment 2) many-to-one mappings that involved both goal-relevant and goal-irrelevant relations. Our results do not resolve the issue of what psychological mechanisms underlie the reporting of homomorphic mappings. The present experiments were based on the framework of the multiconstraint theory, which assumes that homomorphic mappings may be generated (and reported) because one-to-one mapping is a soft constraint (as implemented in the ACME model of Holyoak & Thagard, 1989a). However, as we noted in the Introduction, it is also possible that one-to-one mapping is a hard constraint, but that people sometimes report homomorphic mappings based upon multiple Gmaps (a possibility consistent with the SME model of Falkenhainer et al., 1989). Further research will be required to determine how homomorphic mappings are computed and under what conditions. This issue is particularly important because it may provide a link between analogical mapping and conceptual change (Spellman & Holyoak, 1992). If people arrive at multiple mappings for a single concept, they may be led to recode their knowledge so as to establish a coherent one-to-one mapping. This could be done either by recoding the ''many as one'' (grouping the multiple correspondences into a unitary concept) or by recoding the ''one as many'' (by differentiating separate roles filled by a single concept; cf. Falkenhainer, 1990; Kedar-Cabelli, 1985).

Other present results are difficult to reconcile with an interpretation of mapping based solely on structural constraints, and instead suggest that the impact of goals cannot be attributed solely to pre-mapping processes that ''filter'' the active representations of the analogs so as to eliminate goal-

irrelevant information. As mentioned above, in Experiment 2 we observed fairly frequent many-to-one mappings that involved *both* goal-relevant and goal-irrelevant relations. In Experiment 3 we used mappings of four-ways ambiguous elements to show that processing goals can interact with goal-irrelevant information to disambiguate mappings. Because the pragmatic manipulation occurred *after* the encoding of both analogs, goal-relevant elaboration was unlikely. In the mapping task, participants' mappings for ambiguous characters in the soap operas were jointly determined by the processing goal and by the incidental Inheritance relations. It is difficult to account for the interactions observed between goal-relevant and goal-irrelevant information in determining participants' mappings except by assuming that goals can attenuate the impact of incidental information on the mapping stage, rather than solely acting by filtering such information prior to mapping. Although it is no doubt possible to develop an account of the present results (or any other pattern of mappings) in terms of some combination of pre- and post-mapping processes, the obtained pattern can be explained parsimoniously in terms of an inhibitory mechanism for control of selective attention, which influences a process of mapping by constraint satisfaction.

A further piece of converging evidence in support of our conclusion that goals act directly on the mapping process is provided by our comparison in Experiment 3 between the mappings obtained indirectly in the plot-extension task (i.e., selection of target characters in writing a plot continuation) and those obtained in the subsequent directmapping task. The resolutions of ambiguous mappings in the two tasks revealed a trade-off between the potency of the processing goal and of the incidental Inheritance relation. The influence of the processing goal was much larger in the plot-extension task than in the mapping task. Conversely, the influence of Inheritance was larger in the mapping task than in the plot-extension task. Note that this trade-off cannot be explained in purely structural terms, for example by claiming that one of the tasks is more sensitive in general to mappings based on relations (either first-order or higher-order). The greater impact of goal-relevant relations on performance in the plot-extension than in the mapping task would suggest that the former task is more sensitive to structure; but the greater impact of goal-irrelevant relations in the mapping than in the plot-extension task suggests precisely the opposite conclusion. Thus an overall shift in sensitivity to structure does not provide a unified account of performance in both tasks. In contrast, as our ACME simulations demonstrate, there is a simple account based on a general shift in goal focus, modulated by degree of pragmatic inhibition. High focus on the goal (i.e., high inhibition) leads to greater sensitivity to goal-relevant relations at the expense of goal-irrelevant relations; lesser focus on the goal (i.e., low inhibition) yields the reverse trade-off. Thus although structural constraints clearly play a central role in the mapping process, it is difficult to maintain the view that mapping is a purely structural module impenetrable by pragmatic influences.

The human capacity to perform soft constraint satisfaction, along with the ability to inhibit competing but irrelevant information, appears to provide a mechanism that allows a thinker's goals to guide the creation of relevant inferences without totally excluding the influence of other potentially useful information. Our evidence suggests that analogical mapping is one form of reasoning (but by no means the only one) in which people use soft constraint satisfaction to modulate the impact of their processing goals.

REFERENCES

Anderson, M. C., & Spellman, B. A. (1995). On the status of inhibitory mechanisms in cognition: Memory retrieval as a model case. *Psychological Review,* **102,** 68–100.

Anderson, J. R., & Thompson, R. (1989). Use of analogy in a production system architecture. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 267–297). London: Cambridge Univ. Press.

Broadbent, D. E. (1958). *Perception and communication.* London: Pergamon Press.

Brown, A. L., & Kane, M. J. (1988). Preschool children can learn to transfer: Learning to learn and learning from example. *Cognitive Psychology,* **20,** 493–523.

Brown, A. L., Kane, M. J., & Echols, K. (1986). Young children's mental models determine transfer across problems with a common goal structure. *Cognitive Development,* **1,** 103–122.

Burns, B. D., & Holyoak, K. J. (1994). Competing models of analogy: ACME versus Copycat. In A. Ram & K. Eiselt (Eds.), *Proceedings of the Sixteenth Annual Conference of the Cognitive Science Society* (pp. 100–105). Hillsdale, NJ: Erlbaum.

Burstein, M. H. (1986). A model of learning by incremental analogical reasoning and debugging. In R. Michalski, J. G. Carbonell, & T. M. Mitchell (Eds.), *Machine learning: An artificial intelligence approach* (Vol. 2, pp. 351–370). Los Altos, CA: Morgan Kaufmann.

Carbonell, J. G. (1983). Learning by analogy: Formulating and generalizing plans from past experience. In R. Michalski, J. G. Carbonell, & T. M. Mitchell (Eds.), *Machine learning: An artificial intelligence approach* (Vol. 1, pp. 137–161). Los Altos, CA: Morgan Kaufmann.

Carbonell, J. G. (1986). Derivational analogy: A theory of reconstructive problem solving and expertise acquisition. In R. Michalski, J. G. Carbonell, & T. M. Mitchell (Eds.), *Machine learning: An artificial intelligence approach* (Vol. 2, pp. 371–392). Los Altos, CA: Morgan Kaufmann.

Catrambone, R., & Holyoak, K. J. (1989). Overcoming contextual limitations on problem solving transfer. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **15,** 1147–1156.

Falkenhainer, B. (1990). Analogical interpretation in context. *Proceedings of the Twelfth Annual Conference of the Cognitive Science Society.* (pp. 69–76). Hillsdale, NJ: Erlbaum.

Falkenhainer, B., Forbus, K. D., & Gentner, D. (1989). The structure-mapping engine: Algorithm and examples. *Artificial Intelligence,* **41,** 1–63.

Faries, J. M., & Reiser, B. R. (1988). Access and use of previous solutions in a problem solving situation. *Proceedings of the Tenth Annual Conference of the Cognitive Science Society* (pp. 433–439). Hillsdale, NJ: Erlbaum.

Forbus, K. D., & Oblinger, D. (1990). Making SME greedy and pragmatic. *Proceedings of the Twelfth Annual Conference of the Cognitive Science Society* (pp. 61–68). Hillsdale, NJ: Erlbaum.

Gentner, D. (1983). Structure-mapping: A theoretical framework. *Cognitive Science,* **7,** 155–170.

Gentner, D. (1989). The mechanisms of analogical reasoning. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 199–241). London: Cambridge Univ. Press.

Gentner, D., & Gentner, D. R. (1983). Flowing water or teaming crowds: Mental models of

electricity. In D. Gentner & A. L. Stevens (Eds.), *Mental models* (pp. 99–129). Hillsdale, NJ: Erlbaum.

Gentner, D., & Toupin, C. (1986). Systematicity and surface similarity in the development of analogy. *Cognitive Science,* **10,** 277–300.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology,* **12,** 306–355.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology,* **15,** 1–38.

Goldstone, R. L., & Medin, D. L. (1994). Similarity, interactive activation, and mapping: An overview. In K. J. Holyoak & J. A. Barnden (Eds.), *Advances in connectionist and neural computation theory, Vol. 2: Analogical connections* (pp. 321–362). Norwood, NJ: Ablex.

Hall, R. (1989). Computational approaches to analogical reasoning: A comparative analysis. *Artificial Intelligence,* **39,** 39–120.

Hofstadter, D. R., & Mitchell, M. (1988). Conceptual slippage and mapping: A report on the Copycat project. *Proceedings of the Tenth Annual Conference of the Cognitive Science Society* (pp. 601–607). Hillsdale, NJ: Erlbaum.

Hofstadter, D. R., & Mitchell, M. (1994). An overview of the Copycat project. In K. J. Holyoak & J. A. Barnden (Eds.), *Advances in connectionist and neural computation theory, Vol. 2: Analogical connections* (pp. 31–111). Norwood, NJ: Ablex.

Holland, J., Holyoak, K. J., Nisbett, R., & Thagard, P. (1986). *Induction: Processes of inference, learning, and discovery.* Cambridge, MA: MIT Press.

Holyoak, K. J. (1984). Analogical thinking and human intelligence. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 2, pp. 199–230). Hillsdale, NJ: Erlbaum.

Holyoak, K. J. (1985). The pragmatics of analogical transfer. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 19, pp. 59–87). New York: Academic Press.

Holyoak, K. J., & Koh, K. (1987). Surface and structural similarity in analogical transfer. *Memory & Cognition,* **15,** 332–340.

Holyoak, K. J., Novick, L. R., & Melz, E. R. (1994). Component processes in analogical transfer: Mapping, pattern completion, and adaptation. In K. J. Holyoak & J. A. Barnden (Eds.), *Advances in connectionist and neural computation theory, Vol. 2: Analogical connections* (pp. 113–180). Norwood, NJ: Ablex.

Holyoak, K. J., & Thagard, P. (1989a). Analogical mapping by constraint satisfaction. *Cognitive Science,* **13,** 295–355.

Holyoak, K. J., & Thagard, P. (1989b). A computational model of analogical problem solving. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 242–266). London: Cambridge Univ. Press.

Holyoak, K. J., & Thagard, P. (1995). *Mental leaps: Analogy in creative thought.* Cambridge, MA: MIT Press.

Hummel, J. E., Burns, B., & Holyoak, K. J. (1994). Analogical mapping by dynamic binding: Preliminary investigations. In K. J. Holyoak & J. A. Barnden (Eds.), *Advances in connectionist and neural computation theory, Vol. 2: Analogical connections* (pp. 416–445). Norwood, NJ: Ablex.

Hummel, J. E., & Holyoak, K. J. (in press). Distributed representations of structure: A theory of analogical access and mapping. *Psychological Review.*

Kasof, J. (1993). Sex bias in the naming of stimulus persons. *Psychological Bulletin,* **113,** 140–163.

Keane, M. T. (1988). *Analogical problem solving.* Chichester, UK: Ellis Horwood.

Keane, M. T., Ledgeway, T., & Duff, S. (1994). Constraints on analogical mapping: A comparison of three models. *Cognitive Science,* **18,** 387–438.

Kedar-Cabelli, S. (1985). Purpose-directed analogy. *Proceedings of the Seventh Annual Conference of the Cognitive Science Society* (pp. 150–159). Hillsdale, NJ: Erlbaum.

Markman, A. B., & Gentner, D. (1993). Structural alignment during similarity comparisons. *Cognitive Psychology,* **25,** 431–467.

Melz, E. R., & Holyoak, K. J. (1991). Analogical transfer by constraint satisfaction. *Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society* (pp. 822–826). Hillsdale, NJ: Erlbaum.

Novick, L. R., & Holyoak, K. J. (1991). Mathematical problem solving by analogy. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **17,** 398–415.

Palmer, S. E. (1978). Fundamental aspects of cognitive representation. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization* (pp. 259–302). Hillsdale, NJ: Erlbaum.

Reed, S. K. (1987). A structure-mapping model for word problems. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **13,** 124–139.

Ross, B. H. (1987). This is like that: The use of earlier problems and the separation of similarity effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **13,** 629–639.

Ross, B. H. (1989). Distinguishing types of superficial similarities: Different effects on the access and use of earlier problems. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **15,** 456–468.

Seifert, C. M. (1994). The role of goals in retrieving analogical cases. In K. J. Holyoak & J. A. Barnden (Eds.), *Advances in connectionist and neural computation theory, Vol. 2: Analogical connections* (pp. 95–125). Norwood, NJ: Ablex.

Seifert, C. M., McKoon, G., Abelson, R. P., & Ratcliff, R. (1986). Memory connections between thematically similar episodes. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* **12,** 220–231.

Spellman, B. A., & Holyoak, K. J. (1992). If Saddam is Hitler then who is George Bush?: Analogical mapping between systems of social roles. *Journal of Personality and Social Psychology,* **62,** 913–933.

Spellman, B. A., & Holyoak, K. J. (1993). An inhibitory mechanism for goal-directed analogical mapping. *Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society* (pp. 947–952). Hillsdale, NJ: Erlbaum.

Tarski, A. (1954). Contributions to the theory of models. *Indigationes Mathematicae,* **16,** 572–588.

Thagard, P., Holyoak, K., Nelson, G., & Gochfeld, D. (1990). Analog retrieval by constraint satisfaction. *Artificial Intelligence,* **46,** 259–310.

Tipper, S. P. (1992). Selection for action: The role of inhibitory mechanisms. *Current Directions in Psychological Science,* **1,** 105–109.

Treisman, A. (1964). Monitoring and storage of irrelevant messages in selective attention. *Journal of Verbal Learning and Verbal Behavior,* **3,** 449–459.

Winston, P. (1980). Learning and reasoning by analogy. *Communications of the ACM,* **23,** 689–703.

Zook, K. B., & Di Vesta, F. J. (1991). Instructional analogies and conceptual misrepresentations. *Journal of Educational Psychology,* **83,** 246–252.

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