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Dynamics of Analogical Retrieval: Evaluating Spontaneous Access by Reversing the Traditional Presentation Order of Analogs During a Hypothesis-Generation Task

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Abstract

Analogical studies demonstrate that participants often fail to retrieve a well-learned base analog during the subsequent processing of a semantically-distant target analog. We evaluated whether presenting the target analog before the base analog increases analogical retrieval during hypothesis-generation. Experiment 1 revealed a higher rate of analogical retrieval when the target analog preceded the base analog, as compared to the traditional “base-target” sequence. Using a factorial design, Experiment 2 assessed whether spontaneously acknowledging the relevance of a subsequently encountered explanation for resuming a failed explanatory attempt requires the presence of structural similarities between the base and target situations. Results demonstrated that the primary contributor to spontaneous reactivation of a failed explanatory attempt is the presentation of an analogous phenomenon, while the presence of a useful explanation alone did not yield a significant impact. These findings contribute valuable insights to the dynamics of analogical retrieval and offer relevant implications for educational strategies.

Keywords: analogy; access; hypothesis-generation; dynamics of retrieval

Introduction

The ability to detect deep abstract commonalities across situations is one of the hallmarks of human cognition. Upon acknowledging that the elements of two seemingly disparate situations are organized by similar systems of relations and roles (i.e., structural similarity), reasoners can tentatively transfer useful information from a well-known situation (base analog) to a less known situation (target analog), thus enhancing its comprehension.

The experimental paradigm most widely used to study how people retrieve and use analogous situations involves two phases. During the learning phase, participants receive a base analog (e.g., a problem and its solution). Following a contextual separation, they are presented with a target situation (e.g., an unsolved problem) whose structure is

similar to that of the base analog. Sadly, most studies demonstrate that in the absence of similar objects and first-order relations (i.e., surface similarity), novice individuals often fail to spontaneously retrieve an analogous case from long-term memory (Catrambone, 2002; Holyoak & Koh, 1987; Keane, 1987; Olguin et al., 2022; Trench & Minervino, 2015).

The traditional research paradigm employed in studies of analogical reasoning is easily generalizable to many educationally-relevant situations (e.g., when students learn some content in class that they may later apply to an exam). In another frequent condition, however, the problem faced by the reasoner *precedes* the situation that could provide a solution. Consider, for example, the famous anecdote of the Swiss engineer George De Mestral. Triggered by a stuck zipper in his wife’s dress, he strived to devise another mechanism that could serve a fastening function without the common issues of obstruction. During a subsequent walk in the countryside, the burrs that had firmly stuck to his dog’s legs reminded him of the problem he had contemplated earlier, leading to the invention of Velcro. In this case, the solution appeared after an unsuccessful attempt to solve the problem. Besides these kinds of anecdotal episodes, evidence from laboratory and naturalistic studies demonstrates the existence of such phenomenon (Moss, et al., 2007, 2011; Shaw, 2022; Sio & Ormerod, 2015).

According to opportunistic assimilation theory (Seifert et al., 1995), unsuccessful attempts to solve a problem lead to the generation of a failure index in long-term memory that renders the unsolved problem comparatively more retrievable than problems that were successfully solved (Seifert & Patalano, 1991; Patalano & Seifert, 1994, Zeigarnik, 1938). A relevant condition for a problem to be stored as a failure index is that the reasoner reaches an *impasse*, wherein solution attempts are abandoned after diligent efforts (Moss, 2011). For an unsolved problem to be retrieved when potentially useful information appears, the relevant cues that future environmental stimuli should display in order to help

retroactively solve the problem must be encoded during the initial processing of the problem, and identification of latter opportunities will depend on the generality of these anticipated cues (*predictive encoding*, Patalano & Seifert, 1997). Upon a fortuitous encounter with one of the stimuli that were predictively encoded as relevant, the initial problem can be reactivated in working memory to resume the solution attempt.

In an extension of the opportunistic assimilation hypothesis to the realm of analogical retrieval, Christensen and Shunn (2005) assessed the extent to which participants returned to a previously unsolved target analog when encountering a base analog with a potentially useful solution. During the main task, 40 participants had to find solutions for eight insight problems. Each problem was presented on a separate page, and participants were allowed to move freely between problems during the experiment. Every five minutes, the experimenter interrupted the problem-solving activity with a second task wherein participants had to rate different solved problems according to their difficulty. The problems to be evaluated in this second activity could be analogous or else unrelated to one of the problems presented during the problem-solving task. Spontaneous returns to a relevant unsolved problem were more frequent when receiving an analogous cue than a distractor, thus supporting the opportunistic assimilation hypothesis. However, one limitation for generalizing their results to real-life conditions concerns the temporal juxtaposition between the problem-solving and the problem-evaluation activities, which might have invited a connection between tasks to a higher extent than a non-overlapping presentation scheme.

The importance of opportunistic assimilation for the study of analogical reasoning concerns whether spontaneous analogical retrieval would increase if the presentation of the target analog preceded the appearance of the base analog. Despite the relevance of this implication, we know of only one study that has attempted to assess whether reversing the presentation order of the base and target analogs could outperform the traditional base-then-target sequence in promoting spontaneous analogical retrieval.

Gick and Holyoak (1980, Experiment 5) found no significant differences in the spontaneous transfer of the base solution to the target problem between a group who received the analogs in the traditional "base-target" presentation order and a "target-base-target" condition who reattempted solving the target after being exposed to the base analog. The fact that both conditions outperformed a third "target-distractor-target" group that worked twice on the target without having received a base analog suggests that, albeit not more advantageous than the traditional base-target sequence, the target-base ordering still allows participants to transfer the base solution to the target. This conclusion, however, should be taken with caution due to the low number of participants in each condition ($Ns < 21$), as well as to the impossibility of determining whether participants in the target-base-target condition noticed the relevance of the base analog during its initial processing or during the second encounter with the target problem.

The first experiment of the present study sought to reassess the relative frequency of base-then-target and target-then-base analogical reminders with a more powerful sample, as well as through an experimental procedure that enables a more rigorous comparison between the base-target and the target-base sequences in terms of their probability of eliciting a spontaneous memory connection between the analogs. When comparing the proportion of subjects who applied the base solution to the target phenomenon, Gick and Holyoak's (1980) procedure does not allow determining the proportion of participants that recalled the base analog but failed to adapt it to the target. We reason that using a direct query about whether participants were reminded of the base analogs not only represents a sensitive measure of analogical access (see Catrambone, 2002; Gentner & Landers, 1985; Ripoll, 1998; Trench & Minervino, 2015), but also allows for a comparison of the base-target and target-base sequences without the need to expose participants to a second presentation of the target. Besides representing a purer measure of retrieval, the fact that participants in the target-base condition are not re-exposed to the target phenomenon eliminates the indeterminacy about the temporal locus of the base-target connection.

Finally, an additional feature of the present study was to frame the presentation of the target analog within *hypothesis-generation*, an epistemically-relevant activity that has remained understudied within the literature of analogical reasoning. Contrary to the transience of the problems we typically face, our explanatory hypotheses are subject to a review process that extends over time, and whose representational change occurs gradually (Carey, 2000; Inagaki & Hatano, 2013; Vosniadou & Skopeliti, 2014). The recursiveness that characterizes the generation of explanatory hypotheses is particularly appropriate for studying the spontaneous retrieval that takes place during the fortuitous encounter with potentially useful information.

Upon confirming the superiority of the target-then-base sequence for eliciting spontaneous analogical retrieval, a second experiment was designed to determine whether this advantage stems from the recognition of a useful explanation in the source analog, as posited by the opportunistic assimilation theory, or else from a structural isomorphism between base and target phenomena, as suggested by the literature on analogical reasoning.

Experiment 1

Method

Participants and Design An initial sample of 82 undergraduate students (Age $M = 24.7$; $SD = 8.5$; 52 women) from university majors unrelated to natural sciences volunteered to participate in the study. After signing an informed consent, participants were randomly assigned to the base-target condition ($N = 39$) and to the target-base condition ($N = 43$).

Materials The base and target situations involved mixtures with non-additive volumes (see Table 1). In the base analog, the volumes of brick stones provided by two different suppliers for the maintenance of tennis courts resulted, when

mixed, in a total volume less than the sum of its individual components. The provided explanation was that as the stones provided by one of the suppliers were smaller than the stones provided by the other, the smaller stones fit into the gaps left between the larger ones. The target analog depicted a situation wherein combining 1L of alcohol with 1L of acetone resulted in a mixture whose volume was 1.9L. Participants were asked to propose hypotheses that could plausibly explain why the resulting mixture was short of 2L.

Procedure The experiment was administered on the Qualtrics virtual platform. In the target-base condition, the first phase of the study was presented as a *hypothesis-generation* task. Participants began by reading a brief instructional material about the concept of causal explanation, which featured a scientific phenomenon along with two explanatory hypotheses. Upon reading this material, they received three counterintuitive phenomena with the task of generating plausible explanations. While the first and third phenomena served as distractors, the second phenomenon served as the target analog. Given the centrality of solution impasses within opportunistic assimilation theory, for each phenomenon participants had to rate on a 10-point scale how confident they were that one of the generated hypotheses was correct. To enforce a contextual separation between this phase and the presentation of the base analog, participants were presented with three pattern-completion exercises from Raven's Progressive Matrices Test (Arthur & Day, 1994). Once this activity was completed, participants moved on to the second phase of the study, which was presented as a *reading comprehension* task. During this activity, participants had to read two different stories, each presented on a different page. For each story, they had to employ a 5-point Likert scale to express the extent to which they found the story to be understandable (1 = not understandable at all; 5 = totally understandable). While the first story served as a distractor, the second story served as the base analog. Following the presentation of the base analog, participants were asked if the phenomenon about the liquid mixture (target analog) had come to their mind, even if briefly, while reading the tennis courts story. Finally, participants were told that the second story of the reading comprehension activity was analogous to the second phenomenon for which they had to generate plausible explanations, and were explicitly asked to explain this second phenomenon by analogy to the base situation. The purpose of this last measure was to assess whether eventual differences in spontaneous retrieval were due to certain intrinsic difficulties of our experimental materials.

The base-target condition received the same tasks and instructions as the target-base group, with the only difference being that the reading comprehension activity was presented during the first phase, and the hypothesis-generation activity was presented during the second phase of the study. Consequently, the recall questions for the target-base condition asked whether the tennis courts story read during the comprehension activity had been spontaneously recalled, even if briefly, while generating hypotheses for the non-additive mixture of liquid substances.

Table 1: Base and target analogs, Experiment 1.

Base analog. A club received an offer to purchase 4m³ of brick stones needed to maintain its tennis courts during the season. The reason for the low price was that the stones were not packaged but delivered in bulk. As there were no containers to store them, the person in charge of the court's maintenance decided to place them in an unused 4m³ kiddie pool. One store provided 3m³ of stones, and another provided 1m³ of another type of small pebbles. To everyone's surprise, when the trucks unloaded the stones, they did not fill the pool to its full capacity: they only filled 3.5m³. Later they understood the cause of this contraction: since the small pebbles were much smaller than the stones, when mixed together the small pebbles tended to fill the empty spaces between the larger stones.

Target Analog. After combining 1 liter of alcohol and 1 liter of acetone, the resulting volume is not equal to 2 liters, but to just 1.9 liters. Why do you think this could have happened?

Data Analysis Participants who reported having spontaneously recalled the critical episode of the first phase while processing the critical episode of the second phase were classified as "retrievers". For participants in the target-base condition, a score greater than 6 on the hypothesis generation task was considered as an indication that a participant had not reached an impasse during her attempts to generate a plausible explanation. Regarding performance on the informed transfer measure, participants' hypotheses were classified as appropriate whenever they mentioned (a) the process of stone compaction or (b) the different sizes of molecules, atoms, or particles as the cause of volume contraction.

Results

Eight participants from the target-base group were excluded from the sample because they either provided the correct hypothesis for the target analog during the hypothesis-generation task or gave a score greater than 6 to their own hypotheses for the target phenomenon, thus failing to meet the impasse criterion that opportunistic assimilation theory deems as a necessary prerequisite for generating a failure index for the target situation.

Whereas 37.14% of participants in the target-base condition reported having retrieved the target phenomenon while reading the base analog, only 15.38% of participants in the base-target group reported having retrieved the base situation while generating hypotheses for the target phenomenon. These results indicate that spontaneous analogical retrieval was significantly higher in the target-base than in the base-target condition, $\chi^2(1, 74) = 4.58, p = .032, \phi = .25$.

No significant differences were found between the average time spent on the target hypothesis for the target-base group and the base-target group (4.37 min. vs. 3.88 min., respectively, $t(73) = 1.99, p = .11$). The time spent on the target phenomenon did not predict spontaneous retrieval ($p = .677$).

The percentage of participants who could generate the expected hypothesis for the target phenomenon upon explicit request was virtually identical for both conditions (71% for the inverted order group and 74% for the traditional order group). The fact that most participants generated the intended explanation when explicitly informed about the relevance of the base analog rules out the possibility that spontaneous retrieval may have been affected by certain intrinsic difficulties of the constructed materials.

Discussion

The low level of retrieval obtained in the base-target group aligns well with most results in the analogical reasoning literature. In the absence of surface similarities between the base and the target analogs, novice participants typically fail to notice the deep structural commonalities between two analogous phenomena. However, the fact that the target-base group showed a significantly higher retrieval is particularly striking considering that the main computational models of analogical retrieval (MAC/FAC, Forbus, et al., 1994; LISA, Hummel & Holyoak, 1997) do not predict any advantage of presenting the target before the base analog, as compared to the traditional order of presentation.

The opportunistic assimilation theory (Seifert et al., 1995) provides a plausible explanation for the advantage of the target-base scheme over the base-target presentation. According to the theory, unsuccessful attempts to generate correct hypotheses for the target phenomenon could have been stored as failure indices in long-term memory which, in turn, aided a fraction of participants in recognizing the usefulness of subsequently encountered information that could potentially achieve this pending goal. As the traditional retrieval mechanism based on the detection of overlapping structure (e.g., MAC/FAC or LISA) would likely still operate under the target-base sequence, the operation of predictive indexing represents a plausible explanation for the increase in retrieval rates that was observed when shifting from the base-target to the target-base sequence.

Considering that the opportunistic assimilation theory does not grant any role to the analogical relationship between the base and target phenomena, a sensible research question concerns the extent to which the cognitive mechanisms postulated by the opportunistic assimilation theory would suffice to promote retrieval of an unexplained phenomenon during the subsequent encounter with a useful explanation (i.e., *explanans*), or whether its operation would still require, as in Experiment 1, a concomitant degree of structural overlap between the base and target phenomena (i.e., *explanandum*). By factorially manipulating the presence of a relevant *explanans* and/or an analogous *explanandum* within a reading material that was incidentally presented after failing to explain a target phenomenon, in a second experiment we aimed to assess if a structural parallelism between the target phenomenon and the potentially useful information to be subsequently presented is a necessary condition to promote the spontaneous retrieval of an unexplained target phenomenon.

Experiment 2

Method

Participants and Design 164 university students (Age $M = 28.5$; $SD = 10.9$; 119 women) from university majors unrelated to natural sciences voluntarily participated in the study. Participants were randomly assigned to four conditions that were related to the kind of information that was incidentally presented after an impasse had taken place. The factorial manipulation between the presence/absence of an explanation and the presence/absence of an analogous story yielded the following experimental conditions: Analog with explanation ($N = 39$), Analog without explanation ($N = 46$), Non-analog with explanation ($N = 40$) and Non-analog without explanation ($N = 39$).

Materials The same target analog from Experiment 1 was used for all groups. For the two conditions receiving an analogical phenomenon during the retrieval phase, the same base story from Experiment 1 was employed (see Table 1). For the two conditions receiving a non-analogous situation during the retrieval phase, a non-isomorphic story to the target was created. In order to maintain all conditions equal in terms of superficial similarities, the non-analogous story included objects and first-order relations that were semantically similar to those of the base analog. The non-analogous situation described a story where bags of stones that were purchased by a club to maintain its tennis courts turned out to be heavier than those of identical dimensions that were purchased the previous year (see Table 2). Conditions receiving an explanation were told that the cause of the phenomenon (be it analogous or non-analogous) was related to the size difference between stones, with smaller stones fitting into the empty spaces between the larger ones. Conditions without explanation did not receive any mention about the causes of the phenomenon.

Table 2: Non-analogous base items, Experiment 2.

Non-analogous base item with explanation: A club needed to purchase 4m³ of brick stones to maintain its tennis courts during the season. When they contacted their trusted supplier, they placed an order for 4 bags of brick stones, each containing 1m³. When the supplier brought the bags to the club, the owners decided to weigh them on one of the available scales. To their surprise, they realized that each bag was heavier than bags of identical dimensions they had bought the previous year. [The reason for this was that the bags they had brought this year were composed of mixed-sized stones, so the smaller pebbles tended to fill the empty spaces between the larger stones].

Note. Text between brackets was only included in the explanation condition.

Procedure All conditions followed the same procedure as the target-base group of Experiment 1. For those groups who did not receive the target explanation, the informed transfer task was eliminated.

Data Analysis The analysis of responses followed the same criteria as in Experiment 1. A logistic regression model was used for the statistical analysis of the data (in R-Studio).

Results

Eighteen participants were excluded from the sample due to having either provided a correct hypothesis during the initial hypothesis-generation task or assigned a score greater than 6 to their initial hypotheses, thus indicating that they had not reached an impasse during the target task.

The proportions of participants who spontaneously retrieved the base situation were 38.89% for the Analog with explanation condition, 58.33% for the Analog without explanation group, 16.67% for the Non-analog with explanation group; and 7.69% for the Non-analog without explanation group (see Figure 1). A logistic regression model revealed a positive effect of the presence of an analogical relationship between the base and the target phenomena (β Estimate = 2.66, SD = 0.69, Wald Z = 3.83, p < .001). However, no significant effects were found for the presence of a useful explanation (β Estimate = 0.69, SD = 0.77, Wald Z = 0.89, p = 0.368) or for an interaction between both factors (β Estimate = -1.32, SD = 0.91, Wald Z = -1.45, p = 0.145).

No group differences were found between the average time spent on the target phenomenon (p = .419), and the time spent on the target phenomenon did not predict spontaneous retrieval (p = .676).

When participants of the explanation conditions were explicitly hinted to transfer the base explanation to the target phenomenon, their success rates did not differ as a function of whether their explananda was analogous or not (75% vs 64%, p = .306), thus ruling out the possibility that spontaneous retrieval may have been affected by one condition bearing more intrinsic transfer difficulty than the other.

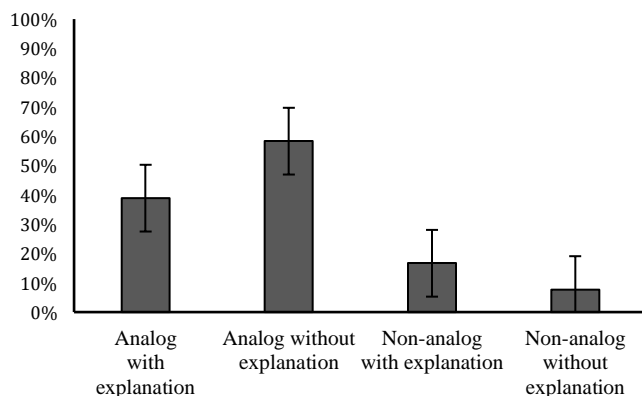


Figure 1: Spontaneous retrieval of related items, Experiment 2.

Discussion

The results from this second experiment indicate that the primary factor causing spontaneous retrieval of a phenomenon for which an initial hypothesis was not deemed successful is the fortuitous encounter with analogous information. When this type of information was accompanied by a relevant explanation, the results were practically identical to those of Experiment 1. Interestingly, retrieval reached its highest level when the analogous situation presented during the retrieval phase was not accompanied by any explanation. This effect could possibly be explained by considering that the base and target phenomena in this case were completely isomorphic, increasing the level of structural similarity between them. On the other hand, although the tasks proposed for the first and last phases of the experiment were explicitly different, the fact that the analogical phenomenon presented in the retrieval phase was not accompanied by an explanation may have led participants to attempt generating hypotheses for that phenomenon. As the cognitive operations engaged during the retrieval phase resembled those of the initial phase, they might have facilitated access to the target phenomenon (see Needham & Begg, 1991). Furthermore, if the absence of an explanation in the base analog led some participants to initiate a search for hypotheses, it is possible that other cognitive processes activated during the task of generating explanations (e.g., comparison and recognition of general patterns, Edwards, et al., 2019; Lombrozo, 2012), could have improved the understanding of the structural aspects of the base story, thus favoring analogical retrieval.

The fact that encountering a potentially useful explanation did not yield a significant effect fails to provide support a to the opportunistic assimilation theory, according to which a fortuitous encounter with relevant information (e.g., an explanation) in the environment tends to trigger retrieval of a previously unsolved problem. However, considering that the target phenomenon differs considerably in terms of semantic similarity with the explanation presented in the base analog, it seems reasonable that individuals may not have succeeded in noticing the relevance of a useful explanation before being explicitly informed of its explanatory potential.

General Discussion

The experimental paradigm mostly used in analogical studies involves presenting a solved problem (base analog) followed by a structurally similar problem to solve (target analog). Even though this sequence is representative of many challenges we encounter in both formal and informal settings, it still fails to capture a frequent real-life condition in which the problem to be solved precedes the potential solution. The present study explored the extent to which reversing the traditional presentation order affects analogical retrieval in the context of a hypothesis-generation task. As opposed to scholarly and everyday problems—most of which either get solved by others or simply cease to exist quite soon—our hypotheses about the world around us tend to undergo slow transformations, in a process of belief-revision that can span

considerably longer time intervals. For this reason, we considered that the ability to capitalize on the serendipitous appearance of relevant information would be particularly adaptive during hypothesis generation.

The results of Experiment 1 revealed that a significantly higher rate of analogical retrieval can be obtained if the target analog is presented before the base analog, as compared to the traditional order of presentation. Although this outcome could not have been predicted from the assumptions of the main computational models of analogical retrieval (e.g., MAC/FAC, Forbus, et al., 1994; LISA, Hummel & Holyoak, 1997), the opportunistic assimilation theory (Seifert et al., 1995) suggests that impasses during problem solving lead to the generation of failure indices in LTM. According to this account, predictive encoding could explain the reactivation of unsolved problems upon later encounters with information that could potentially serve to find a solution to the original situation.

In a subsequent experiment, we set forth to separate the contributions of predictive encoding and structure-based access to the memory connections that take place during the target-then-base order of presentation. The results of Experiment 2 showed that the primary factor contributing to the spontaneous retrieval of an unsuccessfully explained target analog was the appearance of an analogous cue, whereas the presence or absence of a useful explanation had a non-significant impact on retrieval.

Although the results of Experiment 2 do not seem to support the predictive encoding hypothesis as much as those of Experiment 1, it is important to consider that in our materials the semantic distance between the elements of the base situation and those of the target phenomenon was considerable. Predicting that a future event in which the non-additive mixture of stones could be a relevant cue to generate hypotheses about liquid mixtures might perhaps require an unusual ability to anticipate the enormous variability of future events that could be useful in addressing a pending explanation. Future studies implementing a less extreme semantic distance should be able to address whether the target-base sequencing still yields an advantage over the traditional base-target presentation, as well as whether the effects of being presented with a useful hypothesis after reaching an impasse still hold in the absence of a concomitant degree of structural overlap between the situations' explananda.

On the other hand, it should be noted that our participants were not instructed to engage in any preparatory effort during the initial hypothesis generation that would assist them in identifying future opportunities in the environment. These anticipatory efforts, however, might still fail in detecting a relevant explanation if the predicted cues retain too many superficial aspects of the original phenomenon. While there is evidence that comparing two unsolved problems can sometimes yield the kind of abstraction that is required for distant transfer (Gentner et al., 2009; Kurtz & Loewenstein, 2007), arriving at this kind of generalization out of a single example still represents a paramount challenge, especially for novices in a domain (Trench & Minervino, 2020). One potentially useful intervention to promote this kind of one-

shot generalization would consist in creatively devising analogous phenomena. Just as in Bernardo (2001), where generating an analogous problem helped participants abstract out its underlying structure in a manner that increased its future retrievability, it is possible that asking participants to craft an analogous phenomenon might likewise aid participants in producing the kind of generalizations that are required for successfully indexing an eventual explanatory failure in LTM.

Finally, the findings of the present study add to a growing body of educational research demonstrating the effectiveness of instructional designs in which problem-solving precedes formal instruction, as opposed to the more traditional "tell-and-practice" models (e.g., Schwartz et al., 2011; Kapur, 2008, 2014; Newman & DeCaro, 2019; see Sinha & Kapur, 2021 for a recent review). This research emphasizes that the disadvantage of teaching concepts before problem-solving is that the details of the learning contents are often memorized by students without effectively grasping their underlying structure. Expectedly, the initial presentation of unfamiliar problems typically results in initial solutions being incorrect. However, these prior instances of working with problems can enable students to conduct a more thorough analysis, preparing them to detect future learning resources that could aid in solving such problems. While the results of Experiment 1 align well with the logic behind the "problem-then-instruction" approach, the fact that in Experiment 2 a useful explanation proved insufficient to increase retrieval unless accompanied by an analogous case indicates that educators need to be cautious about the kind of information presented during the instructional stage. For students to capitalize on an opportunity where a potentially useful hypothesis is presented, educators should also include an analogous component along with the provided explanation. But even taking this into consideration, the low level of retrieval reported in our experiments seems to indicate that most of these opportunities are likely to be missed. This set of challenges underline the need for future research endeavors aimed at enhancing students' ability to recognize useful analogies when the opportunity arises.

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