Spontaneous and Voluntary Analogical Retrieval During Problem-Solving and Hypothesis Generation

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Abstract

Theoretical models of analogical retrieval implicitly assume that the cognitive system continuously scans long-term memory based on the contents of working memory (WM). Experiment 1 revealed that when a target analog is presented in the context of a problem-solving activity, a prompt to search for analogous situations adds nothing over-and-above the probabilities of being spontaneously reminded of an analogous problem. More exploratory in nature, Experiment 2 presents the first experimental evidence of analogical retrieval during hypothesis generation. Our prompt to search for analogous phenomena increased access to distant analogs, suggesting that hypothesis-generation does not reliably elicit a search for analogous phenomena. Results suggest that a search for analogous cases is not automatically triggered by the contents of WM, and that the nature of the tasks in which the analogs are embedded determines whether a search for analogs will be initiated.

Keywords: analogy; retrieval; problem-solving; hypothesis generation

Introduction

A central goal of education relates to the possibility of applying knowledge in contexts and to contents different from those of the initial learning (Barnett & Ceci, 2002; Day & Goldstone, 2012). The process of connecting a current situation (target analog) to stored situations sharing a common structure (base analogs) lies at the core of successful transfer. Through a mapping between both situations, unmapped elements of the base analog can be inductively projected onto the target, thus enhancing its representation.

In contrast to the ease with which two situations can be aligned in working memory (WM), evidence accumulated that base analogs stored in long-term memory (LTM) are seldom retrieved unless their constituent elements are semantically related to those of the target (e.g., Gentner, Rattermann, & Forbus, 1993; Keane, 1987; Trench & Minervino, 2015). This dependence on low-level, surface similarities has been justified both computationally and evolutionarily. On the one hand, computational modelers have argued that the cost of performing a full structural mapping between the target and all potentially analogous situations in LTM would be computationally prohibitive (see, e.g., Forbus, Gentner & Law, 1995). On the other hand, our reliance on surface similarity was supposed to represent no big loss in the Pleistocene's environment wherein our ancestors evolved (the *kind-world hypothesis*, Gentner, 1989). In the words of Gentner et al., (1993, p. 567): "if something looked like a tiger, it probably *was* a tiger". Hence, our newly evolved machinery for understanding distant analogies might be running on the output of similarity-based memory systems geared towards prediction, and ill-suited for the kind of creative, cross-disciplinary analogies that characterize educationally-relevant activities such as argumentation, problem-solving, or hypothesis generation.

If a focus on surface similarity represented an adaptive means for ensuring the retrieval of nearly identical episodes, it seems sensible to infer that the machinery in charge of this monitoring should continuously scrutinize LTM based on the contents of WM. Even though proponents of dominant computer models of analogical retrieval (e.g., MAC/FAC, Forbus et al., 1995; LISA, Hummel & Holyoak, 1997) have not explicitly specified whether their algorithms were meant to represent spontaneous access, voluntary search, or both, the architecture of the programs is largely compatible with the automaticity assumption. In LISA, for example, the ordering in which target propositions are selected to become active in WM determines the retrieval outcomes and subsequent mappings.

Consistent with this implicit "automaticity" assumption, the great majority of behavioral studies of analogical transfer were aimed at assessing whether an experimentally provided source analog had been spontaneously accessed during the processing of the target (e.g., Anolli et al. 2001; Catrambone

& Holyoak, 1989; Gick & Holyoak, 1980, Kurtz & Loewenstein, 2007). In contrast to the scarcity of distant retrievals within this literature, a handful of studies explicitly asking participants to base persuasive arguments on analogous situations obtained a surprisingly high production of interdomain analogies (e.g., Blanchette & Dunbar, 2000). Trench, Olguín and Minervino (2016) manipulated the presence of an explicit prompt to base persuasive arguments on analogous cases known by participants. Even though results revealed that the explicit disposition to think of analogous cases increased the number of analogies among persuasive arguments, there was no principled way of distinguishing true cases of analogical retrieval from the *ad hoc* fabrication of analogous situations. In a recent study, Martinez-Frontera (2015) embedded the voluntary search manipulation within a two-phase transfer paradigm less vulnerable to the distortive effect of analogy fabrication. During a weekly class of a Psychology course, participants were informed that the US and Russia had agreed to discontinue the production of the FLZ nuclear weapons, with extant missiles being kept in secure arsenals supervised by both countries. The story ended that after the mysterious disappearance of two warheads, a spread of nuclear radiation caused the death and illness of hundreds of people. Forty-five minutes later, participants were asked to participate on a study on argumentation. The target situation told that the H flu had just been eradicated, and that scientists were planning to preserve the last samples for research purposes. While participants in the unprompted condition were asked to generate persuasive arguments that could be used to convince the scientists that the samples should be destroyed, participants of the prompted condition were also required to ground their arguments on analogies to known situations. As in Trench et al. (2016), the explicit indication to think of analogous cases strongly increased interdomain retrieval. How to explain this effect?

For a voluntary search manipulation to elicit a measurable effect, one condition that should be met is that, counter to the automaticity assumption, the cognitive task wherein the target analog is embedded should fail to reliably elicit a search for similar situations in LTM, such that an explicit indication to carry out this kind of search could potentially add something over and above the natural proclivity to search for analogous cases. Given that analogical arguments tend to be judged as being less persuasive than their factual counterparts (Keane & Bohan, 2004), it is possible that the argumentation task might not have sufficed to reliably initiate a search for analogous cases in LTM. But even if a prompt to search for analogous cases in fact elicits a search process that the overarching task would not trigger by itself, the kind of representations typically serving as targets of said cognitive task should potentially afford the retrieval of a distant analog from LTM, provided that a search process has been initiated. In case this kind of target representations did not support distant retrieval at all, the addition of a deliberate intention to search for analogous cases would still fail to elicit a measurable effect.

In the case of argumentation, the voluntary search manipulation might have worked due to the fact that, on top of eliciting a search process that would not have been triggered otherwise, the targets of analogical arguments were particularly advantageous for eluding the computational complexities involved in retrieving distant analogs from LTM. One such advantage might relate to the fact that the targets of analogical argumentation are fully understood by the argumentator, being the purpose of the analogy not to increase one's own understanding, but that of the recipient. As such targets do not need to be "completed" by means of unmapped source relations (e.g., a causal link between two lower-order relations), they can be considered *connected* in the sense that one could navigate the whole hierarchy of propositions without jumping from one cluster of propositions to another. As demonstrated by O'Keefe and Costello's (2008) computational model—which was explicitly engineered to reproduce Blanchette and Dunbar's (2000) finding that persuasive analogizing often leads to interdomain retrieval—the connected nature of target representations could potentially render interdomain retrieval computationally tractable.

In contrast to the typical targets of argumentation activities, the representations that typically serve as targets of problem solving and hypothesis generation are incomplete by nature, such that the retrieval of a better-known analog might work as a source for exporting inductive inferences to the target. The aim of the present research was therefore to assess whether the effectiveness of a voluntary search manipulation would generalize to these epistemologically relevant activities, in which inductive projection plays a more crucial role.

While no studies on problem-solving have manipulated whether participants are explicitly prompted to think of analogous situations during the processing of the target problem, across-studies comparisons suggest that participants' attempts to find a solution automatically elicit a search for base analogs in LTM. For instance, using roughly comparable materials, Keane (1987) and Gick and Holyoak (1980) assessed the retrieval of a base story during a contextually separated problem-solving activity. Even though only in the former study participants were asked to think of analogous problems, both obtained comparable rates of retrieval. Despite several procedural mismatches, one can tentatively explain the lack of differences between these studies by positing that the activity of attempting to solve a problem might naturally trigger a search for analogous situations, such that an explicit prompt to remember analogous situations adds little over and above the mere disposition to solve the problem. However, the fact that retrieval of the base analogs was close to zero in both studies suggests that the intrinsic difficulty for retrieving the military story during the processing of the radiation problem was so extreme that an otherwise successful prompt to look for analogous stories ended up not yielding noticeable effects. By explicitly manipulating whether participants are asked to think of analogous situations, Experiment 1 will reach beyond "across-studies" evidence by way of isolating the effect of voluntary search from other mismatching variables.

As with our explanation for the success of the voluntary search manipulation during argumentation, our prediction about its effectiveness during problem-solving derive from (a) the extent to which this particular activity would naturally trigger a search for analogous situations in LTM, and (b) the extent to which the type of representations that typically serve as target analogs for this activity support the extraction of powerful memory cues for searching LTM. With regards to the first aspect, current theorization about problem solving suggests that weak heuristics such as analogical reasoning are normally recruited whenever strong heuristics are not available (Weisberg, 2006). Along these lines, we speculated that as the operators of open-ended problems are neither explicit in the problem's formulation nor obvious to a non expert population, the task itself might naturally invite a search for similar situations, therefore leaving little margin for improvement by means of an explicit prompt to think of analogous situations. Concerning the second component of our analysis, the structural features of open-ended problems are often discriminated from superficial features only in hindsight, that is, once a source analog has suggested a working solution. Hence, the open-ended nature of unsolved problems might complicate the extraction of concise and powerful memory cues. Based on the above considerations we predicted that, in contrast to the case of argumentation, the activity of solving a problem would not benefit from an explicit prompt to think of analogous cases.

Experiment 1

Method

Participants. A total of 140 undergraduate students (Age *M* = 22.51, *SD* = 4.08, 101 Female) volunteered to participate in the study. They were randomly assigned to the problem-solving condition (N = 70) and the analogical problem-solving condition (N = 70).

Procedure and materials. The learning phase of the experiment was administered by the instructor of an introductory Psychology course during a typical lecture, and was presented to participants of both groups as a reading-comprehension activity. Participants received three short stories of between 170 and 200 words and were instructed to read them very carefully, since they would have to answer questions about the stories without being able to reread them. While the first and last stories served as distractors, the central story was structurally similar to the target situation to be presented during the subsequent phase. This base story told about a large fire at a botanical garden, which could only be suffocated by delivering several hundred liters per second. After being warned by the local guys that using his gigantic water pump to aspire water from a nearing pond would irreversibly damage the exotic specimens, the Fire Chief came up with the idea of recruiting several smaller pumps from neighboring fire divisions, and directing them to the fire from various locations (see complete materials in Table 1). Participants were allotted 12 min to read the stories and 5 more min to answer two comprehension questions about each. In order to enforce a strong contextual separation, the transfer phase was administered by the experimenters between 30 and 45 min after the first phase, and presented to participants of both groups as a study on problem-solving. Participants in the analogical problem-solving condition received an instructional material on the effectiveness of solving problems by identifying analogous situations, which included two examples of how retrieving an analogous situation can aid in solving a current problem. These examples included an intradomain and an interdomain analogy so as not to bias participants' conceptualization of *ideal* analogical comparisons in any particular direction. Once the 10 min allotted to reading the instructional materials had elapsed, participants were presented with Duncker's (1945) *Radiation* problem, a hypothetical situation in which a patient has an inoperable tumor in his stomach which could be destroyed by certain kind of ray of sufficient intensity, but with the consequence that a beam of the required intensity would also destroy the surrounding tissues. Participants' task consisted in devising ways of using this kind of rays to destroy the tumor, but without harming the healthy tissues (see complete materials in Table 1).

The procedure followed with the problem-solving condition was similar to that of the analogical problem-solving condition, with the difference that participants received neither an instruction about the usefulness of analogy nor an indication to think of analogous situations prior to solving the problem.

Participants of both conditions were explicitly encouraged to include as many different solutions as they could think of within the 10 min frame allotted to completing the task. Since it is possible that some participants of either group might retrieve the base situation of the first phase but decide not include it among the proposed solutions, a post-task questionnaire directly queried participants about whether any of the stories read during the text-comprehension activity had come to mind, even if just briefly, while they were generating solutions to the radiation problem. Participants responding "yes" were asked to state exactly which story (or stories) had come to mind during the previous activity. Our dependent measure consisted in whether participants reported having been reminded of the source story during the problem-solving activity. Given that an adequate encoding the base analog in LTM represents a precondition for retrieval to occur, a final section asked participants to describe the Fire Chief story with as much detail as possible.

Data analysis. Two raters blind to the objectives of the study were handed participants' descriptions of the source story. They were instructed to sort as "adequate" those descriptions mentioning (a) a fire, (b) the need to direct a flow of water of several hundred liters per second, (c) the fact that such a rate would harm the vegetal species, and (d) the strategy of pointing weaker jets from different directions. Judges reached 88% of agreement, and solved cases of disagreement by discussion.

Table 1: Materials used in the problem-solving and the analogical problem-solving conditions, Experiment 1.

Base analog. Boston's botanical garden is famous for the variety of its exotic species. One summer, a large fire developed in a central sector of the garden. The Fire Chief said that the water contained in the garden's pond would suffice to suffocate the fire, but only in pumped by the largest jet at a rate of at least 1000L per minute. The authorities of the garden did not authorize the use of a water jet of such power, since it would irreversibly damage the exotic specimens of the garden. The Fire Chief called all the nearby fire stations, and asked them to send their low-power pumps immediately. When the pumps arrived, he connected them to the pond, pointed them to the fire from different directions, and turned them on all at once. Since they collectively carried more than 1000L per minute, they suffocated the fire. And as each individual jet was rather weak, the exotic specimens were not irreversibly harmed.
Target analog. Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumor if used at a sufficiently high intensity. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays, but without destroying the healthy tissue?
[Analogical] Problem-solving task. Write down all the solutions that you can think of. [Before generating each solution, try to remember other problems or situations that are analogous to that of the tumor, be them taken from medicine or from any other field].

Note: The text between brackets was only included in the analogical problem-solving condition.

Results and Discussion

Nine participants in the analogical problem-solving condition and seven participants in the problem-solving condition were excluded from the initial sample due to not having correctly encoded the base analog in LTM. As predicted, participants in the analogical problem-solving condition were not reminded of the base analog more frequently than in the problem-solving condition (39.34% vs. 36.51%, χ^2 (1, 124) = 0.11, p = .7401, φ = .03), a result that is consistent with our speculative across-studies comparison between Gick and Holyoak (1980) and Keane (1987)[1].

[1] At first sight, our prompting manipulation might appear to be highly related to Gick and Holyoak's (1980) contrast between participants who solved the radiation problem before vs. after a hint to consider the stories read during a previous phase of their procedure. Despite this seeming commonality, the psychological constraints for capitalizing on such hint contrast sharply with those involved in our prompt to "think of analogous situations". As opposed to the later case, in which the reasoner would need to probe the whole of LTM for potential matches, Gick and Holyoak's episodic reference to their learning set allows the reasoner to sequentially match the target against each of only three candidate situations, thus reducing an otherwise prohibitive computation to a much more manageable set.

In contrast to the very low percentages of spontaneous retrievals obtained by Gick and Holyoak (1980) and Keane (1987), the rate of analogical retrievals in our unprompted condition was far from a floor effect. Hence, the lack of differences obtained in the present study can not be attributed to an intrinsic difficulty for retrieving the source in response to the target. Rather, it suggests that the activity of attempting to solve a problem naturally elicits a search for analogous cases, in light of which an explicit indication to conduct a memory search adds little over-and-above this natural proclivity.

While problem-solving and argumentation have long been regarded as central targets of psycho-educational research, hypothesis generation has only recently come of age as a target of psychological investigation (Lombrozo, 2006). Despite the seeming centrality of analogical reasoning in the genesis of scientific ideas, no experimental studies to date have delved beyond the information gained by retrospective or observational studies of the use of analogy by expert scientists. By applying the procedure of Experiment 1 to a hypothesis-generation activity, Experiment 2 addressed the extent to which students are spontaneously reminded of distant analogs while generating plausible hypotheses, as well as whether an indication to think of analogous situations can render distant retrievals more likely.

Experiment 2

Method

Participants. An initial sample of 140 undergraduate students (Age M = 22.34, SD = 4.51, 92 Female) volunteered to participate in the study. Participants were randomly assigned in equal number to the hypothesis-generation condition and the analogical hypothesis generation-condition. Given that participation in Experiment 1 could inconveniently make participants aware of the connections between the learning and the transfer phase, none of Experiment 2 participants had previously taken part in Experiment 1.

Procedure and materials. The learning phase of the experiment was administered by the instructor of an introductory course during a typical lecture, and was presented to participants of both groups as a reading-comprehension activity. Participants received three short stories of between 100 and 140 words and were asked to read them very carefully, since they would have to answer questions about the stories without being able to reread them. While the first and last stories served as distractors, the central story was structurally similar to the target situation to be presented during the subsequent phase. This base analog told about a plan to fill a fractured swimming pool of 600m3 with an incompressible material. Even though the owners had ordered 350m^3 of small pebbles and 250m^3 of a comparatively larger type of stones, the smaller pebbles naturally tended to fill the interstitial space between the stones of the larger type, thus falling short of filling the pool to the top (see materials in Table 2). Participants of both conditions were allotted 10 min to read the stories and 5 more min to answer two comprehension questions about each.

In order to enforce a strong contextual separation between the learning and the transfer phases, the latter was administered by the experimenters during the following class, and presented to participants as a study on hypothesis generation. Before receiving the target situation, participants of the hypothesis-generation condition were handed an instructional material that covered general features of explanatory hypotheses, and illustrated the concept of explanatory hypothesis with two examples, none of them of analogical nature. In contrast, the material handed to the analogical hypothesis-generation condition focused on the use of analogies in explanation, featuring examples of both intra and interdomain analogies. Once the 10 min allotted to reading the instructional materials had elapsed, participants of both groups were presented with a target situation pertaining to the domain of chemistry, but which maintained structural similarities with the rather physical situation serving as a base analog. The target situation stated that the action of adding 1L of water to 1L of alcohol did not yield exactly two liters of solution, but instead 1.9L (see complete materials in Table 2). While participants in the hypothesis-generation condition were simply asked to come up with possible explanations for the presented phenomenon, participants in the analogical hypothesis-generation condition were further asked to think of analogous situations that could inspire potential explanations for the presented phenomenon. Participants of both conditions were explicitly encouraged to include as many different explanations as they could think of within the 10 min frame allotted to the explanation task. They were also told not to care much about whether the generated hypotheses would likely represent the scientifically accepted account of such phenomenon.

Since it is possible that some participants of either group might retrieve the base situation of the first phase but refrain from including it in their hypotheses, a post-task questionnaire directly queried participants about whether any of the stories read during the text-comprehension activity had come to mind, even if just briefly, while they were thinking of potential explanations. Participants responding "yes" were further asked to state exactly which story (or stories) had come to mind during the explanation activity. Our dependent measure consisted in whether participants reported having been reminded of the source story during the hypothesis generation activity. Finally, participants were asked to describe the swimming pool story with as much detail as possible.

Data analysis. Two independent raters blind to the objectives of the study were handed participants' descriptions of the swimming pool story. They were instructed to sort as "adequate" those descriptions explicitly mentioning (a) the objective of filling a swimming pool with a hard material, (b) the availability of stones of two different sizes, (c) the fact that the addition of their initial volumes equaled that of the empty pool, and (d) the fact that as small pebbles tended to occupy the empty space among larger stones, the mixture fell short of filling the pool to the top. Judges reached 85% of agreement, and solved cases of disagreement by discussion.

Table 2: Materials used in the hypothesis-generation and the analogical hypothesis-generation conditions, Experiment 2

Base analog. When the pool of the club got completely fractured, members agreed to fill its volume of 600m^3 with an incompressible material, so as to allow the installation of a tiled floor on its upper face. One warehouse provided 350m3 of small pebbles, and another store provided 250m^3 of a larger type of stones. Trucks from both warehouses unloaded the stones in the sidewalk, and workers kept filling their wheelbarrows with stones from either pile and throwing them into the pool. To everyone's surprise, the 600m^3 of stones fell short of filling the pool to the top. The reason was that as large stones were mixed with small pebbles, the smaller units tended to occupy the empty spaces left between the larger ones.
Target analog. When two liquid substances are combined, on occasions the volume of the resulting solution does not equal the sum of the initial components. For example, when combining 1L of alcohol with 1L of water, the resulting solution does not yield a volume of 2L, but one of only 1.9L. What could be the cause of this intriguing phenomenon?
[Analogical] hypothesis-generation task. Using your imagination, try to provide explanations for why the end volume may not have equaled the sum of the initial volumes of alcohol and water. [Before generating each of your explanations, make an effort to remember other phenomena or situations that are in some sense analogous to the above phenomenon. Don't care much about whether such analogous situations come from Chemistry, or from any other field].

Note: The text between brackets was only included in the analogical hypothesis-generation condition.

Results and Discussion

Nine participants were excluded from the initial sample due to not having correctly encoded the base analog in LTM. In contrast to the results of Experiment 1, participants in the analogical hypothesis-generation condition were more frequently reminded of the base analog than participants in the hypothesis-generation condition (45.45% vs. 27.69%, $\chi^2(1, 131) = 4.45$, $p = .0349$, $\varphi = .18$. The success of this prompting effect leads to two conclusions. On the one hand, it suggests that the activity of trying to generate a plausible explanation does not automatically initiate a search for source analogs in LTM, thus leaving some room for improvement by means of a deliberate intention to look for analogous situations. On the other hand, it implies that the mental representations that characterized the situation used as the target for hypothesis generation must have supported the extraction of powerful cues to search LTM.

General Discussion

Even though problem-solving has captured much more attention from analogy research than any other activity, no studies to date have focused on whether a deliberate intention to recall analogous situations can augment the retrieval of analogous problems across thematic domains, leaving us only with evidence from across-studies comparisons between problem-solving studies that had

either prompted or not prompted participants to look for analogous situations. While the lack of ostensive differences between these studies did not suggest that voluntary search can augment retrieval during problem-solving, it is known from other studies using the military-tumor problems that the mere retrieval of the source story does not reliably lead to successful transfer of the convergent solution (Anolli, Antonietti, Crisafulli & Cantoia, 2001). Hence, Experiment 1 advanced prior research in two ways: by manipulating whether participants are asked to think of analogous situations, as well as by assessing whether the source analog had come to mind during their attempts to solve the target problem, irrespective of its final application to the target situation. In line with the abovementioned across-studies comparison, the results from Experiment 1 failed to show an advantage of the prompted over the unprompted condition.

Our predictions for the effectiveness of the voluntary search manipulation during problem-solving were based on (1) whether the activity of solving a problem would naturally invite a conscious search for analogous sources in LTM, and (2) whether the mental representations that characterize typical targets of problem-solving activities tend to support the extraction of powerful cues to search LTM. In accord with classic theorization in the problem-solving domain at large (e.g., Weisberg, 2006), we had anticipated that many participants would naturally appeal to consciously searching for analogs at some point along the problem-solving process, especially after reaching an impasse in their quest for solutions. Hence, an explicit indication to search for analogous solutions could be somewhat redundant with what participants would naturally do. To complicate matters more, we reasoned that the open-ended nature of most problems contrasts sharply with the "completeness" of the target topics of argumentation, which can be initially blurry to the recipient of the argument but must be clear to the argumentator. In the problems typically employed in the Gick and Holyoak tradition, the distinction between relevant and irrelevant features often gets clarified only in hindsight, once a satisfactory solution has been encountered. To give an example from our materials, the additivity of rays coming from different directions is neither explicitly nor implicitly present in the problem statement, and some reasoners could have the aprioristic intuition that opposing rays would *cancel* each other. The lack of a voluntary search effect in Experiment 1 suggests that *at least* one of the above factors is operating during problem-solving.

In Experiment 2 we turned our attention to hypothesis generation, a creative activity that has been grossly overlooked both as a topic of educational psychology (Lombrozo, 2006) and as a topic of analogical reasoning in particular. The few existing empirical studies of analogical abduction are either retrospective (e.g., Gentner et al., 1997, Nersessian, 1992) or observational (e.g. Dunbar, 1997). Hence, no experimental studies have addressed the factors that facilitate (or hinder) how novices can generate their own analogies to make sense of novel or unexplained phenomena. Results from the unprompted hypothesis generation condition revealed that about one quarter of participants spontaneously retrieved a distant analog in the course of attempting to provide an explanation to the target phenomenon. More importantly, a comparison between the prompted and the unprompted conditions revealed that our indication to think of analogous cases elicited a moderate increase in the retrieval of a distant but analogous situation. Using the same explanatory scheme as in Experiment 1, we interpret the effect of our voluntary search manipulation as suggesting (1) that the activity of accounting for hitherto unexplained phenomena does not naturally elicit a conscious search for analogous situations in a reliable manner, thus leaving some room for improvement by inducing a voluntary search, and (2) that the representations that typically serve as targets of hypothesis generation to some extent support the extraction of useful memory cues with which to search LTM. Quite intuitively, it would seem that the representations that serve as targets for hypothesis-generation are both *incomplete* and *disconnected*, since the explanation itself completes the description of the phenomenon, possibly by causally connecting hitherto unconnected relations or facts. How, then, to account for the retrieval advantage elicited by our indication to think of analogous cases? We speculate that typical *explananda* must possess some representational features that compensate for their relative incompleteness. One potential advantage of the representations that typically serve as targets of hypothesis-generation relates to their organization into fields of knowledge for which one can quite aprioristically envision neighboring domains that are likely to be subject to similar laws. For example, the flow of heat between elements of unequal temperature could intuitively be related to other physical and/or chemical phenomena such as the transfer of electric charge, radiation, or humidity. In contrast, the typical targets of problem-solving (e.g., how to eliminate a tumor) seem less informative about other fields of knowledge that might host analogically-related phenomena. On top of this advantage, the structural features of unexplained phenomena would seem more likely than those of problem-solving to be captured by concise linguistic expressions. As posited by several authors (Gentner & Kurtz, 2005, Markman & Stilwell, 2001, Oberholzer, Trench, Kurtz & Minervino, 2018), schema governed categories such as *assault*, *award* or *inoculation* capture the common organizational elements of the exemplars of categories of events. Hence, upon encountering an intriguing instance of "synchronization" whose underlying causes lie beyond our knowledge (e.g., why neighboring clocks tend to oscillate *in phase*), one can identify situations bearing inferential potential simply by evoking other cases of synchronization (e.g., birds in a flock, menstrual cycles, pedestrians on a hanging bridge), and assessing whether the explanatory structure of these situations can be productively exported onto the target domain.

To summarize, the present research points to two important aspects overlooked by empirical and computational investigations on analogical retrieval: whether a voluntary search for analogs represents an advantage over spontaneous

analogical remindings, and whether this advantage depends on the cognitive activity in which the analogizer is involved. By embedding retrieval into different activities relevant to education, the present research represents a potential bridge between current algorithms of analogical thinking and the real-world activities whose patterns of analogical retrieval they are meant to reproduce. Further pursuing this line of research might inspire the refinement of current theoretical models, so as to better account for how the mechanisms responsible of analogical retrieval adapt to the rich variety of activities that analogical retrieval can productively subserve.

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