# Promoting Spontaneous Analogical Transfer by Idealizing Target Representations

**Máximo Trench (maxtrench@gmail.com)**
Department of Psychology, Universidad Nacional del Comahue,
IPEHCS/CONICET-UNCo. Quintral 1250, Bariloche, Rio Negro, Argentina

**Lucía Micaela Tavernini (micaelatavernini@gmail.com)**
Department of Psychology, Universidad Nacional del Comahue
IPEHCS/CONICET-UNCo, Irigoyen 2000, Cipolletti, Río Negro, Argentina

**Robert L. Goldstone (rgoldsto@indiana.edu)**
Department of Psychological and Brain Sciences, Indiana University
1101 E. 10th St., Bloomington, Indiana

## Abstract

Recent results demonstrate that inducing an abstract representation of target analogs at retrieval time aids access to analogous situations with mismatching surface features (i.e., *the late abstraction principle*). A limitation of current implementations of this principle is that they either require the external provision of target-specific information or demand very high intellectual engagement. Experiment 1 demonstrated that constructing an idealized situation model of a target problem increases the rate of correct solutions compared to constructing either concrete simulations or no simulations. Experiment 2 confirmed that these results were based on an advantage for accessing the base analog, and not merely on an advantage of idealized simulations for understanding the target problem in its own terms. This target idealization strategy has broader applicability than prior interventions based on the late abstraction principle, because it can be achieved by a greater proportion of participants and without the need to receive target-specific information.

*Key words:* analogy, transfer, idealization, retrieval

## Introduction

Analogical reasoning represents a powerful heuristic for creative problem solving. By matching an unsolved situation (the *target analog*) to a stored exemplar whose solution is known (the *base analog*), the base solution can be transferred to the target problem. One of the most robust findings in the experimental literature on analogical transfer is that people often fail to spontaneously retrieve analogous situations when they do not share surface features with the target situation being processed (Gick & Holyoak, 1980; Keane, 1987; Trench, Oberholzer, & Minervino, 2009, for a discussion of naturalistic findings, see Trench & Minervino, 2015).

A considerable body of research has sought to enhance spontaneous analogical retrieval by means of promoting a more abstract encoding of the base analogs, so as to render them more accessible during later encounters with analogous situations lacking surface similarities with the base analogs. Two successful interventions have consisted in presenting the base analog together with its abstract schema (Goldstone & Wilensky, 2008) or with a second analogous situation (Catrambone & Holyoak, 1989), and asking participants to compare them. More stripped-down interventions include asking participants to discuss the base analog with another student (Schwartz, 1995), to explain the problem to themselves (Ahn, Brewer, & Mooney, 1992) or to construct a structurally equivalent problem (Bernardo, 2001). Even if participants are not asked to elaborate on the base situations, transfer advantages can still be obtained by means of removing irrelevant information in the base analog (Goldstone & Sakamoto, 2003), and even by replacing domain-specific terms of the base situation with domain-general ones (e.g., replacing “typing” by “writing”, Clement, Mawby, & Giles, 1994). What all of these interventions have in common is the highlighting of the abstract structure of the base analogs. As future, relationally similar examples will have a stronger match with such stripped-down representations than they will with specific examples having surface features that mismatch, the future retrievability of relationally encoded base analogs increases. Despite the relative success of these interventions, they cannot be applied to already learned situations or procedures that had not been originally encoded in ways that highlighted their abstract structure.

### The late abstraction principle

Kurtz and Loewenstein (2007) reasoned that as retrieval depends on the degree of match between the stored items and the memory probe, the beneficial effect of relational schemas should also apply when elaborating on the target analog at retrieval time. The removal of lower-level information was hypothesized to increase distant retrieval (1) by granting more weight to structural predicates due to the normalization of content vectors, and (2) by reducing the unwanted activation of competing situations that maintain only superficial similarity with the target. To gather behavioral evidence for this theory-laden prediction, Kurtz and Loewenstein (2007, Experiment 1) assessed the effectiveness of an intervention that consisted in providing participants with a second (unsolved) problem that was isomorphic to the target problem to be solved, and asking them to compare both problems prior to attempting their solution.

As was the case with the "base comparison" interventions, the abstraction process induced by this "target comparison" procedure resulted in enhanced transfer of the base solution as compared to the standard base-target paradigm. In subsequent work, Gentner, Loewenstein, Thompson and Forbus (2009) generalized the benefits of the target comparison strategy to autobiographical memories that were acquired several years prior to the experimental session, and also simulated the process of backward transfer using a retrieval algorithm and a set of stories that were developed before the late analogical encoding hypothesis had been proposed. To carry out these simulations, Gentner et al. (2009) fed MAC/FAC (Forbus, Gentner, & Law, 1995), with either the original stories from the Karla the Hawk series of studies (Gentner, Rattermann, & Forbus, 1993) or with their respective abstract schemas, and had it run on a long-term memory comprising analogical matches, mere appearance matches, and several filler stories. In line with the target-comparison studies, MAC/FAC retrieved more analogical matches when using the schemas rather than detailed stories as working memory cues.

As suggested by the results of the target-comparison studies, the process of *late analogical abstraction* opens a promising avenue for retrieving base situations whose initial encoding was not especially engineered to highlight their abstract properties, and which represent the vast majority of the situations we learn within and outside instructional settings. In contrast to the widespread potential applicability of the late analogical abstraction principle, however, the specific target-comparison intervention falls short of representing a truly portable cognitive strategy because participants will depend on the external provision of a second analogous problem for every new target problem they are to solve.

With the aim of helping learners capitalize on late analogical abstraction without needing to be provided with additional information about the target, Minervino, Olguín and Trench (2017) demonstrated that analogical transfer from a distant source analog can be enhanced by asking participants to invent a new unsolved problem analogous to the target. Even though successful problem constructors were much more likely than unsuccessful constructors to transfer the base solution to the target problem, only a small proportion of participants succeeded at fabricating an analogous problem, an activity that seems to require a great deal of world-knowledge and above-average intellectual engagement.

In order to devise more widely applicable ways of capitalizing on the late abstraction principle, in the present study we identified an easily executed strategy credited with having enhanced the retrievability of base analogs during their initial encoding, and assessed whether its application to the target analog proves advantageous for retrieving analogous problems lacking surface similarities.

## Concrete vs. idealized representations

Goldstone and Sakamoto (2003) examined whether there was an effect of training with concrete or idealized graphics on spontaneous transfer of a general principle called "competitive specialization." Participants were trained with an Ants and Food simulation with concrete graphics (black ants and small fruit) or idealized elements (black dots and green blobs) as shown in Figure 1. Afterwards they were asked to explore another instance of the competitive specialization principle in which initially undifferentiated matrices progressively learn to respond to a predefined set of letter inputs. Results revealed that participants in the idealized condition showed better transfer to the Sensors and Inputs quiz than in the concrete condition.

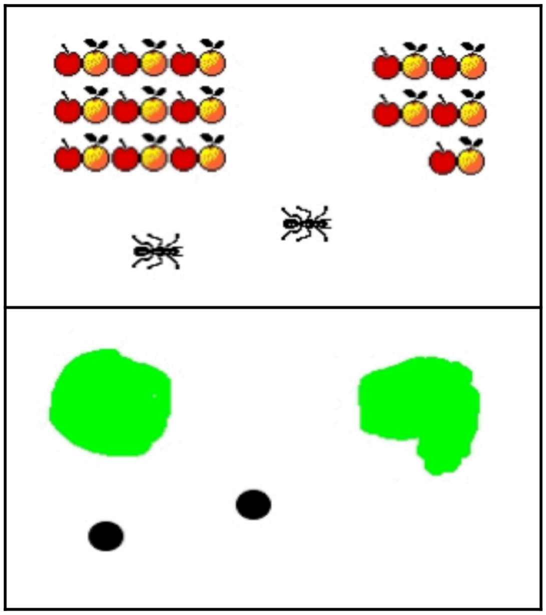

Figure 1. Snapshots of the concrete and idealized simulations of base analogs employed by Goldstone and Sakamoto (2003).

In order to assess whether a comparable transfer advantage can be obtained by inducing a more idealized representation of the target analog at retrieval time, we had three groups of participants learn how to solve a "collision" problem in which a plane and a helicopter travelled towards each other at different speeds. After a distracting task, participants were presented with a problem pertaining to a different family of algebra problems (i.e., "work problems"), but whose abstract structure was similar to that of the learned problem. In this problem, participants had to calculate the time that two painters would need to jointly paint a wall, given the times that each of them would have needed to paint it on his own. Before being asked to actually solve the problem, two of the groups were presented with a set of manipulatives and were tasked with carrying out an approximate representation of the situation described by the target problem as it unfolded from the initial moment until the moment when the wall got completed. While participants in the *concrete* condition received a realistic illustration of a horizontally laden wall and two smaller rectangles printed with drawings of painters, participants in the *idealized* condition received similarly sized paper rectangles without any figurative illustrations.

## Experiment 1

### Method

**Participants and design** A total of 90 participants were recruited from the Department of Psychological and Brain Sciences participant pool at Indiana University-Bloomington. All participants signed an informed consent for participation in the study, and were compensated with course credit. An equal number of participants (*N* = 30) were randomly assigned to the idealized, the concrete, and the no simulation conditions.

**Procedure and materials** The experimental session was introduced to participants as dealing with the effectiveness of instructions for solving different kinds of algebra problems. Participants were told that for most of the problem types to be covered during the session, they would begin by trying to solve a problem of such type on their own, follow by reading instructions on how to solve such problem, and finish by applying the learned strategy to a subsequent problem of the same type. Unbeknownst to participants, the first block served to encode a base analog and its solution, the third block was used as a test of whether participants spontaneously applied the base solution to a seemingly unrelated problem that admitted a similar solution strategy, and the middle block served to contextually separate the first and third blocks. Upon receiving a booklet containing the materials, they were told that they would be informed in advance how much time they would have for carrying out each of the tasks, and that they could only proceed to the following page of the booklet once the experimenter had notified them that the allotted time for the current activity had elapsed. Participants were also provided with a pencil, an eraser, and an electronic calculator. The session was administered in small groups ranging from one to ten, with each participant working individually.

During the first block of problems (i.e., the encoding phase), participants of all groups were presented with a typical "collision" problem in which a plane and a helicopter initially located at two cities 2000 miles apart started travelling towards each other at different speeds (See Table 1). Participants were allotted 5 min to calculate the time the aircrafts would need to pass next to each other. Once the allotted time had elapsed, they were given 3 min to read a worked solution to such problem that included a standard illustration in which the plane and the helicopter were located at their respective cities A and B, which were in turn connected by a straight horizontal line. Participants were given 4 more min to apply the learned strategy to a similar problem in which a helium balloon and an elevator located at the top vs. bottom of a tall building begin travelling toward each other at different speeds (see Table 1). Given that achieving a basic understanding of the base problem and its solution represents a necessary prerequisite for subsequent transfer to occur, participants who failed to apply the base solution to this second problem were withdrawn from further analysis.

Table 1: Base and target problems used in Experiment 1

**Base problem:** A plane flies at 600 mph, while a helicopter flies at 100 mph. Imagine that the plane starts flying from City A to City B at the same time that the helicopter departs from city B to City A. How long will it take them to pass each other, if the cities are 2000 miles apart?

**Base problem 2:** While a helium balloon goes up at a speed of 2 feet per second, an external elevator travels at a rate of 4.5 feet per second. Suppose that the elevator starts descending from an altitude of 100 feet at the same moment that the balloon is freed from street level. How long will it take them to pass each other?

**Target problem:** Fred can paint an 18-feet wall in 8 hours, while Bob can paint such wall in 5 hours. How long will it take them to paint such wall in case they painted it together?

The second block of problems had the same structure and time allowances as the encoding phase, with the difference that it involved learning and applying a simple procedure for solving combinatorics problems that were unrelated to the prior problems. It thus served to contextually separate the encoding and transfer phases.

The third section (i.e., the transfer phase) was presented to participants of all groups as dealing with "work" problems, and had a different structure than the two previous phases. For brevity, we begin by describing the procedure followed by the concrete simulation group, and proceed by describing how the other conditions differed from such condition.

Participants of the concrete simulation condition received a typical work problem in which they had to calculate the time that two painters would need to jointly paint a wall, given the times that each of them would have needed to paint it on his own (see Table 1). They were given 2 min to read the problem very carefully, but they were asked to refrain from attempting a solution until explicitly indicated by the experimenter. Right below the problem text, the page displayed a 6.37 in x 1.84 in sized illustration of a brick wall printed in greyscale. Upon receiving two small paper rectangles each one illustrated with a figurative drawing of a painter (one grey and one black, see Figure 2), participants were asked to take advantage of these manipulatives to carry out an approximate representation of how the painting of the wall unfolds over time, from the moment the painters start their job until the moment when it gets completed. In order to get a record of the specifics of each participant's simulation, the next page included three similar walls meant to represent three different snapshots of the dynamic simulation they had just performed. Upon receiving four additional paper painters (two grey and two black) and a glue stick, they were allotted 2 min to produce a record of the simulation they had just performed by means of sticking two painters onto each wall in a manner faithful to the locations of each of the painters at three different moments: (1) at the exact moment when they started painting [top wall], (2) at an intermediate stage of the process [center wall], and (3) at the exact moment when the painting job was completed [bottom wall]. Once the time allotted to this activity had elapsed, participants were given 5 min to solve the problem by any means.

The procedure followed by the idealized simulation group was identical to that of the concrete simulation condition, with the difference that the manipulatives used during the simulation were relatively more abstract. While the wall consisted of a white 6.37in x 1.84in sized rectangle, the two painters were represented by 1.6in x 0.75 in sized grey/black paper rectangles.

The procedure followed by the no simulation group was identical to that of the simulation conditions, with the difference that participants were not asked to simulate the situation models of the target problem prior to attempting its solution.

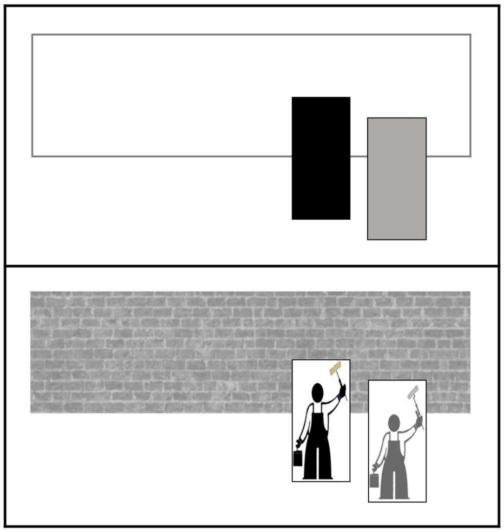

Figure 2: Manipulatives employed for the idealized (top panel) and concrete (lower panel) representations of the target problem.

**Data analysis** Two independent judges sorted the solutions to the posttest (the "collision" problem featuring a balloon and a helicopter) as either correct or incorrect. Solutions were scored as "correct" whenever (1) the collision time obtained was expressed with at least one decimal position and coincided with the exact solution, and (2) the participant showed how such result was derived. Eight participants (five from the concrete simulation condition, three from the no Simulation condition and one from the idealized Simulation condition) were not able to apply the base solution to the balloon problem, and were thus removed from further analyses. Two additional judges blind to the purposes of the experiment followed the above criteria to score participants' solutions to the target problem. Judges reached 94% agreement regarding solutions to the balloon problem and 96% agreement regarding solutions to the target problem. Cases of disagreement were resolved by discussion.

## Results and Discussion

The rates of correct solutions to the target problem were 36%, 79%, and 51% for the concrete, idealized and no simulation conditions, respectively. The spontaneous transfer rate in the idealized condition was reliably greater than those obtained in the concrete, $\chi^2(1, N = 54) = 10.43$, $p = .0012$, and in the no simulation conditions, $\chi^2(1, N = 56) = 4.7$, $p = .0302$. The rates of spontaneous transfer did not differ between the concrete and the no simulation conditions, $\chi^2(1, N = 52) = 1.32$, $p = .2506$ These results indicate that idealized representations were more advantageous than concrete representations for eliciting correct answers to the work problem. On the other hand, the fact that the idealized simulation condition also outperformed the no simulation condition suggests that there are genuine benefits of idealization as opposed to disadvantages due to concrete representations.

In a manner similar to the transfer advantage of comparing two analogous targets (Gentner et al. 2009), the observed advantage of the Idealized Simulation Group in generating correct solutions suggests that there is a general advantage of lean representations for accessing analogous situations lacking superficial similarities with the target. However, an alternative explanation could be that the concrete representations of the painters might have invited a dynamical representation that was inconsistent with the "convergent" representation that characterized the base problems. If the concrete simulation of the painters' activity recruited a "socially laden" representation in which the painters advance in parallel fashion—e.g., to talk to each other—rather than in the more transfer-appropriate "converging" motion, this idiosyncratic accidental feature could have contributed to their inferior transfer performance. In order to assess this possibility, we sorted participants' representations as "convergent" vs. "non convergent" according to the way in which they had glued the painters onto the three walls that were meant to record three informative snapshots of how participants intuitively imaged the process as it unfolded over time. This analysis revealed a nonsignificant trend towards a greater use of the convergent representation in the concrete simulation condition (96%) than in the idealized simulation condition (76%), $p = .056$ (Fisher exact test). Given that the opposite trend would have been expected under the socially-laden interpretation account, the relative advantage of idealized simulations appears not to be due to an intrinsic advantage this kind of representations for prompting a convergent motion simulation.

Another alternative explanation for the superiority of target representations for eliciting correct solutions to the work problem could be that such advantage was originated, not in the benefits of our idealized materials for analogical transfer (as posited here), but rather in their potential to promote a better understanding of the target problem in its own terms, thus leading to a higher probability of solving such problem by first principles. According to various authors (see Belenky & Schalk, 2014 for a discussion) learning is facilitated when representations convey the minimum detail that is necessary to grasp the quantitative structure of a problem. As an example, the removal of potentially distracting irrelevant features like the quasi-regular pattern of the bricks or the left vs. right handedness of the painters could have helped participants build a more accurate representation of the temporal dynamics of the problem (e.g., the different speeds of each painter), which may in turn serve as a secure foundation from which to control the accuracy and soundness of algebraic manipulations (Minervino, Trench, & Oberholzer, 2009).

In order to assess how the concrete and idealized simulations enforced in Experiment 1 impacted the raw probabilities of solving the target problem in a non-analogical fashion, in Experiment 2 the transfer phases of the idealized, concrete and no simulation conditions were not preceded by the presentation of a structurally equivalent base analog.

## Experiment 2

### Method

**Participants and design** A total of 90 participants ($N = 30$ per condition) were recruited from the Department of Psychological and Brain Sciences participant pool at Indiana University-Bloomington, and were compensated with course credit.

**Procedure and materials** The experimental session was introduced to participants as dealing with the effectiveness of different instructional aids for solving algebra problems, and took place after participants completed an unrelated experiment whose length was roughly equivalent to the time taken by participants of Experiment 1 to complete the encoding plus distracter phases. Upon receiving a booklet containing the materials, they were told that they would be informed in advance how much time they would have for carrying out each of the tasks, and that they could only proceed to the following page of the booklet once the experimenter had notified them that the time allotted to the current activity had elapsed. Participants were also provided with a pencil, an eraser, and an electronic calculator. The session was administered in small groups ranging from one to ten, with each participant working individually.

Participants of the simulation conditions received the painters' problem coupled with the same manipulatives and the same simulation tasks as in the corresponding groups of Experiment 1. After completing the simulation tasks, they were given 5 min to try solving the problem by whatever means. The procedure followed by the No Simulation Group was identical to that of the simulation conditions, with the difference that participants were neither provided with manipulatives nor invited to simulate the situation model of the problem prior to attempting its solution. Coding of correct solutions followed the same criteria as in Experiment 1, with judges reaching total agreement.

### Results and Discussion

The rates of correct solutions to the target problem were 37%, 30%, and 33% for the concrete, idealized and no simulation conditions, respectively. The rate of correct solutions in the idealized condition did not differ from that obtained in the concrete condition, $\chi^2(1, N = 60) = 0.3$, $p = .5839$. Similarly, differences were neither found between the no simulation and the idealized simulation conditions, $\chi^2(1, N = 60) = 0.08$, $p = .7773$, nor between the no simulation and the concrete simulation conditions, $\chi^2(1, N = 60) = 0.07$, $p = .7913$. The fact that the rate of correct solutions obtained by the Idealized Simulation Group was not even numerically higher than those of the concrete and the no Simulation conditions (in fact it was slightly lower) confirms that the advantage of idealized simulations over the other conditions of Experiment 1 did not originate in their ability to promote a better comprehension of the target problem, but rather in an advantage for transferring a previously learned solution to a superficially dissimilar target.

## General Discussion

The present results are compatible with Gentner et al.'s (2009) late abstraction principle, which postulates that just as source abstractions can be beneficial for later analogical retrieval (i.e. forward transfer), manipulations aimed at highlighting the structure of the target can enhance the retrieval of superficially similar base analogs whose encoding was not intended to emphasize their structural features. It should be noted, however, that the perceptual nature of our concrete vs. idealized manipulation is very different from the "conceptual" abstraction induced by Kurtz and Loewenstein (2007) or Minervino et al. (2017), and computationally simulated by Gentner et al. (2009). In the above studies (see Trench & Minervino, 2017 for a review), the domain-specific elements of the original problems (e.g., "destroy a tumor") are allegedly replaced by more domain-general expressions (e.g., "neutralize a central target"), which could promote distant retrieval in at least two different ways: (1) by granting more relative weight to the relational predicates of target representations, and (2) by decreasing the retrieval of *mere appearance matches* that could outcompete useful base situations with dissimilar surface features but similar structure. The fact that we obtained similar results by means of removing perceptual detail from the target representations suggests a subtle parallelism between the abstraction process that takes place in tasks like problem comparison or problem construction and the kind of idealization induced by our manipulation of the target. Akin to the advantage of abstract retrieval cues in the MAC/FAC simulations of the late abstraction principle, the observed advantage of idealized simulations of the target analog might have originated in their tendency to be, on average, perceptually more similar to the superficially dissimilar base analogs compared to their alternative concrete representations, as well as in their being less likely to evoke superficially matching situations that could outcompete the base analog. The present results thus contribute to enlarging the empirical basis of the late abstraction principle, while at the same time broadening its scope so as to include a perceptual dimension that has not been thus far discussed in the existing literature.

Much of the excitement over target elaborations stems from the possibility of retrieving base analogs learned under conditions that were not especially engineered to highlight their abstract features. If the *encoding specificity hypothesis* applied, however, any advantage of distilling abstract or idealized representations of the target would be limited to maximizing the retrieval of stored representations whose initial encoding had already emphasized those same features (Tulving & Thompson, 1973). As discussed in more detail elsewhere (Trench & Minervino, 2017), there are several ways in which a base analog can be suboptimally encoded, and yet benefit from a more structural representation of the target.

Beyond their relevance for theoretical models of analogical retrieval, the present results bear implications for the design of interventions aimed at fostering a flexible use of learned contents. On the one hand, the fact that asking participants to carry out idealized simulations led to higher solution rates than not requiring them to perform any kind of simulation indicates that the superior performance of the idealized condition was not based on an intrinsically detrimental effect of concrete simulations. More importantly, the activity of constructing idealized representations of the target overcomes important limitations of previous instantiations of the late abstraction principle. With regards to Kurtz and Loewenstein's (2007) target-comparison intervention, an important shortcoming had to do with the need to provide participants with a second analogous target for every problem to be solved by analogy. Even though Minervino et al.'s (2017) target-construction intervention was not subject to this crucial limitation, only a small proportion of participants were able to generate an isomorphic problem. In contrast to the above instantiations of the late abstraction principle, the cognitive strategy assessed in the present study can be easily implemented by a great majority of participants, and without needing to be provided with additional information about the target. Future research should assess whether the advantages of target idealization can be combined with the benefits of *strategic search* (see e.g., Trench, Olguín, & Minervino, 2016), as well as whether they generalize to other educationally relevant activities such as generating explanatory hypotheses for poorly understood phenomena or communicating complex ideas to others.

## Acknowledgments

This work was supported by Grants PICT 2352 and 2650 from the ANPCyT of Argentina, Grants B213, C123 and C134 from the National University of Comahue, and by a Fulbright research fellowship to the first author of this paper.

## References

Ahn, W. K., Brewer, W. F., & Mooney, R. J. (1992). Schema acquisition from a single example. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 391-412.

Belenky, D. M., & Schalk, L. (2014). The effects of idealized and grounded materials on learning, transfer, and interest: An organizing framework for categorizing external knowledge representations. *Educational Psychology Review*, 26, 27–50.

Bernardo, A. B. I. (2001). Analogical problem construction and transfer in mathematical problem solving. *Educational Psychology, 21*, 137–150.

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

Clement, C., Mawby, R., & Giles, D. (1994). The effects of manifest relational similarity on analog retrieval. *Journal of Memory and Language, 33*, 396–420.

Forbus, K., Gentner, D., & Law, K. (1995). MAC/FAC: A model of similarity-based retrieval. *Cognitive Science*, *19*, 141–204.

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

Gentner, D., Loewenstein, J., Thompson, L., & Forbus, K. (2009). Reviving inert knowledge: Analogical abstraction supports relational retrieval of past events. *Cognitive Science*, *3*, 1343-1382.

Gentner, D., Rattermann, M. J. & Forbus, K. D. (1993). The roles of similarity in transfer: Separating retrievability from inferential soundness. *Cognitive Psychology*, *25,* 431–467.

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

Goldstone, R. L., & Sakamoto, Y. (2003). The transfer of abstract principles governing complex adaptive systems. *Cognitive Psychology, 46*, 414-466.

Goldstone, R., L., & Wilensky, U. (2008). Promoting transfer by grounding complex systems principles. *Journal of the Learning Sciences*, *17,* 465-516

Keane, M.T. (1987). On retrieving analogues when solving problems. *Quarterly Journal of Experimental Psychology, 39*, 29–41.

Kurtz, K., & Loewenstein, J. (2007). Converging on a new role for analogy in problem solving and retrieval: When two problems are better than one. *Memory & Cognition, 35*, 334-341.

Minervino, R., Olguín, V., & Trench, M. (2017). Promoting interdomain analogical transfer: When creating a problem helps to solve a problem. *Memory & Cognition*, *45*, 221-232.

Minervino, R., Trench, M., & Oberholzer, N., (2009). Concrete and imagined simulations of situation models enhance transfer of solutions to structurally different algebra word problems. In N. A. Taatgen & H. Van Rijn (Eds.), *Proceedings of the 31st Annual Conference of the Cognitive Science Society* (pp. 1394-1399). Austin, TX: Cognitive Science Society.

Schwartz, D. L. (1995). The emergence of abstract representations in dyad problem solving. *The Journal of the Learning Sciences, 4*, 321-354.

Trench, M., & Minervino, R. (2015). The role of surface similarity in analogical retrieval: Bridging the gap between the naturalistic and the experimental traditions. *Cognitive Science, 39,* 1292-1319.

Trench, M., & Minervino, R. (2017). Cracking the problem of inert knowledge: Portable interventions to access distant analogs from memory. In B. H. Ross (Ed.), *The Psychology of Learning and Motivation*, Vol. 66 (pp. 1-42). San Diego, CA, Academic Press.

Trench, M., Oberholzer, N., & Minervino, R. (2009). Dissolving the analogical paradox: Retrieval under a production paradigm is highly constrained by superficial similarity. In B. Kokinov, K. Holyoak & D. Gentner (Eds.), *New frontiers in analogy research* (pp. 443-452). Sofia: NBU Press.

Trench, M., Olguín, V., & Minervino, R. (2016). Seek, and Ye shall find: Differences between spontaneous and voluntary analogical retrieval. *Quarterly Journal of Experimental Psychology, 69,* 698-712.

Tulving, E., & Thompson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review, 80,* 352–373.