

ANALOGICAL THINKING

THE ROLE OF EXTRA-CONTEXTUAL AND CONTEXTUAL SIMILARITIES  
IN ANALOGICAL MAPPING

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Resumen

Se llevó a cabo un experimento para determinar la validez psicológica del tratamiento que recibe el componente semántico en el establecimiento de correspondencias analógico por parte de la Teoría de Proyección de la Estructura de Gentner (1983, 1989; Gentner & Markman, 1997) y la Teoría de las Múltiples Restricciones de Holyoak y Thagard (1989a, 1995). Los participantes del grupo experimental recibieron un texto fuente en el que se narra que un hecho (causa) había provocado un segundo hecho (efecto). Siendo enfrentados después a un texto objetivo en el que se describía un hecho objetivo (similar al hecho efecto fuente) de causa desconocida, se les pidió que, basándose en la narración fuente, hipotetizaran cuál, entre dos hechos candidatos a causa, podía haber provocado el hecho objetivo. La *analogía* era ambigua si se seguían criterios semánticos y no podía *desambiguarse* a partir de criterios sintácticos o pragmáticos. Los participantes de este grupo decidieron sus correspondencias siguiendo similitudes semánticas contextuales y no en cambio el tipo de similitudes

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semánticas extra-contextuales incorporadas por las teorías nombradas en sus modelos computacionales. Los participantes del grupo control debían realizar la misma tarea que el grupo experimental (hipotetizar cuál podía haber sido la causa del hecho objetivo), pero no recibían ningún análogo previo. Estos participantes eligieron como causa el hecho alternativo al elegido por el grupo experimental, lo que indicó que la elección de este grupo no estuvo determinada por la plausibilidad intrínseca, en el dominio objetivo, del hecho elegido. Los resultados son discutidos considerando la crítica de Hofstadter y el Grupo FARG (1995) a la forma en que la *semántica* es tratada por el modelo estándar del establecimiento de correspondencias analógico.

*Palabras clave:* Analogía - similitud - semántica.

### Abstract

The psychological validity of the treatment given to *semantic similarity* constraints in analogical mapping by the Structure-Mapping Theory of Gentner (Gentner, 1983, 1989; Gentner, & Markman, 1997), and the Multiconstraint Theory of Holyoak, and Thagard (1989a, 1995) was assessed in an experiment. Participants were asked to interpret an *analogy* in which, for some source elements, syntactic, and pragmatic criteria permitted alternative mappings, which were ambiguous when semantic principles were taken into account. Data showed that people base mappings on contextual semantic similarities, rather than on extra-contextual semantic similarities like the ones incorporated by these theories in their computational models. The results are discussed in light of the criticism formulated by Hofstadter, and the FARG Group (1995) of the way semantics is treated by the dominant style of modeling analogical mapping.

*Key words:* Analogy - similarity - semantic.

There has been broad agreement that it is useful to distinguish at least six major subprocesses in analogical thinking:

- a.- Forming mental representations of the well-understood analogue (source analogue: SA) and the less well-understood analogue (target analogue: TA).
- b.- Retrieving the SA given the representation of the TA.
- c.- Finding a mapping between source and target elements.
- d.- Deriving inferences for the TA.
- e.- Evaluating and adapting these inferences.
- f.- Inducing a schema from the comparison of the two analogues (e.g., Gentner, 1983, 1989; Holyoak, Novick, & Melz, 1994; Keane, Ledgeway, & Duff, 1994).

The Structure-Mapping Theory (SMT) (Gentner, 1983, 1989; Gentner, & Markman, 1997), and the Multiconstraint Theory (MCT) (Holyoak, 1984a, 1984b, 1985; Holyoak, & Hummel, 2001; Holyoak, & Thagard, 1989a, 1989b, 1995, 1997; Hummel, & Holyoak, 1997) have dominated the discussion about mapping (the core sub-process of analogical thinking), and inference generation since the 80s. The SMT supposedly represents a syntactic point of view of mapping (cf., Abrantes, 1999; Gentner, 1989), which postulates that humans perform this sub process following purely formal rules. The MCT allegedly represents instead a pragmatic and semantic perspective to this step, which considers that mapping involves an interplay between syntactic, semantic, and pragmatic restrictions. Our concern in this paper is limited to the influence of semantic components on mapping, and we will concentrate on the treatment given to semantics in SME (Falkenhainer, Forbus, & Gentner, 1989), and ACME-CWSG (Holyoak, & Thagard, 1989a; Holyoak et al., 1994), the computational programs most extensively developed and tested by the SMT, and the MCT, respectively.

## The Structure-Mapping Theory and SME

The SMT assumes that human knowledge is represented in the form of propositions that include:

- a.- *Entities*: single elements that stand for objects, such as *ball*.
- b.- *Attributes*: unary predicates representing properties of objects, such as RED (ball).

- c.- *Functions*: unary predicates used to state dimensional properties, such as SIZE (ball).
- d.- First-order relations: multiples predicates that link two or more objects, such as KICK (paul, ball).
- e.- Second (or higher order) relations: predicates that link relations themselves, such as CAUSE (KICK [paul, ball], BREAK [paul, glass]).

According to the SMT, *analogy* is a device for conveying that two situations share relational structure (systems of relations governed by higher order relations) despite the existing differences in the objects and attributes that make up the situations. In literal similarity, one expects to find instead both a common relational structure and common object properties (Gentner, 1983, 1989; Gentner, & Markman, 1997).

SME is a symbolic system, which operates with inviolable rules and takes as inputs prepositional descriptions of the SA and the TA. The aim of program is to find the maximal (i.e., largest and deepest) coherent relational match between the two analogues, leaving out isolated relations and not taking into account object attributes. It applies the following initial conditions to stipulate which kinds of matching are allowed and which are not:

- 1.- Formal identity: correspondence hypotheses between elements are limited to those that are of the same formal type: objects to objects,  $n$ -place relations to  $n$ -place relations, first-order relations to first-order relations, etc.
- 2.- Semantic identity for relations: relations can be mapped only if they are identical in meaning.
- 3.- Identity of roles for objects and functions: argument correspondence hypotheses between objects and functions are generated only if they belong to already matched identical relations, and according to their roles (e.g., agent, patient, medium, object, etc.).

Once all local matches have been generated, the program incrementally coalesces them into a few maximal structurally consistent global mappings, which represent the possible interpretations of the analogy. A structurally consistent mapping is one that satisfies the following constraints: (1) parallel connectivity: if a pair of source, and target elements are placed in correspondence, then the arguments of those elements must also be placed in correspondence, and (2) one-to-one mapping: each element in one representation match to at most one element in the other representation. As a further step,

SME uses the established mappings to suggest predictions about the TA. If there is a relation (or object) that belongs to the source relational system being projected, but is not found in the target system, it becomes a candidate relation (or object) in the TA. Finally, each interpretation is given a syntactic evaluation, which is based on the number of local matches and on the depth of the system of matches (the systematic principle; Falkenhainer et al., 1989).

## The Multiconstraint Theory and ACME-CWSG

ACME-CWSG is a hybrid system, which combines prepositional representations (very similar to SME's) with connectionist-style processing. Its initial conditions are inviolable but its constraints are flexible. The MCT frames the problem of analogical mapping in terms of parallel satisfaction of multiple soft constraints that jointly determine the optimal correspondences between the elements of the SA, and the TA. The program constructs a network in which nodes stand for mapping hypothesis, and weighted links between the nodes represent constraints between these hypotheses.

One difference between SME and ACME is that this program does not require semantic identity of relations to pair them, thus allowing the mapping of non-identical (and even non-similar) relations. As in SME, however, elements can only be paired if they are formally identical and, in the case of objects, if they play the same roles.

ACME's syntactical constraints are very similar to SME's. To enforce structural consistency, symmetric excitatory links are created between mapping hypotheses that satisfy the constraint of parallel connectivity, and symmetric inhibitory links are generated between mapping hypotheses that violates the *one-to-one* constraint.

Another difference between SME and ACME is that this system incorporates the intervention of semantic constraints during mapping, which supports possible correspondences between elements with reassessed semantic similarities. The program implements the constraint of semantic similarity by connecting any mapping unit relating two similar predicates (describing relations, objects, or object properties) to a special semantic unit. The MCT does not share the SMT's sharp distinction between analogy and literal similarity (see, e.g., Holyoak, & Thagard, 1989b), and that is why ACME, in contrast to SME (this program attends only to semantic similarities –identities– between relations), considers similarities between objects and object properties during analogical mapping. ACME also has a pragmatic unit, which favours mapping hypotheses that fit the goals of the analogist.

Once the connectionist-mapping network containing the units and the links has been constructed, 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 analogues. Albeit implicitly, ACME implements an evaluation principle very similar to SME's systematic one, favouring bigger and deeper mappings over smaller and shallower ones. For generating inferences, ACME is augmented by CWSG (Holyoak et al., 1994). Previously unmapped relations (or objects) are carried over as hypothetical relations (or objects) in the TA.

### A drawback shared by the SMT and the MCT in their treatment of semantic similarity in analogical mapping

Contrary to what has been postulated by some authors (e.g., Abrantes, 1999; Gentner, 1989), Johnson-Laird (1986), and Keane (1988) have argued that SME is not a purely syntactic program, since it includes a clearly semantic mapping rule: source and target relations can be matched only if they are identical in meaning. Minervino, and Adrover (2000) have further proposed that both programs treat the influence of semantics on analogical mapping in a similar way: the sub-process is conceived as affected solely by similarities established before and independently of the mapping process. In the present study, we will refer to this kind of similarities as extra-contextual similarities: ES. For example, people may judge that *boiling potatoes* and *roasting meat* are similar ideas, since *boiling* and *roasting* are two cases of *cooking*, and *potatoes* and *meat* two instances of *foods*. According to the MCT, if one of these expressions appears in the SA and the other in the TA, the analogist would favour matching them, considering the general previously known similarity maintained by their elements. For the SMT, the mapping between these expressions would require the relations they include (BOIL and ROAST) to appear initially represented as identical predicates (e.g., as COOK; this is simply the extreme point of ES similarity); also in contrast to ACME, SME would ignore object similarities. The approach to semantics in analogical mapping that considers only ES will be named in this article as the standard approach. As can be appreciated, ES are thought to be maintained by single elements of propositions (symbols representing relations, objects, object properties, etc.), without taking into account the more complex structures (propositions, analogues, etc.) the elements being compared belong to.

We will differentiate ES from contextual similarities (CS), that is, from similarities that correspond to a specific context of an analogical comparison but cannot be thought of as general similarities. For example, 'Peter took the car keys to open the suitcase's padlock' and 'Peter forgot the metro line's name to go to Hyde Park' could be considered, as we will exemplify, as two forms of 'being absent-minded' in the context of a specific comparison, but not two extra-contextually similar expressions in the standard approach's sense, since their elements (take and forget, car keys and metro line's name, open and go, and suitcase's padlock, and Hyde Park) are not similar things out of the context of that specific comparison.

The standard approach to the impact of semantics on analogical mapping has been judged insufficient by several authors (e.g., Falkenhainer, 1990; French, 1995; Hofstadter, & the FARG Group, 1995; Minervino, & Adrover, 2000; Mitchell, 1993). Not all the semantic similarities that people need to consider in order to make analogical correspondences have been established prior to the mapping stage (ES); very frequently, some similarities have to be discovered and conceptualized in the context of the comparison at hand (CS).

Suppose, for example, that a particular SA includes the above-mentioned information that 'Peter took the car keys to open the suitcase's padlock', and the information that 'Mary got worried about Peter's state'. Suppose now that the TA includes the information that, at a later time, 'Mary got worried again about Peter's state'. If you have two candidate events as possible causes to explain Mary's second worry: (1) 'Peter took the house keys to open the bottle of beer', and (2) 'Peter forgot the metro line's name to go to the Hyde Park', which would you postulate as the possible cause of Mary's second worry about Peter's state? Despite the existing ES between 'Peter *took* the car *keys* to *open* the suitcase's padlock' and 'Peter *took* the house *keys* to *open* the bottle of beer' (two cases of *taking keys to open something*), you will probably choose mapping 'Peter took the car keys to open the suitcase's padlock' to 'Peter forgot the metro line's name to go to Hyde Park', conceiving that they are two cases of, say, 'being absent-minded' and, therefore, two indicators, perhaps, of Peter's stress, the thing that worries Mary (we are supposing you have considered that taking the house keys to open the bottle of beer is not a slip but an intentional and effective action). You will probably decide that, at least in this context of comparison, this CS is what matters, and not the apparent ES you may have also noticed.

Due to its rule of identicality in meaning as a condition for mapping relations, SME could not pair the relation predicates TAKE and FORGET

and OPEN and GO; consequently, it would match ‘Peter took the car keys to open the suitcase’s padlock’ to ‘Peter took the house keys to open the bottle of beer’ (as we said, the program does not consider object similarities). ACME would also choose this mapping, considering the existing identities between relations (TAKE and TAKE, and OPEN and OPEN), and also the presence of similarities between objects (car keys and house keys). The problem we want to illustrate with this example is that ES could be sometimes not sufficient to generate the correspondences needed in analogical mapping, and can even be misleading if superficial pairings that compete with more abstract and adequate ones are favoured (Gentner, & Toupin, 1986; Minervino, & Adrover, 2000; Ross, 1987, 1989).

To sum up, SME can disambiguate mappings considering either ES between relations (identities vs. no identities; as it would do in the given example), formal characteristics of the to-be-paired information (formal identity vs. no formal identity; this rule can not help in the given example), or formal positions of the elements to be matched (the matching between some information could satisfy structural consistency, but the matching of some other may not; this rule can not help in the given example). ACME can disambiguate mappings following these same formal criteria, taking into account variable degrees of similarity between all kinds of elements (as it would do in the given example), or considering pragmatic factors (in the given example, pragmatic factors would not help since the purpose of the system is to identify the cause of the target event, and either of the two cause-candidate events could satisfy this role). Thus, in a situation like the one presented in this example, in which the alternative mapping can not be disambiguated on syntactic or pragmatic grounds, the programs would have no option but to follow ES, and this type of semantic similarities, in the given example and in many other cases, may result insufficient, since mapping seems to be guided sometimes by the discovery and conceptualization of CS.

## **Method**

### **Experiment**

In this experiment we wanted to demonstrate that people confronted with a semantic ambiguous analogical mapping task, not decidable on syntactic and pragmatic grounds, sometimes follow CS, resisting the pressure of competing ES. As we said, under these conditions, both SME and ACME would follow ES instead, the only ones these programs are able to consider. Suppose SME receives the following analogical tasks:

Source analogue: In 1998, MIND, and LIFE, two groups of psychologists working on human eating disorders, applied for a grant offered by the IDEAS Foundation to support research in psychology. There was only one grant available. Considering that MIND, but not LIFE, *would organize meetings to discuss the philosophical origins of their therapy techniques*, the foundation gave the grant to MIND.

Target analogue: In 1999, PSYCHE and HEALTH, two groups of psychologists working on human phobic disorders, applied for a grant offered by the IDEAS Foundation to support research in psychology. There was only one grant available. Considering that (a) PSYCHE, but not HEALTH, *would organize meetings to discuss the practical applications of their therapy techniques*, and (b) HEALTH, but not PSYCHE, *would consult bibliography to investigate the historical antecedents of their therapy techniques*, the foundation gave the grant to one of the groups. If we suppose that the foundation acted this time in a way similar to last year, to which group do you think the foundation gave the grant?

Source and target texts are exactly the same except for the fact that the target text describes two proposals (Psyche's, and Health's) instead of the only one described in the source text (Mind's; see Figure 1). In general terms, ACME and SME would have no problem determining the best mapping between the analogues, guided by their syntactic and semantic principles. The only mapping problem for them would be deciding if the first or the second target proposal (TP1 or TP2) should be mapped to the source proposal (SP) and, therefore, if the first or the second group should be mapped to the source one, that is, if Psyche or Health received the grant.

The TP1, and the TP2 are formally identical to the SP, so neither SME nor ACME could disambiguate the mapping considering formal aspects of the proposals, since they are both completely acceptable in syntactic terms. Due to its inviolable condition of semantic identity for relations, SME would map the TP1 to the SP (*organize* ↔ *organize*, and *discuss* ↔ *discuss*). The alternative mapping hypotheses, the TP2 to the SP, is forbidden for SME (*organize* ↔ *consult*, and *discuss* ↔ *investigate*). For ACME, it is not possible to disambiguate the mapping taking into account pragmatic factors, since the system is trying to identify the cause of the target event, and the TP1, and the TP2 could indistinctly play that role. Therefore, ACME would also disambiguate the mapping under the influence of the ES maintained by

source and target elements (remember that ACME considers similarities not only between relations but also between objects and object properties). To imagine how ACME would proceed, we have to do some specifications and make some decisions.

ARCS (Thagard, Holyoak, Nelson, & Gochfeld, 1990) is the program with which the MCT simulates the retrieval sub-process of analogical thinking. The system incorporates a semantic database, which draws its organization from an automated thesaurus, WorldNet (Miller, Fellbaum, Kegl, & Miller, 1988). The similarity of any two concepts can be computed in ARCS as a function of their overlap in the semantic database. Two predicates are semantically similar if they are identical, or if they participate in lexical relations such as synonymy, hyponymy (predicates representing things of the same kind; e.g., *dog* is similar to *cat* since they are two instances of *pet*), entailment (e.g., *planning* entails *thinking*), etc. ACME is not equipped with semantic knowledge like ARCS is. In the case of ACME, the information about ES is intuitively estimated by the programmer, and then provided by him or her to the system. However, when giving information to ACME about degrees of semantic similarities, the MCT's programmers tend to follow criteria of ES similar to the ones incorporated in ARCS (cf., Holyoak, & Thagard, 1995).

Table 1 shows intuitively estimated ES, on a scale ranging from 1 (the lesser similarity) to 5 (identity), for the alternative element pairings that include the mappings between the SP and the TP1 (ES pairings; in italic letters), and the mapping between the SP and the TP2 (CS pairings; in normal letters). For these estimations, we followed an adapted and simplified version of the criteria employed by ARCS to compute similarity between predicates (cf., Thagard et al., 1990). We adjusted them considering, on the one hand, the criteria used by the MCT when deciding about degrees of similarity to be considered by ACME: the theory tends to consider kind relations for nouns (e.g., *president* is similar to *fuehrer*), synonym or entailment relations for verbs (e.g., *occupy* is similar to *invade*), and synonym relations for adjectives (e.g., *wet* is similar to *soggy*). On the other hand, we tried to ensure that the chosen criteria make sense for the specific pairs of elements included in the analogy employed in this study (e.g., it may make less sense to evaluate if *organize* and *consult* are synonyms than to evaluate if *organize* entails *consult* in some degree). We assigned 5 points to all pairings of identical elements; we assigned points according to a 5-point scale to synonyms (we applied synonym criterion to adjectives), to elements that are instances of the same category or maintain a member-class relationship (we applied this criterion to nouns), and, finally, to elements that maintain

entailment relations (we applied this criterion to verbs). Based on the ES intuitively hypothesized in Table 1, ACME would map, as SME, the SP to the TP1 and not to the TP2.

Our experiment was developed to demonstrate that, in an analogical mapping task like the one presented above, most people prefer to follow CS rather than ES, disregarding the condition of semantic identity for relations proposed by the SMT, and the softer similarity constraints (applied to relations, objects, and object properties) proposed by the MCT.

The basic structure of the experiment was as follows. All participants received an extended version of the target text presented above. Prior to this target story, participants in the analogy group had to read an extended version of the source text shown above. Source and target stories were identical in formal terms, and nearly identical in semantic ones (only a few objects were substituted for very similar ones), except for the information that gave rise to the ambiguous mapping: the source proposal could be matched with either of two target proposals under syntactic and pragmatic considerations. One of the target proposals maintained more ES with the SP when compared with the other. They were both formally identical to the SP. Participants were asked to guess to which group the grant had been given this year ‘under the supposition that the Foundation acted this time in a way similar to last year’ (the term *similar* is what is was open to interpretation). In a mapping task like this, both SME and ACME would prefer to map the proposals that maintain more ES. We predicted that participants in this group would prefer instead the mapping that involved less ES, but implied, as we believed, CS (we hypothesized that the SP, and the TP2 could be seen by participants as two cases of groups that, say, ‘would *address*, in *systematic ways*, the question of the *roots* of their therapy techniques’).

Participants in a control group first had to read an easy logical task and its solution. Being informed that the second task had no relation at all to the first one, they then received the same target story received by the analogy group, and were asked to guess ‘on their own criteria’, to which group, the grant had been given. If target-only participants showed no bias toward one proposal or, as we in fact expected, showed a bias toward the proposal favoured by ES in the analogy group (TP1), then preferences among experimental participants for the other proposal (TP2) could be attributed to the influence of the SA, and not to some intrinsic plausibility of the chosen target proposal in the target domain.

To have independent measures of the degree of ES perceived by people between the elements to be matched, we asked a third group to rate the similarity between the source elements composing the SP and the target ele-

ments that could be alternatively mapped to them, corresponding to the TP1 or the TP2.

## Participants

Ninety voluntary third-year undergraduate students of psychology of Universidad del Salvador (Buenos Aires - Argentina) participated in the study. Thirty were randomly assigned to the analogy condition, thirty to the target-only condition, and thirty to the similarity-rating group.

## Design and procedure

The independent variables were: (1) ES between source and target proposal (SP-TP1: high; SP-TP2: low), a within-subjects variable, and (2) condition (analogy vs. target-only), a between-groups variable. The dependent variable was chosen target proposal (TP1 or TP2). Participants were tested in small groups of 3-6 students. There was no time limit for any task.

**Analogy group:** Participants in the analogy group read the source text, and then performed a written task designed to evaluate their comprehension of it. They were allowed to look back at the text to complete the comprehension task. They then read the second text, and completed its corresponding comprehension evaluation. After this evaluation, participants were asked: (1) to hypothesize which group won the new grant, under the supposition that the foundation had acted this second time in a way similar to last year, (2) to justify their answers, and (3) to tell in what way they found the chosen target proposal similar to the source one. They were allowed to look back at both texts to answer these questions.

**Target-only group:** Control participants were told that they would be presented two totally unrelated tasks. They read an easy logical task and its solution; afterwards, they received the target text. Next, they performed the corresponding written comprehension evaluation task. In this group, participants were asked to guess, using their own criteria, which group won the grant, and to justify their choice. They were allowed to look back at the text to answer these questions. The comprehension evaluation tasks were included to eliminate data from experimental or control participants who showed they hadn't understood the source or the target story.

Similarity-rating group: Similarity-rating participants were asked to rate pairs of elements on a 5-point scale for similarity. In the task for nouns, they were asked to evaluate to what extent they considered each pair of elements (e.g., *meeting* and *bibliography*) as two instances of some same concept. In order to consider all possible similarity kind of relations, they were afterwards asked to evaluate to what extent they considered the first element (e.g., *meeting*) an instance of the second one (in this case, *bibliography*); next, they were asked the same question with the order of elements changed. We selected the higher rate of similarity given by each participant. In the case of adjectives, participants were asked to evaluate to what extent the pair of elements presented (e.g., *philosophical* and *historical*) could be considered as synonymous. Finally, in the case of verbs, participants were asked to evaluate to what extent the first element of the presented pair (e.g., *organize*) described an activity that could be considered as part of the activity described by the second element (in this case, *consult*); after that, they were asked the same question with the order of elements changed. We chose the highest similarity rating from these two evaluations. The three tasks were explained orally and in writing, and participants received four orally presented solved examples per task (no element of these example pairs was part of the texts composing the analogy). The second and third tasks were explained and presented only when participants had finished the previous ones. Each task included four easy pairs (composed of elements not included in the analogy; e.g., in the task for nouns we included the pairs *car-laundry* and *car-apple*); we included these items in order to find out if participants had understood the task. Data from participants who clearly showed they hadn't understood any of the three tasks would be eliminated.

## Materials

The source and target texts were presented on individual sheets (the complete versions of the stories can be seen in Appendix A). Group names and order of presentation of the target proposals were counterbalanced. Comprehension tasks were presented on separate sheets and consisted in completing the first part of the most important sentences of the texts. In the target evaluations, the questions asking which group had won the grant and why appeared at the end of these sentences (the analogy group participants were also asked in what sense they found the chosen target proposal similar to the source one; see Appendix A). The material for the simi-

larity-rating group consisted of three separate sheets: one each for the noun, adjective and verb tasks. The pairs of elements to be evaluated that did not correspond to the analogy were always presented first. The order of presentation of the remaining pairs (the critical ones) was counterbalanced. The order of presentation of the three tasks was also counterbalanced.

## Results and Discussion

The authors of this study independently evaluated the comprehension tasks performed by participants. They considered that a text had been understood if all sentences were correctly completed. In no case was there a discrepancy between the two evaluators, and the comprehension tasks revealed that all participants understood the source (analogy participants) and target texts (analogy and target-only participants). No analogy and target-only participant was therefore discarded from data analysis.

Participants were considered to have understood the similarity-rating task if they answered, in a sensible form, the four easy first pairs included in each of the three tasks (the tasks for nouns, the task for verbs, and the task for adjectives). The two authors of this study independently determined if the different similarity-rating tasks were understood by participants. In no case there was a discrepancy between the two evaluators, and the answers given to the four first pairs revealed that all participants understood the three tasks. No similarity-rating participant was therefore discarded from data analysis. Some similarity-rating participants asked if there was some mistake in the task when they faced the pairs of identical elements (e.g., *discuss* and *discuss*). The experimenter answered that there was no mistake, and that they had to evaluate using the scale given to what extent the two identical elements were similar. However, a few participants gave 4-points to some of these pairs, instead of 5, as we expected. Apparently, this aspect of the task struck some participants as strange. Table 2 shows the mean ratings given by similarity-rating participants for all the alternative pairings of elements that entailed the mapping between the SP, and the TP1, and the mapping between the SP and the TP2, and the *t* statistics computed to compare the means of the ratings of the alternative matching. As can be seen, origin (SP) was evaluated as more similar to antecedent (TP2; CS pairing) than to application (TP1; ES pairing), and philosophical was evaluated as more similar to historical (TP2; CS pairing) than to practical (TP1; ES pairing). The elements of the three identical pairs (SP-TP1; ES pairings) were

evaluated, instead, as more similar than the elements of their competing pairings (SP-TP2; CS pairings). When we compare the total points obtained by the ES pairings with the total points obtained by the CS pairings, the data showed that the first ones surpass the second by 4.5 points. If the overall mean of the ES pairings, 3.74 ( $SD = 1.59$ ), is compared with the overall mean of the CS pairings, 2.84 ( $SD = 1.27$ ), it can be concluded that the proposals that maintain ES were rated more similar than the ones that maintain CS,  $t(200) = 5.42$ ,  $p < .01$ .

Figure 2 shows the proposal target choices made by the analogy and the target-only groups. Of the 30 analogy participants, six chose the TP1 (the one that maintained ES with the SP) and 24 chose the TP2 (the one that maintained CS with the SP), and of the 30 only-target participants, 23 chose the TP1, and 7 chose the TP2. Thus, although people working out of the context of the analogy tended to evaluate the SP as more similar to the TP1 than to the TP2, as was demonstrated by the data obtained from the similarity-rating group, analogy participants preferred to map the SP to the TP2 than to the TP1 (to the TP2: 80%; to the TP1: 20%),  $\chi^2(1, N = 30) = 19.27$ ,  $p < .001$ . This preference can not be attributed to some intrinsic plausibility of the TP2 in the target domain, since the target-only group showed a clear preference for the TP1 (TP1: 77%; TP2: 23%),  $\chi^2(1, N = 30) = 15.00$ ,  $p < .001$ . There was an association between group and target proposal choices,  $\chi^2(1, N = 60) = 17.09$ ,  $p < .001$ .

Several authors (e.g., Falkenhainer, 1990; French, 1995; Hofstadter, & the FARG Group, 1995; Minervino, & Adrover, 2000; Mitchell, 1993) have argued that both SME and ACME inconveniently reduce the influence of semantics on mapping to the effects of previously assessed and general-purpose similarities between prepositional elements, and do not consider the fact that sometimes people arrive at adequate analogical correspondences through the discovery and conceptualization of similarities that can not be known in advance but instead emerge in the context of the comparison at hand. The ambiguous mapping that includes the analogy of this experiment cannot be decided on syntactic or pragmatic grounds (the TP1, and the TP2 are formally identical to the SP, and either of them could satisfy the purpose of the task, that is, both could play the role of the cause of the to-be-explained target event). If SME, and ACME were confronted with this analogy, they would both choose the match of the source and target proposals that maintain ES. SME would have no other option, since the pairing of non-identical relations is forbidden by this program. ACME would compute the ES maintained by the elements (relations, objects, object properties) composing the alternative pairings of the competing mappings, SP-TP1 and SP-

TP2 (in truth, it would be informed by the programmer about them). It would then choose the same mapping chosen by SME. The results of our experiment demonstrate that people do not always behave in the same way these programs do. Analogy participants passed over ES and followed CS, solving the task in an alternative way. The conclusion is that people are able to find CS on their own and to decide mappings following this kind of similarities, therefore postulating more abstract and adequate mappings when suitable than would be proposed by SME and ACME in the same circumstances.

How is it possible that programs that are supposed to be able to make complex analogies such as the ones generated in science or in philosophy cannot make the apparently simple analogy solved by people in our experiment? According to Hofstadter, and the FARG Group (1995), this is because these programs make these complex analogies due solely to the tailored analogue representations they receive (constructed ad hoc to facilitate the finding of the correct correspondences), and not by virtue of applying genuine intelligent analogical mechanisms. We can illustrate the point argued by Hofstadter and colleagues with the analogy included in our experiment, postulating how the SMT and the MCT would perhaps proceed so that SME and ACME, respectively, successfully make the analogy.

If the SMT or the MCT had to simulate this analogy, the programmers of SME and ACME would design the source and target representations in such a way that the programs would choose the CS-based mapping (SP-TP2) and not the ES-based one (SP-TP1). For instance, SME's programmers would code the desired source and target relations to be mapped by the program (relations that maintain some degree of ES or no similarities at all, but known in advance by the programmer as maintaining CS in the particular analogy being simulated) as identical relations. In this analogy, we can postulate that the programmers would represent the SP, and the TP2 using, say, the predicate ADDRESS for both proposals, with the SP initially appearing as, for instance, 'ADDRESS (mind, technique-origins)', and the TP2 as, for example, 'ADDRESS (health, technique-antecedents)'; the TP1 would be represented, on the contrary, by another relational predicate, for example, 'DISCUSS (psyche, technique-applications)'. Following its initial condition of identical meaning for relations, SME would map the propositions that include the same relations. The differences between the original relations have been judged as not important, and the relations have been considered as meaning exactly the same; this has been done, however, by the programmer, who has in mind the final product of the analogical process, and not by the program itself (as should have been). It is in this sense that SME's (and ACME's) programmers have been accused of tak-

ing excessive advantage of having the desirable mapping in mind when they define the representations of the SA and the TA, in the sense that they especially tailor them to elicit the expected mapping for a specific analogy.

The MCT could facilitate the mapping task to ACME via the presentation of the TP2 as more extra-contextually similar (than the TP1) to the SP. Alternatively, ACME's programmers could facilitate the task to ACME in two other ways: the TP2 could initially appear as the cause of the target event, or as the only cause-candidate, the program then being able to identify the cause of the target event on syntactic grounds alone. The problem with this way of finding CS consists is that it requires that both domains are well structured from the start of the analogical process, and this is probably not the case for situations in which we are using some well-understood SA for structuring some less well-understood TA.

Going back to the problem of semantics in analogical mapping, it can be said that as the standard programs are not able to discover and conceptualize CS on their own, the programmers directly indicate them via re-representing non general similar elements as similar ones, or via some other ad hoc ways (e.g., some combination of formal aspects of representations and some mechanisms that take into account these aspects). The point is that if ACME and SME were faced with the analogical task presented to the analogy group in this study, they would follow ES, since they are not able to identify not previously known similarities (CS), and it seems clear that, in situations like this simple one, ES are insufficient.

What is lacking in the field on analogical thinking is an explanation of how people discover and conceptualize CS. We can highlight the CS maintained by the SP, and the TP2 describing them, for instance, as 'the groups would address (via discussing [SP] and investigating [TP2]), in systematic ways (organizing meetings [SP] and consulting bibliography [TP2]), the question of the roots (philosophical origins [SP] and historical antecedents [TP2]) of their therapy techniques'. The two authors of this study independently analyzed the descriptions of the similarities maintained by the SP and the TP2 given by analogy participants. They took the description given above as reference for classifying them. The necessary and sufficient concepts that had to appear in a description of the similarity of the proposals so as to be considered as an instance of the description presented above were address (or some clear synonym, e.g., confront) and roots (or some clear synonym, e.g., basis). They agree in 14 of the 16 descriptions classified as positive cases (24 of the 30 analogy participants chose the TP2), and they decided the other two cases by discussion.

We can describe the SP, and the TP1 as two instances of, say, ‘the groups would organize meetings to discuss different aspects (philosophical origins [SP] and practical applications [TP1]) of their therapy techniques’. Employing a similar methodology used with the alternative mapping (now the necessary and sufficient concepts were organize meetings to discuss [or some clear synonyms]), we independently concluded and agreed that five of the six analogy participants that chose the TP1 gave descriptions similar to this.

Although it is relatively easy to imagine how analogy participants arrived at a common description of the SP and the TP1 via some induction mechanisms, we are far from being able to explain how participants arrive at the common description of the SP and the TP2. We can only make some suggestions concerning the abilities necessary for constructing such a description.

People seem to have some abilities that allow them to re-represent their initial representations of the source and target events, e.g., the proposals SP and TP2. This process of re-representation is aimed at highlighting some abstract common aspects of these events (e.g., the groups ‘will address the problem of the roots of the techniques’). It also seems that the description of the common aspects of the SP, and the TP2 can not be constructed making use solely of concepts available and organized in some kind of IS-A semantic network (Falkenhainer, 1990) like the ones the standard approach would like to add to their mapping modules (Falkenhainer et al., 1989; Holyoak, & Thagard, 1995); would be discuss and investigate represented in that network as two instances of address? it seems that this is a contextually determined re-representation. Analogy programs must therefore include some capacity to restructure their initial descriptions or to add new descriptions in the course of analogical mapping, something that is not possible in programs like SME or ACME. One of the principal limits of the standard treatment of analogical similarity could be the belief that the construction of representations of the analogues and the mapping of them can be modelled independently because they are not inextricably intertwined (Hofstadter, & the FARG Group, 1995). It makes sense to suppose that the way in which two situations are understood is affected by how each is mapped onto the other. Although both the SMT and MCT have recognized that analogical thinking includes abilities of re-representation (cf., Gentner et al., 1997; Holyoak, & Thagard, 1989a), their modeling style has tended to hide the fact that their computational models do not include such mechanisms, and that such mechanisms can not be absent in any moderately competent system of analogical reasoning. In fact, SME, and ACME are normally presented as very successful programs that can make analogies in

a wide variety of domains and contexts, which gives the idea that we can construct very successful analogical programs without the necessity of incorporating mechanisms for re-representing and for discovering CS in them. In this study we have tried to show that these mechanisms seem necessary for making very simple analogies (very simple ones for humans but impossible for ACME, and SME).

Mapping the SP to the TP2 -and not to the TP1- also supposes passing over very apparent similarities between the SP, and the TP1 (i.e., the fact that both proposals said that the source and target groups would organize meetings to discuss). These similarities must be evaluated by the analogist as relatively superficial when compared with the more abstract ones discovered between the SP and the TP2. What seems clear from this analysis is that the evaluation of the profundity or superficiality of common aspects of potentially map able elements must take place in light of the specific context of the comparison at hand. Therefore, it is not sufficient for an analogy engine to have some mapping module that receives information of prior assessed similarities, ones supposedly to be valid for any comparison context (ES); some similarities must be reassessed (or just discovered and conceptualized) in response to pressures that can not be apparent prior to the mapping task -CS- (Hofstadter, & the FARG Group, 1995).

Mapping the SP to the TP2 -and not to the TP1- also implies leaving aside differences between the SP and the TP2 (i.e., the differences between organizing meetings and consulting bibliography, the two alternative ways of addressing the problem). It is thus not sufficient for an analogy engine to evaluate similarities between elements during mapping; the differences between them must be also judged, something that systems like SME and ACME do not do (Minervino, & Adrover, 2000).

Table 1  
Intuitively estimated extra-contextual similarities for SP-TP1 and SP-TP2 (alternative) pairings

Alternative pairings (corresponding to SP-TP1 or SP-TP2)	Criteria employed to judge similarities According to the kind of elements		
	Synonymy Relations (Adjectives)	Kind Relations (Nouns)	Entailment Relations (Verbs)
<i>Organize</i> ↔ <i>organize</i>			5
Organize ↔ consult			2
<i>Discuss</i> ↔ <i>discuss</i>			5
Discuss ↔ investigate			3
<i>Meeting</i> ↔ <i>meeting</i>		5	
Meeting ↔ bibliography		1	
<i>Origin</i> ↔ <i>application</i>		1	
Origin ↔ antecedent		4	
<i>Philosophical</i> ↔ <i>practical</i>	1		
Philosophical ↔ historical	3		
<i>Overall mean</i> (ES)		3.4	
<i>Overall mean</i> (CS)		2.6	

*Note:*

*Source proposal* (SP): MIND would organize meetings to discuss the philosophical origins of their therapy techniques.

*Target proposal 1* (TP1): PSYCHE would organize meetings to discuss the practical applications of their therapy techniques.

*Target proposal 2* (TP2): HEALTH would consult bibliography to investigate the historical antecedents of their therapy techniques. Pairings in italic letters correspond to the SP-TP1 mapping, and pairings in common letters to the SP-TP2 mapping.

Table 2  
Results of the similarity-rating task: mean ratings for SP-TP1 element pairings and SP-TP2 element pairings. Computed *t* statistics

	<i>M</i>	<i>SD</i>		<i>M</i>	<i>SD</i>	<i>t</i> (50)
SP-TP1 (ES) pairings			SP-TP2 (CS) pairings			
Organize ↔ organize	4.93	0.25	Organize ↔ consult	2.40	0.97	13.86*
Discuss ↔ discuss	4.77	0.43	Discuss ↔ investigate	3.03	1.10	8.05*
Meeting ↔ meeting	4.97	0.18	Meeting ↔ bibliography	2.47	1.41	9.65*
Origin ↔ application	2.60	1.07	Origin ↔ antecedent	3.97	1.13	4.81*
Philosophical ↔ practical	1.43	0.77	Philosophical ↔ historical	2.33	0.96	4.00*

\* Significant at 0.01 levels

*Note:*

SP: source proposal

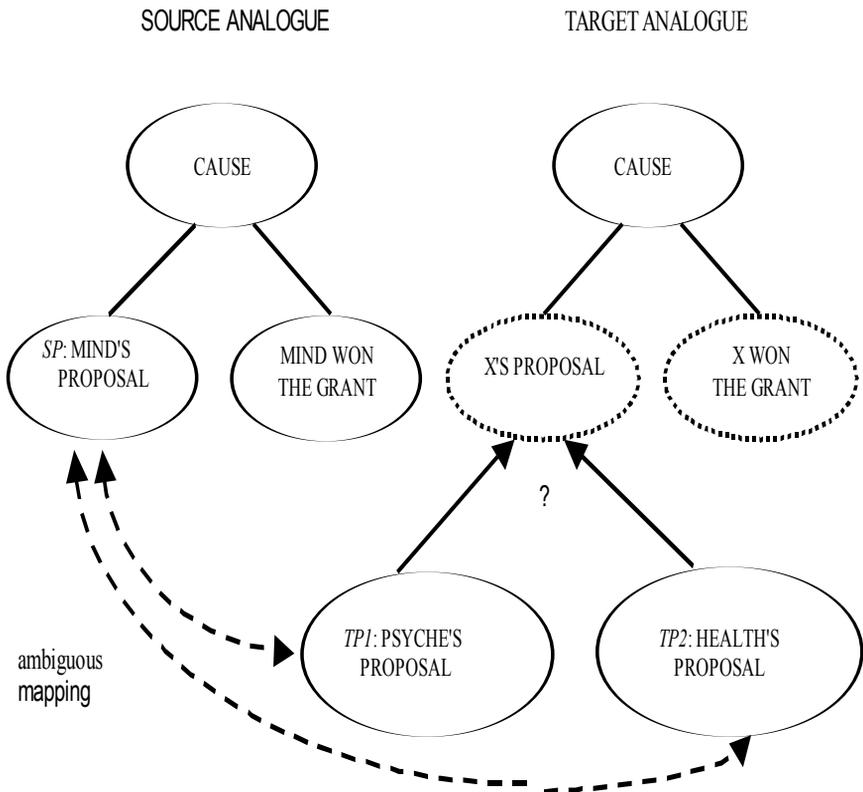
TP1: target proposal 1

TP2: target proposal 2

ES: extra-contextual similarities

CS: contextual similarities

Figure 1  
 Analogies in which the correspondences for some source elements are semantically ambiguous (they could be based on extra-contextual similarities or contextual ones)



**Note:**

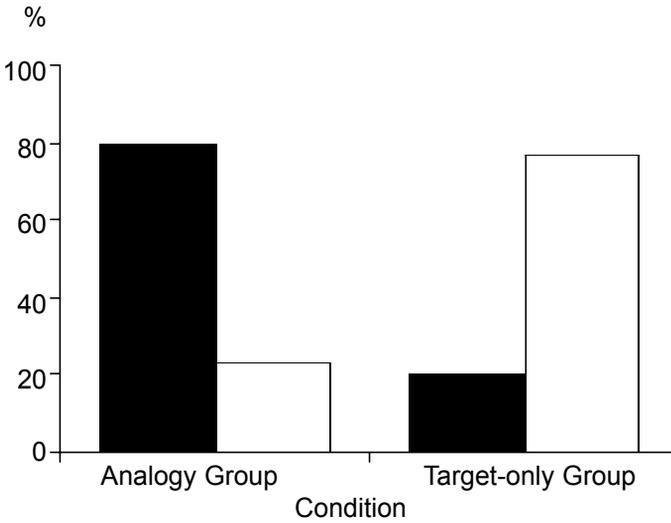
*Source proposal (SP):* MIND would *organize meetings to discuss* the philosophical origins of their therapy techniques.

*Target proposal 1 (TP1):* PSYCHE would *organize meetings to discuss* the practical applications of their therapy techniques (it maintains extra-contextual similarities with the SP).

*Target proposal (TP2):* HEALTH would consult bibliography to investigate the historical antecedents of their therapy techniques (it maintains contextual similarities with the SP).

Figure 2

Percent of participants in each condition choosing target extra-contextual similar proposal (ESP) and target contextual similar proposal (CSP)



*Notation*

■ CSP

□ ESP

## Appendix A

### Source and target stories employed in the experiment and questions answered by the analogy and the target-only groups

#### Source analogue of the analogy group

##### *Financial support for psychological research*

During 1998, MIND and LIFE, two groups of psychologists working in Madrid on human eating disorders (for instance, anorexia), needed financial support in order to continue investigating in the area. The IDEAS Foundation of Madrid invited applications to researchers in psychology for a grant. Both groups applied for it. The two applications were well accepted, since it was considered that both groups had good antecedents. However the Foundation had to make a decision about which of the two groups to finance, since there was only one grant available. Considering that MIND, but not LIFE, would organize meetings to discuss the philosophical origins of their therapy techniques, the Foundation gave the grant to MIND.

#### Target analogue of both groups

##### *Financial support for psychological research*

During 1999, the IDEAS Foundation of Madrid invited applications to researchers in psychology for a grant. PSYCHE and HEALTH, two groups of psychologists working in Madrid on phobic disorders (for instance, claustrophobia), needed financial support in order to continue investigating in the area. Both groups applied for the grant. The two applications were well accepted, since it was considered that both groups had good antecedents. However the Foundation had to make a decision about which of the two groups to finance, since there was only one grant available. Considering that:

PSYCHE, but not HEALTH, would organize meetings to discuss the practical applications of their therapy techniques;

HEALTH, but not PSYCHE, would consult bibliography to investigate the historical antecedents of their therapy techniques; the Foundation gave the grant to one of the groups.

*Similarities in analogical mapping*

*Questions answered by analogy group participants:*

If we suppose that the Foundation acted this time in a way similar to last year, to which group and why do you think the IDEAS Foundation gave the grant?

The Foundation gave the grant to ...

because this group ...

I consider that this group's proposal was similar to MIND's, insofar as...

*Question answered by target-only group participants:*

To which group and why do you think the IDEAS Foundation gave the grant?

The Foundation gave the grant to ...

because this group...

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