Individual Differences in Spontaneous Analogical Problem-Solving: The Reflective Mind Account

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Abstract

Analogical problem-solving involves transfer of knowledge that has been obtained from a source analog and successfully applying it in the solution of a structurally similar target problem. What is usually found in the so-called hint/no-hint paradigm is that spontaneous solution to a problem is hard to achieve. This leaves the possibility for individual differences. This study searched for and found a positive correlation to exist between scores on the Cognitive Reflection Test and spontaneously solved analogical problems which, although a weak one, possibly accounts for the differences that exist between people who need a hint to solve an analogical problem, and people that do not need a hint.

Keywords: Analogy; Analogical problem-solving; Reflective Mind thinking; Cognitive Reflection Test

Introduction

Imagine you are presented with a problem – an oil well is on fire and is consuming large amounts of petrol every minute. You know you have enough foam to put out the fire, but if you use the one large hose that is available to shoot it at the well, the fire can be extinguished, but the pressure would also destroy the machines around the well that facilitate the oil extraction, which would be an expensive cost. If you use one of the several smaller hoses that are also available, the machines will be spared, but the fire would not be extinguished. How can this problem be resolved? Now, imagine that without any external hint to relate the problem to anything, you recall a story about an exhibition designer, who has to figure out a way to illuminate a replica of a ship, that is positioned in the center of transparent tank filled with water and fish that are sensitive to light. If the designer illuminates the replica with a powerful spotlight, the fish will be disturbed, but if she uses a low-powered spotlight, the ship would not be illuminated enough. So she decides to use several low-powered spotlights to illuminate the replica from several directions, which will not disturb the fish, but the focused light would be enough to illuminate the ship. In fact, these two superficially dissimilar problems are analogous – the solution to the fire problem is to shoot the foam using many small hoses from different directions so as to spare the machines, but also to provide enough foam to extinguish the fire. How many people would spontaneously think of using the solution of the problem they know to solve the analogous one? Probably not many, given that the stories appear to be different on the surface. The successful solver would probably need to be able to reflect on what he is processing, to suppress the irrelevant information, and set his priorities in accordance to the task at hand.

The paradigm that is used in studying analogical problem-solving requires a relevant analog known to the solver to be available, as well as the target problem that is presented to be sufficiently novel and challenging in order for the analogy to be useful (Gick & Holyoak, 1983). The framework that is generally required for the solver to represent the analogical relationships involves first of all a story describing the problem and how it is solved to be read and understood. Once the information is represented, it can be used to generate solution to the target problem by mapping the similar relations of the two systems, employing a top-down reasoning, forming expectations, and finally using the mapping in order to generate the solution to the target problem (Gick & Holyoak, 1980).

The "retrieval gap" in analogical problem-solving

In order to analogously solve the problem, participants must retrieve the correct analogical relationships. The role of retrieval is usually investigated in the so-called hint/no-hint paradigm (Novick & Holyoak, 1991). By giving a hint to the solver in one of the two experimental conditions, they are informed that the two stories are connected and the solution to one of them can be used in solving the other. If they are not given a hint in the no-hint condition, solving the target problem would indicate spontaneous analogical transfer. What is usually found is that about 75% of the people solve the Radiation problem[1] using the correct analogical solution when the appropriate analog story[2] had

[1] The Radiation problem is about a doctor who wishes to destroy a tumor in his patient's stomach using a ray. However, if he emits the rays at high intensity, the tumor will be destroyed, but so will be the healthy tissues of the patient. If a lower intensity is applied, the tissues will not be affected, but neither will be the tumor. In fact, the solution to this problem is analogous to the base Attack-Dispersion problem and requires the doctor to emit the rays at lower intensity from different directions simultaneously in order for the concentrated forces of the rays to destroy the tumor.

[2] The Attack-Desperation Problem was considered to be the superficially dissimilar analog of the Radiation Problem in Gick and Holyoak's study (1980). In that story a general wants to capture a fortress located in the center of the country. The problem arises when the general realizes he cannot send his troops all at once due to the mined roads, but if he divides his troops to small

been previously presented and they are given explicit hint to use that story for the solution (Gick & Holyoak, 1983). However, if no base story analog is presented, only less than 10% of the participants manage to find the correct solution. What Gick and Holyoak (1983) have found when their participants read the Attack-Dispersion story as a base, disguised to be remembered for a subsequent recall, is that 30% of them arrived at the correct solution of the Radiation problem presented subsequently, without receiving any hint, i.e. spontaneously. This apparent difference in the difficulty of mapping and retrieving the correspondences of an analog are referred to as "retrieval gap" (Holyoak, 2012), and can be considered in terms of at least 3 explanations:

Structural and surface similarity Problem-solving using analogs is very much dependent on the level of structural and surface similarity between the two stories in terms of the level of facilitation of retrieval (Blanchette & Dunbar, 2000; Holyoak & Koh, 1987). More specifically, if the superficial features of the base story are more similar to the ones of the target problem, spontaneous retrieval of convergence solution to the Radiation problem is as high as 90%, compared to about 20% if the surface features were dissimilar (Blanchette & Dunbar, 2000). It is suggested that because an analog that is from a remote domain, it does not share many of the salient surface features of the target, which might block the spontaneous retrieval of relevant analogs, unless the solver is able to focus on aspects that are causally related for the target (Holyoak & Koh, 1987).

The experimental paradigm Blanchette and Dunbar (2000) show in their experiments the importance of the experimental setting in which the participants reason analogically. In the so-called "reception paradigm", the participants are given base and target problems and are required to identify the relations between them. As Blanchette and Dunbar's (2000) experiment shows, this type of setting constraints the participants and prompts them to make more analogies based on superficial similarity. On the other hand, an experimental setting organized in a "production paradigm" involves participants being given the target problem and being asked to generate possible source stories, arguably resulting in analogy generation based on deep structural features. Two of the experiments in Blanchette and Dunbar's study (2000) involved analogical reasoning using production paradigm. The results clearly indicated production of more analogies that were structurally similar. Their third experiment used arguments from the previous two experiments as stimuli, but the task was arranged in a reception paradigm. The results showed domination of retrieval of superficially similar stories. The findings are explained in terms of different type of encoding in the different types of tasks. In "reception paradigm" tasks, the initial presentation of the problem is usually guised as a comprehension evaluation or measuring recall, which arguably causes the encoding to be more superficial. Furthermore, the base representation building may not necessarily include the relevant relations for the subsequent analogical problem solving. The "production paradigm", on the other hand, involves the participants in deeper structural encoding of the problem from the beginning, possibly resulting in more structurally similar analogies.

Possibility for individual differences The previously mentioned source Radiation problem, when learned in a different context, enables problem solvers to spontaneously produce the correct analogous solution to the superficially similar Lightbulb problem for 81% of the participants even several days after the presentation of the base problem (Holyoak & Koh, 1987). The results for the spontaneously solved problems are discussed in terms of the possible demand characteristics of the task, or in other words that the participants might suspect the two stories to somehow be related due to them being present in the same experiment (Gick and Holyoak, 1983). This might suggest the possibility of individual differences to be present, specifically that some people might be sensitive to events occurring in the same context and interpret them as connected. Day and Goldstone (2011) discuss the possibility of individual differences in intelligence or the level of engagement in the experiment to be responsible, at least to some extent, for the difference between the transfer and the reported understanding of the analogy itself. Another possibility for individual differences in spontaneous analogical problem solving can be drawn from the so called Reflective Mind (Stanovich, 2012). According to the Tripartite model (Stanovich, 2012), the Reflective Mind is able to initiate the suppression of the initial response, due to its higher cognitive level control, that is carried out by the Algorithmic mind[3]. The Reflective mind is tested in the so-called typical performance situations, in which participants solve tasks without overt instructions to maximize their success. Spontaneous problem solving resembles a typical performance situation, since participants in the no-hint condition are not explicitly instructed to find and use the analogy with previous problems. Moreover, the mechanisms of Reflective mind such as cognitive decoupling operation, allows a suppression of the initial response that is provided by the Autonomous mind and creating a secondary representation of the world that could be manipulated until the correct solution is reached and then applied in reality. Just like Day and Goldstone (2011) have argued that some individual differences due to intelligence (i.e. Algorithmic Mind) may explain the superior problem solving performance of some individuals, we argue that differences regarding the Reflective Mind can also be expected in analogical problem solving. Indeed, spontaneous analogies are especially interesting case for individual differences

units and attacks from many directions, they will not be affected and the combined forces will capture the fortress.

[3] Algorithmic mind can be associated to fluid intelligence capacities. It is a Type 2 processing, which is typically linked to situations that require an optimal performance and a correct answer should be obtained (Stanovich, 2012).

stemming from the Reflective mind. On the one hand, the ability to create a secondary representation of the problem that may hold and manipulate the base and target problems seems to guarantee a successful analogical problem solving. On the other hand, Holyoak (2012) has argued that the difficulties which people experience in spontaneous analogical problem solving in particular indicate that analogical mapping requires a Type 2 processing.

Correlation between Reflective mind thinking and spontaneous analogical problem solving

The main goal of this study is exploratory – given that not much is known about individual differences in spontaneous problem solving, especially with regard to the Reflective mind, the aim would be to find a correlation between these two variables. More specifically, possible individual differences might be expected in the no-hint condition, where spontaneous analogy-making depends on the correct identification of the structural similarities in the two problems, as well as the appropriate mapping, which might be reasonable to expect from people with higher rational dispositions who are arguably better at prioritizing goals and performing well without overt instructions what exactly is expected of them.

Method

Design

This is a correlational study, aiming to research whether a positive correlation exists between scores on the Cognitive Reflection Test and the analogical problems that are solved spontaneously. For the purposes of the research, a reception paradigm was used. The research has been approved by the ethical commission at the New Bulgarian University.

Stimuli

Analogical stories The stimuli for the analogical problem-solving task consisted of six problems: three bases and three targets. The problems were selected so that they can be structurally identical, but superficially dissimilar.

- Red Adair & Aquarium problems

The first set of analogous stories consisted of the Red Adair problem (Kurtz & Loewenstein, 2007) and the Aquarium problem (Catrambone & Holyoak, 1989). The former described a problem, in which an oil well that is burning has to be extinguished. If a big hose is used to shoot the foam into the well, the machines in the well that facilitate petrol extraction will be destroyed, even though the fire will be put out. But if one of the many smaller hoses is used, the machines will be spared, but the fire will not be extinguished. For the Aquarium problem, a replica of a ship had to be illuminated for an exhibition, without disturbing the fish swimming around it, which were sensitive to light. If one powerful spotlight was used, the fish would be disturbed and the replica illuminated, and if one less powerful spotlight was used – the fish would not be disturbed, but the replica would not be illuminated. The solution for both problems involved "convergence of forces", or using small amounts of force from different directions (small hoses to put out the fire and low-powered spotlights to illuminate the ship). The Red Adair problem was modified so as to obtain full structural similarity with the Aquarium, by making the using of large force from one direction causing damage to peripheral elements (machines for petrol extraction in Red Adair and the fish in Aquarium).

- Garden and Marching band problems

The second set of stories were the Garden problem and the Marching band problem (Novick & Holyoak, 1991). These were mathematical problems, involving finding how many plants a family can have in their garden, given that they had chosen the exact number of plants, which could be divided into 10, 4, and 5 kinds of plants, but there would be space for 2 more plants. Only when they divide them in 6, they fit in without remainder. The Marching band described musicians marching in rows of 12, 8, and 3, but having one musician march alone. Only when they march in rows of 5, there is nobody left out. The successful solution procedure for both problems is to find the lowest common multiple of the given three divisors that leave a constant remainder, then to generate multiples of that number, add the remainder to each of them, and finally find from this set the number that is divisible to the fourth number without a remainder.

- Orange and Tribe problems

The third pair of stories consisted of the story about the sisters, who were quarreling because each of them wanted one orange for herself. The problem was resolved when the mother found out that one of the sisters wanted to use the peel of one orange for baking, and the other wanted to eat the fruit, so each of them took the respective part of the whole orange (adapted from Fisher, Ury, & Patton, 2011). An analog to this story was created, which was about two clans from the same tribe, that have recently captured an island, and each of the clans wants the whole island for themselves. So the chief of the tribe steps in and finds out that one of the clans wants the island for its territory, and the other one wants it because the people on the island pertain to their clan. The solution, then, is to divide the people from the territory, so that each side can be satisfied.

Cognitive Reflection Test The extended version of Cognitive Reflection Test (CRT) (Toplak, West & Stanovich, 2014) was used as a measure of Reflective Mind. CRT was introduced by Frederick (2005) and measures cognitive reflection – a concept defined as "the ability or disposition to resist reporting the first response that comes to mind". Toplak et al (2014) have expanded the CRT to a total of seven questions in a study assessing people's tendency to process information miserly. Each of the seven questions presented a problem, which had an intuitive, but wrong answer immediately coming into mind, and requiring the suppression of that answer and searching for the correct one. For example, a problem describing that a bat and a ball cost 1.10 dollars in total, and the bat costs a dollar more

than the ball, asks how much the ball costs. An intuitive answer would be 10 cents, but the correct one is 5 cents.

Participants

A total of sixty-seven participants took part in the study (18 males). All of them were native Bulgarians. They participated either for partial fulfilment for a course credit, or voluntarily. Forty-seven of the participants were students at the New Bulgarian University. The participants' age ranged from 18 to 53 years (M = 25.18, SD = 8.21).

Procedure

The procedure consisted in participants signing an informed written consent, and solving all six problems and the CRT individually in a single 45-50 minute session. First, the three base problems were presented one by one, with participants having 5 minutes to solve for each problem. If the participants failed to produce the correct solution, it was given to them. Then the CRT was given, with 10 minutes time to complete it. Finally, the three remaining target problems were given one at a time.

In order to control which of the target problems were solved spontaneously, the participants were given 5 minutes per problem, and if they did not produce the correct solution, they were given a hint to use one of the previously solved problems and additional 2 minutes were allowed. If again there was no correct solution, a second hint was given to use the specific analogous base problem to solve the current one, again allowing for additional 2 minutes.

The analogical problems were chosen in such a way, so as to be symmetrical, as well as structurally identical. Due to this fact, the analogical pairs were alternated with respect to being either a base or a target, with the Red Adair problem appearing half of the times as base, half of the times as target. The same applied for all six problems. The presentation of the base and target stories was balanced, with each of the stories appearing first, second or third as a base and first, second and third as a target equal amount of times. The full randomization resulted in 72 possible presentations of the problems without repetition of the presentation order. Thus, each participant was given a unique sequence of problems arrangements, with 67 out of the 72 randomized possibilities being used in the study.

Results and discussion

Analysis of the analogical problems

Several types of analyses were made on the obtained data. Firstly, the time to solve the base and target problems was calculated. The mean time to solve all three base problems was 198.29 sec (s^4=115.44), whereas the target problems were solved faster for an average of 161.88 sec (s=129.77). That difference was significant (t(66)=3.76, p=.00), indicating that some facilitation due to analogical transfer may have taken place. The tasks in each analogical pair were randomly assigned to the base or target position, thus any differences between the base and target task cannot account for the observed faster solutions of the target compared to the base problem. Moreover, only response time for correctly solved, but not for unsolved targets was faster than the base solution time: F (1,66)=38.32, p=.00 (Figure 1). Solved targets were worked out faster than solved base problems. Unsolved problems took up approximately the same amount of time, irrespective of the base-target role they have played in a given analogy. Therefore, analogy, rather than task order, may explain the obtained facilitation in solving the target tasks.

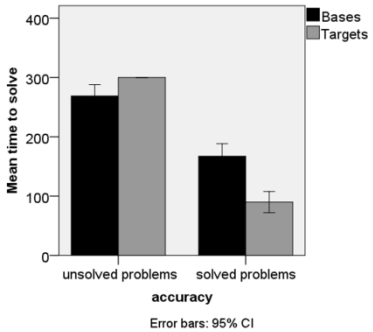

Figure 1: Time needed to solve successfully or not a base and a target problem (in seconds).

Huge differences in both response time and accuracy, however, were observed between the individual problem pairs which share analogous relational structure. The analogical pair Garden and Marching band (noted G and M, respectively) were correctly solved as bases for average of 183.43 sec (s = 44.17), which took the longest amount time to be solved out of the three pairs. The Orange and Tribe pair (noted O and T, respectively) took 70.52 sec on average (s = 73.22) or was fastest of the three problems to be successfully solved as bases, and the Red Adair and Aquarium problems (noted R and A, respectively) took on average 146.00 sec (s = 90.25) to be solved correctly as bases (see Figure 2).

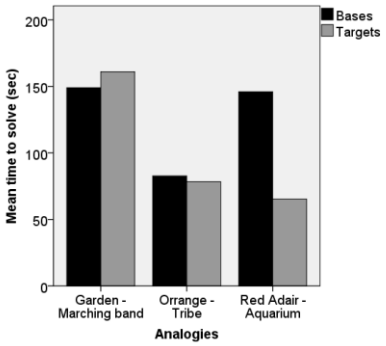

Figure 2: Time needed to correctly solve a problem from an analogical pair as a base and as a target (in seconds).

One-Way ANOVA yielded statistically significant difference with respect time to solve the bases (F (2, 104) = 14.40, p =.00). Specifically, according to a Fisher LSD post

[4] Standard deviation in seconds.

hoc test the pair O and T was solved correctly faster as a base compared to G and M (p =.001) and faster than R and A (p =.00). The pair G and M did not differ from R and A (p > .05). Target problems from the analogical pair G and M were solved for 187.75 sec (s = 72.62), which again was the longest amount of time out of the three problems. O and T were correctly solved for 67.18 (s = 91.88), and R and A – for 62.18 sec (s = 64.43) (see Figure 2). There was again significant difference between time needed to solve targets from each pair (F (2, 117) = 4.82, p= .01). Fisher LSD post-hoc test showed that the G-M pair was correctly solved as a target for the slowest amount of time compared to O-T (p =.004) and R-A (p =.002), while there was no significant difference between R-A and O-T pairs (p > .05).

Additionally, the number of spontaneously solved target analogies was calculated for each pair. The analogical pair G-M was solved spontaneously only 4 times, or by 5.97% of the people. For the pair O-T the number was 55 (82.01%), and for the pair R-A it was 61 (91.05%) (Figure 3). The difference between the number of spontaneously solved problems from the pair G-M was significant from that of O-T (χ^2 (1, N=59) = 78.76, p=.00) and also from R-A (χ^2 (1, N=65) = 97.07, p = .00). The difference between O-T and R-A pairs was not significant. Likewise, participants reported less often that they have been aware of the analogy between the problems in the G-M, compared to the other analogous pairs: F (2, 200) = 39.72, p=.00.

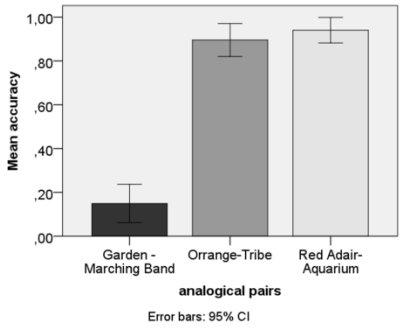

Figure 3. Relative frequency of solved target problems for each analogical pair

In sum, the superficially dissimilar analogous problems used in that study were quite different with respect to solution time and accuracy. Some of the target problems were solved faster and more accurately (i.e. O-T and R-A) than others (i.e. G-M). The target problem itself can hardly explain that discrepancy, since both tasks in each pair were randomly assigned as base and target for each participant. The order of the three base and the three target tasks was also randomized across participants.

In this specific case, the G-M pair consisted of mathematical problems that, although analogical, might be impeding the correct mapping or retrieval that is necessary for correct solution just because of the difficulty of the problem itself. Given that mathematical expertise has been found to be an important predictor of analogical transfer (Novick & Holyoak, 1991), it could be reasonable to expect that for this specific analogical pair, some additional factors might have operated by impeding the transfer. The retrieval gap (Holyoak, 2012), however, seems to be wider for some analogous problems, but not for others, probably depending on the specific expertise of participants, as suggested in our study, where most participants had background in humanities[5] and failed to solve the G-M problem that requires mathematical skills (Novick & Holyoak, 1991).

Correlational analyses: who solves problems by means of spontaneous analogies

A correlational analysis was conducted between the variables scores on the Cognitive Reflection Test and the number of analogical problems that were solved correctly without an explicit hint (i.e. spontaneously). Importantly, a Kolmogorov-Smirnov test was applied to test for normality the two variables. Both of them were not normally distributed (p = .000), which required utilizing a non-parametric correlational test, such as Spearman's rank order correlation. There was a significant positive correlation obtained between the two variables (r_s (67) = .25, p = .045). The results indicate that a high score on the CRT tends to go together with higher number of spontaneously solved analogical problems. A scatterplot summarizes the results (Figure 4).

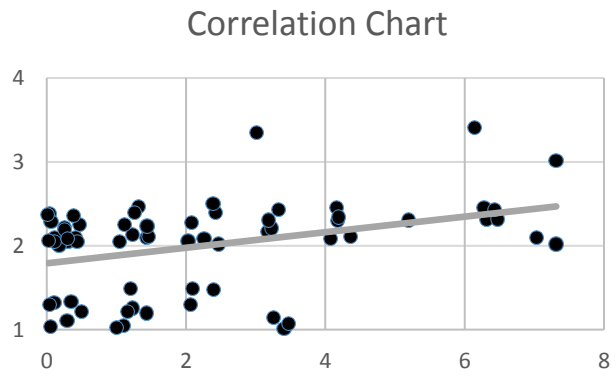

Figure 4: Scatter plot with jitter, showing the correlation between scores on CRT and spontaneously solved analogical problems. The x-axis represents the score on CRT, the y-axis represents the number of spontaneously solved analogical target problems.

Discussion

This study demonstrates that a positive correlation exists between the score on the Cognitive Reflection Test and the number of analogical problems that are solved spontaneously. Given the rationale of the hypothesis, this result can be explained in terms of individual differences with respect to the Reflective mind (Stanovich, 2012) at least partially accounting for the analogical problems that

[5] 64 out of the 67; 3 participants had studied technical specialties

are solved without a hint. Although the correlation is weak, the results indicate that the goals and hypothesis of the research are in the right direction.

Generally, what was found in this investigation was that people solve different analogical problems with a different amount of speed and also different degree of success. The finding that the analogical pair G – M was solved less than the other ones and for more amount of time might point to the idea that the nature of the problems themselves might play a role in how easy or how fast the solution is extracted from the base problem in order to be applied to the target one. A possible explanation remains to be looked for in expertise in solving mathematical problems (Novick & Holyoak, 1991) In addition, the nature of the CRT itself could be questioned as to the extent it requires a certain level of expertise. Thomson and Oppenheimer (2016) have developed an alternate version of the CRT which addresses the criticisms to the original form – that it relies on mathematical sophistication to produce the correct answer.

The weak correlation that was found between scores on CRT and the spontaneously solved analogical problems needs to be compared to other similar correlations of CRT and cognitive abilities. For example, Toplak, West, & Stanovich (2011) show significant correlations to exist between CRT and syllogistic reasoning tasks (r = .36), heuristic-and-biases tasks (r = .42), executive functions measures (.17 to .34) and thinking dispositions measures (.18 to .19). Thus, the current study seems comparable to others with respect the strength of association between CRT and tasks involving reasoning measurement.

It should be noted, however, that correlations between CRT and cognitive ability measured by Wechsler Abbreviated Scale of Intelligence has been found to exist (r = .32), suggesting some overlap between the two (Toplak et al., 2011). A possibility to search for a partial explanation of spontaneously solved analogical problems in the cognitive ability of intelligence, thus, cannot be fully overruled.

Conclusion

The reported correlation between the Reflective Mind measure and spontaneous analogical problem solving adds a new explanation for the retrieval gap in analogical reminding. Low superficial similarity and non-compatible relational structures between the base and target problems may explain the difficulties that participants robustly demonstrate in psychological labs when analogical problem solving abilities are tested by the means of the reception paradigm. Nevertheless, generally 20% of participants find the analogous solution (Holyoak, 2012), despite the mentioned difficulties that the reception paradigm seems to impose on them. The reported correlation indicates that among the key abilities within the profile of the successful problem solver is the reflective reasoning. It presumably enables the motivated search for possible connections between the tasks, and possibly a re-representation of the relevant relations, if needed for the purposes of the analogical problem solving. Therefore, spontaneous analogy making may benefit from the reflective reasoning, since it most probably transforms the task into an explicit task for searching the analogy, or at least boosts the motivation to cope with the task.

Acknowledgements

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