Automatic and Strategic Search During Analogical Retrieval

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Abstract

The present study investigates two key aspects of analogical retrieval: (1) whether other activities different from problem solving automatically elicit a search for analogical sources, and (2) whether strategic search can overcome the superficial bias observed in classical experiments. In Experiment 1, participants had to generate persuasive arguments for a target situation under three experimental conditions: without indication to use analogies, with instruction to use analogies, and with indication to search for sources within four predefined domains: health, human relations, housekeeping, and breeding of animals and plants. Responses from the first condition showed that argumentation rarely triggers spontaneous analogical retrievals, a result that is at odds with most studies on problem solving. Results from the remaining conditions demonstrated that the superficial bias can be strategically reversed when participants are suggested to focus on specific domains. Experiment 2 replicated this last result with the simple instruction to search within domains *different* from that of the target (i.e., without being provided with a list of specific domains). The theoretical and educational implications of these findings are discussed.

Keywords: Analogy, retrieval, similarity, transfer.

Introduction

Analogical reasoning consists in acknowledging that the objects of two situations are organized by an identical system of relations (Gentner, 1983). Across activities as diverse as problem solving, instruction or argumentation, finding the right analogical correspondences allows transferring knowledge from a known situation (the *base analog*: BA) to novel situation (the *target analog*: TA) in order to improve the representation of the latter. A traditional taxonomy distinguishes between *intradomain analogies* (i.e., when BA and TA pertain to the same thematic domain) and *interdomain analogies* (i.e., when BA and TA belong to thematically separate domains). In intradomain analogies, the compared analogs maintain *superficial similarity,* as corresponding objects and relations tend to be semantically similar.

A number of empirical studies have demonstrated that people can easily understand analogies even in the absence of superficial similarity (e.g., Gentner, Rattermann, & Forbus, 1993, see Holyoak, Novick & Melz, 1994, for a review). In contrast with the relative easiness of finding the right mapping between a BA and a TA that are simultaneously active in working memory (WM), the process of retrieving interdomain BAs from Long Term Memory (LTM) turns out to be rather taxing. As in most studies in the memory literature, the standard paradigm for investigating the conditions that foster analogical retrieval comprises two different phases. During the learning phase, participants receive the BAs embedded in tasks aimed at enforcing a proper encoding of the BAs in LTM. During the retrieval phase, sometimes temporally and/or contextually separated from the first, participants receive the TAs embedded in target tasks for which retrieving the BAs becomes crucial, and experimenters assess whether the processing of the TA triggers the retrieval of the critical BA. Studies using this paradigm showed that intradomain BAs are retrieved between two and four times more frequently than interdomain BAs (Holyoak & Koh, 1987; Keane, 1987). These findings led researchers to conclude that superficial similarity represents a crucial precondition for analogical retrieval. On the other hand, computational modelers of analogical retrieval agree that the computational cost implicated in carrying out a structural mapping between a TA and every potential BA in LTM would be psychologically implausible (Forbus, Gentner & Law, 1994; Thagard, Holyoak, Nelson & Gochfeld, 1990).

Under these considerations, proponents of the structure mapping theory (Gentner, 1983) developed MAC/FAC (Forbus, Gentner & Law, 1994), an algorithm designed to mimic human patterns of analogical retrieval through psychologically realistic computations. MAC/FAC, for *Many Are Called, Few Are Chosen,* divides retrieval into two phases: MAC, a fast superficial filter, and FAC, a structural matcher.

The MAC phase begins by generating content vectors for the TA and every representation in LTM, with each content vector being generated by assigning a position in an ordered series to all concepts in LTM, and counting how many times each concept appears in each BA. Upon taking the vector products between the content vector of the TA and the vector of all situations in LTM, the MAC stage submits the winning BAs (most of them superficially similar to the TA) to the FAC stage. For each BA, FAC starts by creating all possible local mappings between elements of the same formal type, with the added restriction that mapped relations must have identical meaning. The program then incrementally coalesces local matches into global mappings that satisfy the constraints of *parallel connectivity* (if two predicates are mapped, their arguments must also be mapped) and *one-to-one mapping* (elements in one analog must map to only one element in the other analog). Finally, FAC scores the quality of global mappings as a function of their size, their depth, and the semantic similarity of their corresponding objects. This last criterion amplifies MACs' bias towards BAs bearing superficial similarity with the TA.

LISA (*Learning and Inference with Schemas and Analogies*; Hummel & Holyoak, 1997) is the latest matcher developed by proponents of the multiconstraint theory of analogy (Holyoak & Thagard, 1989, 1995). Its architecture aims at encompassing retrieval, mapping, inference and schema abstraction by a unified set of core processes that are more neurally plausible than in earlier attempts (e.g. ARCS; Thagard, Holyoak, Nelson & Gochfeld, 1990). LISA's architecture is a system for representing dynamic role-filler bindings in WM and encoding them in LTM for later retrieval. When a proposition unit (P) like *John loves Mary* gets activated, it propagates top-down activation to subproposition units (SPs) that represent bindings between each of the case roles of the proposition and its corresponding filler. During the lapse while each SP unit remains active, it transfers top-down activation to two independent structure units representing a case role and its filler (e.g., *John* and *lover*) which fire in synchrony with each other and out of synchrony with the units of the complementary SP (i.e. *Mary* and *beloved*). Case roles and their fillers—which represent the lower level in the structural hierarchy—in turn activate a collection of semantic units representing their meaning. Therefore, when a proposition such as *John loves Mary* is selected, the semantic primitives of *lover* (e.g., *emotion1*, *positive1*, and *strong1*) fire in synchrony with the semantic primitives of *John* (e.g., *human*, *male* and *adult*), while units representing the *beloved* role (e.g., *emotion2, positive2* and *strong2*) fire in synchrony with units representing *Mary* (e.g., *human*, *female* and *adult*). When the semantic primitives of a given role-filler binding in the TA fire in WM, predicate, object and SP units from one or various BAs compete in responding to this array as a function of the extent to which their semantic units overlap. As in MAC/FAC, LISA's reliance on semantic similarities between BAs and TAs leads to a majority of superficial remindings.

In contrast with the emphasis placed in justifying the appropriateness of the representational and computational assumptions incorporated in each of the above models (e.g MAC/FAC uses serial operations on symbolic representations while LISA uses connectionist computation on distributed representations), the proponents of these models are ambiguous as to whether the models account for spontaneous remindings, voluntary remindings, or both. Given the importance of this distinction within current memory research (see Mace, 2010, for a review), the first objective of the present study is thus to investigate to what extent the search for BAs in LTM is automatically triggered by the processing of the TAs. A second objective of the present study concerns whether voluntary retrieval of BAs is invariably biased towards superficial matches, as in current implementations of the above models, or if search for BAs can be strategically circumscribed to areas of knowledge different from that of the target—a central preoccupation of psychologists and educators (see, e.g., Loewenstein, 2010). Before presenting our study, the available evidence bearing on these two questions is briefly reviewed.

Automatic vs. Voluntary Search for Base Analogs

It is a common experience to be spontaneously reminded of analogous cases while carrying out thoughtful activities like science teaching, explanation, and persuasive argumentation. However, a sensible question to be asked concerns to what extent being engaged in the above activities automatically initiates a search for BAs in LTM. Even though no single study has yet manipulated whether or not participants are explicitly invited to "think of analogous problems", across-studies comparisons within the problem-solving literature suggest that participants' attempts to find a solution automatically elicit a search for BAs. For instance, using roughly comparable stimuli, Keane (1987) and Holyoak and Koh (1987) assessed the retrieval of a BA during a temporally and contextually separated problem solving activity. Even though the former study (but not the latter) explicitly asked participants to look for analogous problems prior to attempting a solution, both obtained comparable rates of retrieval, which suggests that the mere disposition to find solutions suffices to trigger a search for BAs. Other studies of spontaneous analogical retrieval during problem solving (e.g., Chen, Mo & Honomichl, 2004) point in the same direction. With these antecedents in mind, the specific question that concerns us here is whether other thoughtful activities such as those listed above also trigger a search for analogous cases in a reliable manner.

A likely candidate task for automatic analogical retrieval is persuasive argumentation. A series of naturalistic studies (e.g., Blanchette & Dunbar, 2000; Trench, Oberholzer & Minervino, 2009; Trench, Olguín & Minervino, 2011) have shown that when being asked to generate analogies to convince somebody of performing an action, people easily retrieve BAs from their autobiographical memory. As in these studies, the procedure followed by one of the groups of the first experiment reported in the present study consisted

in presenting participants with a target situation admitting two alternative lines of action, and asking them to provide as many analogies as they could in favor of one of such actions. In order to shed light on whether the activity of finding persuasive arguments automatically triggers a search for relevant BAs, we had another group receive the same TA and the same instructions to argue in favor of the intended action, but without any hint to base their arguments on analogous situations.

Voluntary Analogical Search: Fixed or Strategic?

As stated above, a wealth of laboratory studies demonstrate that search for BAs yields mostly superficial matches to the TA. Even though most retrieval algorithms were specially engineered to mimic such pattern of results, some of them left open the question of whether such superficial bias could be "tuned" by the analogizer, be it by means of adjusting the weight given to object attributes by the structural component of the system (FAC), or by having the whole retrieval algorithm run on a subset of MLP selected via other general mechanisms of memory such as spreading activation or indexing (Gentner & Forbus, 1991, p. 4).

Consistent with this last possibility, Ripoll (1998) postulated the psychological reality of a synthetic level of representation that specifies the thematic domain to which a given problem/story belongs, and demonstrated how these "domain tags" operate during the time-course of analogical retrieval. The procedure consisted in coupling superficially similar and superficially dissimilar target problems with a heading intended to activate a domain tag (e.g., "a learning problem"), which could match (or not match, depending on the condition) the domain tag of the base problem. Using concurrent measures of retrieval, Ripoll (1998) found that the presence of shared surface features facilitated retrieval, but only when the domain tags of the problems matched.

In the first experiment of the present study, the second and third groups received a TA and an instruction to search for potential analogous situations that could be used to convince the main character of the TA to pursue a given action. However, while participants of the second group were not given any indication to focus search in any particular direction, participants of the third group were provided with domain tags representing domains thematically distant from the TA, and were asked to search for potential situations within such domains. The comparison between the types of analogies provided by these two groups seeks to extend Ripoll's (1998) findings in two ways. On the one hand, they test the psychological reality of domain tags outside the realm of analogical problem-solving. Most importantly, though, they explore whether these tags can be strategically exploited by the analogizer during voluntary analogical reminding.

Experiment 1

Method

Participants and Design One hundred and twenty undergraduate students at Universidad Nacional del Comahue volunteered to participate in the experiment (Mean age = 21.49, *SD* = 3.42). An even number of participants was randomly assigned to the argumentation condition (G_{AR}), the analogical argumentation condition (G_{AN}), and the analogical argumentation with predefined domains condition (G_{AN+D}). The variables *indication to use analogies* (two levels: with and without explicit indication to use analogies) and *provision of search domains* (two levels: with and without indication to search within particular domains) received between subjects manipulation. The dependent variables were the number and type (intra/interdomain) of the proposed BAs.

Materials and Procedure Before advancing to the target task, participants of all groups received an instructional material on argumentation. The material handed to the G_{AR} covered general features of arguments, but did not describe specific types of arguments (e.g., analogies). The material handed to the G_{AN} and the G_{AN+D} described the use of analogies in persuasion, illustrating with two examples the distinctions between intra and inter-domain analogies, as well as between analogies based on situations retrieved from memory and analogies based on invented situations. Once the 10 min allotted to reading the instructional material had elapsed, participants of all groups were given TA describing the situation of a family that was accumulating an important debt in the balance of their credit card. All groups had to generate as many arguments as they could to persuade them to cut expenses immediately in order to cancel the debt, on the grounds that otherwise it would grow so big that future cuts would need to be even more dramatic. Whereas instructions given to the G_{AR} did not mention the convenience of including analogies to prior cases among the persuasive arguments, participants of the G_{AN} and G_{AN+D} were asked to base their arguments on analogies to known situations. The difference between G_{AN} and G_{AN+D} was that while participants of G_{AN} received no instructions concerning the domains of the BAs, participants of the G_{AN+D} were asked to sequentially focus their search within four domains *different* from economy: health, human relations, housekeeping, and breeding of animals and plants. In order to prevent participants of the G_{AN+D} and G_{AN+D} from reporting BAs not originated in retrieval processes they were encouraged to base their analogies on past episodes which had happened to them or to others, or that were learned from verifiable sources such as newspapers, books, movies, etc. Participants of G_{AR} and G_{AN} were given 20 min to complete the argumentation task. In the case of G_{AN+D}, participants were allotted 5 min for each of the suggested domains. Once this time had elapsed, participants of all groups were allotted 5 more minutes to report all other arguments (or analogies, depending on the group) that had come to mind during the previous phase but were not reported for whatever reasons. This question was intended to neutralize an eventual conscious editing of retrieved BAs, (cf. Trench, Olguín & Minervino, 2011), like when a BA is rejected for not being persuasive, or for not pertaining to the specific domain that was requested (e.g., in G_{AN+D}).

Data analysis Two judges received instruction on the concept of analogy, as well as on the general distinction between intra and interdomain analogies. For the particular TA at stake, they were instructed to regard as "analogical responses" all proposals including the following elements: (1) a problem of increasing magnitude, (2) a delay in the attempts to solve it, and (3) a consequent increase in the cost of solving it. Regarding the intra/interdomain distinction, judges were instructed to score as intradomain all situations where the problem of increasing magnitude was economic (e.g., a public debt) and to score as interdomain all instances in which the problem of increasing magnitude was not of economic nature (e.g., an illness or addiction). Given that we sought to detect all the BAs that were retrieved from LTM in response to the target task, judges were handed all responses produced by the participants, regardless of whether they were reported during the argumentation phase, or during later requirement to list all other situations that had come to mind during the first task, but were not included among the final proposals. Judges agreed in 82% of the cases regarding the analogical status of proposals, and in 94% of the cases regarding their intra/interdomain nature. Cases of disagreement were resolved by open discussion.

Results and Discussion

Across conditions, participants proposed a mean of 2.10 responses (*SD* = .94), out of which 44% were rendered "analogical" by the judges. Further comparisons and statistical analyses were restricted to analogical proposals. Our first empirical question concerned whether the task of generating persuasive arguments would reliably elicit a search for BAs in LTM, as observed within the literature on analogical problem solving. Taking together intra and interdomain proposals, participants of G_{AR} retrieved a total of 7 BAs in response to the TA (*M* = .18, *SD* = .45). This level of analogical retrieval is markedly lower than that of G_{AN} (*M* = .73, *SD* = .60), where participants were explicitly asked to base their arguments on analogies to known situations, $t(72.14) = 4.658$, $p < .01$. Given the performance exhibited by the G_{AN}, the disappointing number of BAs retrieved by participants of G_{AR} cannot be attributed to a lack of BAs available in LTM for retrieval. Rather, it indicates that that the pragmatic of generating persuasive arguments for a real-world target situation does not reliably elicit a spontaneous search for relevant analogs in LTM. A likely explanation for the difference between our results and those obtained with problem solving tasks might lie in the fact that the types of problems typically used (e.g. the tumor problem) do not admit direct methods of solution (e.g., means-ends analysis). Perhaps with other types of problems, the spontaneous use of analogies would be less frequent, as it happened in the present study.

Our second empirical question dealt with whether the search mechanisms underlying voluntary analogical retrieval are invariably set to favor superficially similar BAs. Judges' analysis of analogical proposals reported by the G_{AN} showed that 62% of the retrieved BAs were semantically similar to the TA, and 38% of retrieved TAs were semantically dissimilar from the TA, a result that reproduces the pattern typically obtained in the literature. In contrast with this standard pattern of retrievals, judges' analyses of analogies generated by the G_{AN+D} showed that whereas 35% of the retrieved BAs came from the same domain of the TA, 65% of the retrieved BAs were interdomain, a result that goes against the superficial bias typically obtained in the literature on analogical retrieval. A comparison between the G_{AN} and the G_{AN+D} in terms of their relative proportions of superficially similar vs. superficially dissimilar retrievals thus demonstrates that the participants can strategically favor the retrieval of one or the other type of BAs, $Z = -2.54$, $p < .05$.

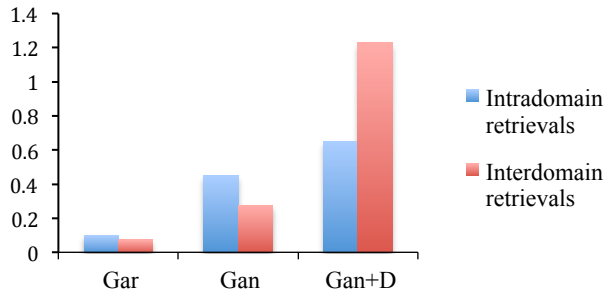

Figure 1. Mean number or retrievals, Experiment 1

An intriguing question raised by the possibility of shifting search away from the target domain concerns whether the increased number of distant matches comes at the expense of missing a number of intradomain BAs that would be retrieved under a non strategically-oriented search, as a "shift of focus" metaphor might suggest. A comparison between the G_{AN} and the G_{AN+D} in terms of the mean number of superficially similar and superficially dissimilar BAs showed that whereas the mean number of distant BAs generated by the G_{AN+D} (*M* = 1.23, *SD* = 1.17) clearly surpassed the mean number of distant BAs retrieved by the G_{AN} (*M* = .28, *SD* = .45), $t(50.48) = 4.806$, $p < .001$, participants of G_{AN+D} did not retrieve a lesser amount of superficially similar BAs than participants of G_{AN} (*M* = .65, *SD* = .83, vs. *M* = .45, *SD* = .50, respectively), $t(64.14) = 1.299$, $p > .05$. Rather than simply shifting the focus towards interdomain retrieval, it seems that participants of G_{AN+D} are *broadening* the scope of their search, an operation that boosts access to distant analogs while still retaining baseline levels of intradomain analogizing.

Even though the educational implications of the observed increment in interdomain analogizing are easy to foresee, an interesting question to be asked concerns whether a reasonable increase in the absolute and relative amounts of interdomain retrievals can still be obtained without providing participants with a set of promising domains within which to search for useful BAs. In Experiment 2, we tested this possibility by comparing the analogical argumentation condition (i.e., the former G_{AN}) against a pro-interdomain argumentation condition without the provision of predefined search areas (G_{ANint}).

Experiment 2

Method

Participants and Design Fourty students at Universidad Nacional del Comahue (Mean age = 20.71, *SD* = 2.05) were randomly assigned to two experimental conditions. The variable *type of argumentation* (two levels: with indication to use analogies vs. with indication to use interdomain analogies) received between subjects manipulation. The dependent variables were the number and type of the proposed BAs.

Materials and Procedure The materials and procedure applied to the G_{AN} were a replication of those followed with the G_{AN} of Experiment 1. The materials and procedure employed with the G_{ANint} were identical to those of the G_{AN} with the sole difference that participants were asked to base their persuasive analogies on episodes pertaining to domains different from that of the TA (i.e., economy). Data analysis was identical as in Experiment 1, with judges' agreement reaching 85% with regards to the analogical status of proposals, and 96% regarding their intra/interdomain nature.

Results and Discussion

Experiment 2 was carried out to assess whether an increase in the absolute and relative amounts of interdomain retrieval could still be obtained without providing participants with a set of interdomain search areas to look for analogous situations. A comparison between the G_{AN} and the G_{ANint} showed that the relative proportion of interdomain analogies proposed by the G_{ANint} was higher than in the G_{AN}, $Z = -1.97$, $p < .05$. Whereas the analogies proposed by the G_{AN} were 63% intradomain and 37% interdomain, the analogies proposed by the G_{ANint} were 40% intradomain and 60% interdomain. Though not as strong as in Experiment 1, this reversal demonstrates that participants can voluntarily alter the superficial bias classically obtained in experiments of analogical retrieval with the mere intention to search for thematically distant sources in LTM.

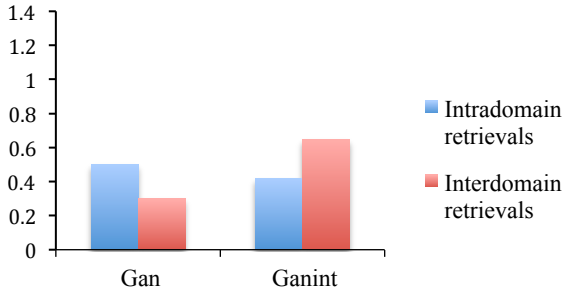

Figure 2. Mean number or retrievals, Experiment 2

As in Experiment 1, the augmented proportion of inter-domain retrievals in the pro-interdomain condition was not obtained at the expense of missing a number of intradomain retrievals. A comparison between G_{AN} and G_{ANint} in terms of the mean number of intra and interdomain retrievals showed that whereas G_{ANint} ($M = .65$, $SD = .98$) clearly surpassed the G_{AN} ($M = .30$, $SD = .46$, $t(55.80) = 2.05$, $p < .05$) in the number of interdomain retrievals, both groups retrieved similar amounts of intradomain BAs ($M = .43$, $SD = .59$ vs. $M = .50$, $SD = .60$, respectively, $t(78) = 0.562$, $p > .05$). Once again, it seems that a strategic search for interdomain BAs can powerfully boost access to distant analogs, while still retaining baseline levels of intradomain retrieval.

General Discussion

In order to reproduce human patterns of analogical retrieval, extant computational models have specified in great detail a number of assumptions about the types of representations and computations implied in retrieving BAs from LTM. In contrast to this long-lasting preoccupation, their presentations are ambiguous as to whether the postulated mechanisms account for the processes of spontaneous reminding, strategic retrieval, or both. Albeit unsystematic, the evidence related to this matter comes mainly from studies of analogical problem-solving, and suggests that both types of search yield similar results, since the mere disposition to find a solution to a problem reliably elicits a search for analogous BAs in LTM.

The first experiment of the present study tackled two interrelated issues. The first one was concerned with spontaneous analogical retrieval, and had to do with whether other thoughtful activities different from problem solving (in this case, persuasive argumentation) can also elicit spontaneous remindings reliably. Results of Experiment 1 showed that when participants are not explicitly asked to base their arguments on analogies to prior cases, this activity seldom occurs spontaneously. In light of the performance of a second group that was explicitly asked to use analogies, the low level of spontaneous retrieval obtained by the first group cannot be attributed to a lack of available BAs in LTM. Rather, it shows that the pragmatics of generating persuasive arguments does not reliably elicit a search for BAs in LTM. These results have implications for models of analogical retrieval, since they can help specify the conditions under which the proposed mechanisms operate.

Our second concern was related to strategic analogical retrieval, and dealt with whether this second type of process can potentially reverse the superficial bias observed in behavioral studies of analogical retrieval, and simulated by computational models. Results showed that when participants are asked to base their arguments on analogies to known situations, they retrieve more superficial than distant matches. However, when provided with a series of distant domains to focus their search, this proportion reverses—a pattern of results that claims for an extension of Ripoll's (1998) domain tags to the arena of voluntary analogical retrieval. It should be noted, however, that our conclusions were based on the use of a single TA. In future studies, it would be desirable to replicate these results with a wider set of materials.

Albeit never implemented, the developers of MAC/FAC left open the possibility of relaxing its superficial bias by either suspending FAC's computation of object attributes, or by having the system run on a subset of LTM selected via mechanisms of spreading-activation or indexing. Given the strong superficial constraints imposed by the MAC stage, it

seems that only by running on a subset of LTM (e.g., on a subset defined by thematic search areas, or domains) the program might have a chance of coping with the pattern of interdomain analogizing elicited during strategic analogical retrieval. In relation to this possibility, the fact that in Experiments 1 and 2 participants of the pro-interdomain conditions still retrieved a significant amount of intradomain matches suggests that, at least with our materials, strategic search can be somewhat demanding, leading to recurrent cycles of non strategic retrieval attempts.

The present results on strategic analogical retrieval also suggest interesting instructional applications, since educators and researchers have long strived to find ways of facilitating cross-domain transfer. In recent times, attention has shifted from promoting an abstract encoding of BAs (e.g., Catrambone & Holyoak, 1989) to improving the encoding of TAs at retrieval time, such as providing participants with two structurally identical TAs, and asking them to compare such TAs prior to attempting a solution (Gentner, Loewenstein, Thompson & Forbus, 2009; Kurtz & Loewenstein, 2007). As Loewenstein (2010) points out, the appeal of this approach lies in its potential to foster retrieval of BAs which might have been encoded in suboptimal ways. However, a practical limitation of the target-comparison method used in the above studies lies in the fact that participants need to be provided with a second TA for every new TA. Even though participants of our G_{AN+D} were also provided with target-specific information at retrieval time (a set of promising domains to search for BAs), the G_{ANint} of our second experiment retrieved mostly interdomain BAs with the sole instruction to search within domains different from the TA, that is, without receiving target-specific information. We believe that the austerity of this last intervention opens up encouraging perspectives for the flexible use of analogy in educational environments.

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