“Problem Solving as a function of Analogous Stories”

In-depth Correlational & Experimental study

Contents

Introduction

Problem solving can be defined as the process of overcoming the obstacles that obstruct the path to a solution. The process of problem solving includes problem identification, problem definition, strategy formulation, organization of information, allocation of resources, monitoring and evaluation. Problem identification is about whether an individual know if he actually has a problem. Problem definition is actually defining what exactly is the problem. The third step is formulating a strategy as to how can the problem be solved; how can the problem be broken down into manageable element. It may also involve synthesis, i.e., putting together various elements to arrange them into something that helps.

The strategy formulation also involves divergent and convergent thinking. Divergent thinking, generating diverse collection of various alternatives that are possible for the problem; however, after considering the possibilities one is required to engage in convergent thinking which means narrowing down the possibilities to converge on one single answer that is best. The fourth step involves organizing the information as to how various parts or pieces of information fit together for the problem. Later, how much time, money, and effort are required to solve the problem is resource allocation, the fifth step. Better the planning as to how to solve the problem, easier it is to implement it. The sixth step involves monitoring, to monitor whether everything is on track as one keeps proceeding to solve the problem. The last step involves evaluating i.e., to evaluate whether the problem was solved correctly. The seven steps have an influence of emotions as to how we implement the steps. There is no optimal sequence that is to be followed, the order of solving the problem can be changed as well. Problem solving, in view-point of Bruner (1973), was an important goal to be pursued by psychology.

Problem solving has been one of the many topics that has been excluded by behaviorist because of the strong belief in the Law of Effect by Thorndike, which stated that if a response leads to a satisfying outcome, the connection between the response and the situation in which it took place, will be strengthened. Gestalt psychologist studied problem solving too, with a focus on how re-constructing or re-organizing the elements of the problem lead to sudden realization of the solution. This can be understood with the Kohler's experiment of Sultan, a chimpanzee who solved the banana problem by the use of insight. This highlights how the sudden perceptions can lead to solving the problem. Via chess and logical theorems, Newell and Simon work can be understood in relation to the Information Processing Approach, which talks about problem solving involving the initial phase in which the problem is defined and represented after which the solver generates and tries possible solutions. Early researchers faced problems with respect to the methodology of the experiments. The experiments were not bound to any

response time like usual experiments instead it involved verbal protocols that is analysing the participants verbalizations. There were various issues with the design, and controls.

Characteristics of Problem-solving

Anderson (1980) stated the characteristics of problem solving. Goal Directedness, is the first characteristic followed by Sequence of Operations, the discernible sequence of separate operations. The third characteristic is Cognitive operations that involves application of various cognitive operations to achieve a goal. Subgoal Decomposition is the fourth and the last characteristic which characterizes each step as a goal in itself which is to be achieved. The vocabulary of problem solving includes the problem space, operators and the goal state. Problem space is defined as various conditions or states that are possible in the problem. It includes initial, intermediate and goal states of the problem. Operators are the set of operations that are legal, that can be performed during finding the solution to the problem. Problem constraints prevent the application of operators. Lastly, the goal state is like an ultimate destination with either specific or not-so specific initial and goal states. With respect to this, problems can be categorized with respect to them having clear paths to a solution. Well-structured problems or well-defined problems are the ones that have clear paths to solutions. There is a possibility of applying a formula like, for example, finding area of a rectangle or solving algebraic math problem.

The problem-solving heuristics include mean-end analysis, generate and test, working backward and backtracking. Whereas, ill-structured or ill-defined problems are the ones that lack clear paths to solutions. The Duncker's radiation problem or the two-string problem are examples of ill-structured problems. They require the use of insights (a distinctive and sudden understanding of the problem or of the technique that aids in problem solving) because there is a need to see the problem in a novel way. Domain knowledge can aid in solving the ill structure problems as well. Justification skills are also used for both, ill-defined and well-defined problems, but they are important is ill defined problems because they are represented in different ways and have many alternative solutions. So, the problem solver needs to choose and justify their selection of a particular representation and solution.

Basics of Analogy and History

Analogy is a relationship between two similar situations, problems or concepts understanding analogy is like putting two similar events or problems into some kind of alignment so that the similarities and the differences can be apparent. When faced with a problem, finding similar or related situation and

build an analogy from it to solve the current problem or situation. Engaging into this process helps us to understanding a huge variety of situations. Using the problems that have already solved for representing and solving current problems is known as analogical problem solving.

Individuals tend to have mental sets that prompt them to work on one aspect of the strategy and excluding the other ones. The carryover of knowledge or skills from one problem situation to another is known as transfer of knowledge. This transfer of knowledge can be either positive or negative. Positive transfer is when the solution of a previous problem facilitates in solving the current problem. This transfer of knowledge can act like an aid to problem solving. While solving a math problem, using the math skills and formulas facilitates in solving. Whereas, when solution of the previously solved problems makes it harder to solve the current problem, it is negative transfer. It may get an individual on a wrong track. Use of new tools or machineries involves negative transfer, as the individuals tries to apply previous use of tools, ending up with no solution or incorrect solution. To study this, participants try to solve a target problem. They are presented with a problem or a story which is the source story or the problem that has some similarities with the problem the participants try to solve, the target problem. The source story will aid in the problem solving.

Steps involved in analogical problem solving.

The process of analogical problem solving involves constructing a representation of the story analogy and the target problem and mapping it on to the problem. an individual needs to use mapping to generate the parallel solution to the target problem. there are several steps that are involved in analogical problem solving like noticing, mapping, schema development and application. Noticing an analogy means noticing that there exist some kind of relationship between two problems. It is like a mental search through the memory or stumble upon a relevant analog. Sometimes, the analogs itself can serve as a hint. Hints and domain specific knowledge allow noticing. People sometimes fail to notice an analogy and this could be because the way in which the information is accessed from the memory, like semantic retrieval cues.

The second step involves mapping, finding a set of one-to-one correspondences between the aspects of one body of information and aspects of another. Mapping may involve comparison of two aspects at a quite concrete level of abstraction, comparison of specific concept to a general schema and induction of schemas for examples. According to Hesse (1966), analogy involves two distinct types of relationships, horizontal mapping (mapping between aspects of two analogs) and vertical mapping (mapping between the two parts of a single analog, having if-then relationship (the antecedent and the consequence condition). Schema development is the developing a mental representation of the underlying

principles that multiple problems have in common, it's the abstract category that the individual analogs instantiate in different ways. The third step is schema development. A schema is a mental representation of the underlying principles that multiple problems share. A schema can be abstracted from the two analogs by the process of **"**eliminative induction". Eliminative induction refers to the deletion of differences between the analogs while preserving their commonalities/similarities. The final step is the application where the individual is expected to use the mapping to develop a parallel solution to the target problem.

Reasoning by analogy v/s schema

Reasoning by analog typically implies a comparison of two concepts (analogs) at the same (usually quite concrete) level of abstraction (heart and a water pump). The new problem may be mapped directly with a prior analog to generate the analogous solution. While the mapped identities will mediate the transfer process, the schema need not exist as a separate concept independent of the two analogs.
Reasoning by schema, is when an independent schema may have already been induced from one or more, prior analogs and stored in memory. The person can directly map the new analog with the schema to construct a solution. Reasoning by schema is considered far better than reasoning by analogy firstly because, the human memory search is guided by semantic retrieval cues. That is, there will be a lot of potential cues to retrieve a problem that is very similar from the same semantic domain, whereas for the analog a disparate domain may lack such transparent resemblances. Secondly, the semantic links that are potential between two stories that are dissimilar, will simply correspond to the basis of the analogy, that is the identities that comprise the implicit schema within each analog. As the schema contains all the aspects common to the two analogs, an analog will be more similar to its schema as compared to another analog. Therefore, an independent schema will facilitate the retrieval and noticing of an analog.

Influencing factors There are two main factors that help facilitate the steps of noticing and mapping during the problem solving. The surface features and the structural features. The surface features have specific elements that make up the problem, something that can be literally seen. While the structural features are the underlying relations among the surface features of the two problems. There is a possibility that the problems might look dissimilar on the surface level but may have underlying relations that are similar. Structural features are not enough to cue the memory. So, in analogies what matters is the structural system of the relationship and not the similarity of the content. Holyoak and Koh conducted an experiment to

investigate the conditions under which people retrieve and notice the relevant elements. Hence, they manipulated different types of similarities. The source problem was Duncker's 'radiation problem' where in the experimental group was taught radiation in the class while the control group had no prior knowledge.

The target problem was the 'light bulb problem' 81% of the participants from the experimental group were able to solve the problem as compared to 10% participants from the control group because of the high surface similarities between the problems (radiation and lasers).

The opposite phenomenon is transparency where in individuals tend to see the analogies where they do not exist because of the similarity in the content. Transparency of the content can therefore lead to negative transfer between isomorphic problems. Results from the past researches have highlighted that transfer is aided by making the surface features more similar and by making the structural features similar as well. One way that helps people notice the structural similarities is through the procedure of analogical encoding. Gentner and Meadow (2003) have highlighted that during analogical encoding participants compare two cases that kind of illustrate a principle. They first taught participants negotiation strategies i.e., compromise, trade-off (illustrated by a story about two sisters quarrelling over an orange, and contingency (illustrated by a situation in which an auther wants 18% royalties but the publishers wanted to pay only 12%). Then they gave two analogies and asked them to compare them; so one group got two cases based on trade-off and another got based on contingency solution. Then, they were given a third case to solve which could have been solved via any strategy, findings indicate that, participants who got the two cases of trade off gave the solution of the target problem also in trade off (almost 60%). And the participants who compared two cases of contingency based solutions gave the solutions based on the contingency negotiation (almost 38%).

So, when the participants engage in comparing the cases, they are more likely to notice the underlying structure. However, when it comes to using the analogy in the real world, things are quite different. Kevin Dunbar (2001), discussed about analogical paradox i.e., the participants in the psychological experiments tend to focus on the surface features in the analogical problems whereas, in real world people frequently use deeper and more structural features.

Experiments by Gick and Holyoak. Gick and Holyoak in 1980 conducted a series of 5 experiments to study the analogical problem-solving. The first experiment was designed to demonstrate that the subjects can use an analogy from a remote domain as a hint for solving a problem. the nature of the solutions varied to study if that influenced the likelihood for subjects to generate specific solutions to the target problem.

subjects were divided in to four conditions receiving either the Attack dispersion story, the Open supply route story, the Tunnel story or no story (control group). The experimental subjects were told to try and use the story problem as a hint in solving the target problem and were allowed to re-read the story analogy at any time. Findings suggest that the frequency of each solution was highest for the subjects who received the relevant story analogy. The 1st experiment highlighted that the generation of analogous solutions involves a conscious process of mapping correspondences between the story and the target problem. The second experiment was designed to study the use of analogies to generate problem solutions without interacting with the experimenter. It also wanted to assess the degree of mapping required to generate a solution on the basis of analogy.

The stories given to the subjects differed in the degree of correspondence. The attack-dispersion story and the parade dispersion story were used in the 2nd experiment. Subjects were not prompted by the experimenter. and therefore, many subjects were unable to produce complete solution. The third experiment participants were first just given the problem statement from the Attack-Dispersion story, and then were asked to suggest what the general might do to capture the fortress. After that the participants were asked to solve the radiation problem, using their solutions to the initial problem as hints. 22 out of 45 of the participants produced the gist of the dispersion solution the general should divide the troops into small groups and send them down different roads. And 45 % of the 22 participants produced onto solution to the radiation problem. The aim of the fourth experiment was to find additional processing required for analogical problem solving. The tasks were simplified in this experiment by allowing the participants to reread the story analogy many times, so the performance would not limit by memory factors. The wine merchant story and the identical twin story were of same length as attack dispersion story but were disanalogous to radiation problem.

A questionnaire was given where participants had to rate which story and to what extent a story helped them to reach the convergent solution to the radiation problem. The results indicated that 92% of participants in the hint condition gave the complete solution to the radiation problem and had no difficult in identifying the critical story analogy. Three participants in the no hint condition found the solution to the radiation problem. None of the participants found the wine merchant story and identical twin story helpful. The aim of the fifth experiment was to find out whether the encapsulation of experience is more or less absolute, or whether there are factors that would make a relevant analogy more likely to be noticed even though it was initially encoded in a recall context. Two possible factors to break encapsulation-reducing the memory load by removing the distractor stories and introducing the incubation condition i.e.,

presenting the story after the problem. In the Story First condition, 41% of the subjects gave the dispersion solution on their first attempt following recall of the story; while in the Story Second condition, 35% of the subjects produced this solution immediately after reading the story. In both the experimental conditions 76% participants came up with the dispersion solution in total, however only 10% did so in the control condition which indicates that just taking a break from the problem is not sufficient to stimulate discovery of the dispersion solution.

In 1983, Gick and Holyoak conducted a series of 6 experiments to investigate the effects of manipulations that might influence the induction of problem schema. Focus was on summarization might have caused schema abstraction as compared to verbatim recall. In the experiment there were analog recall, analog summary and control summary conditions. It was found that summarization did not facilitate either noticing or applying analogy because whether it was before the hint or after the hint the analog recall condition and analog summary condition did not differ significantly. It was highlighted how ceiling effect could account for the result. Summary condition did not outperform the recall condition, when there was no hint. In the 2nd experiment the story analogy was augmented by the explicit verbal statement of the principle underlying the implicit problem schema. The 'general' problem was used along with the radiation problem. There was a principle alone condition where the subjects did not receive the story. The solution frequencies did not differ significantly among the conditions either before the hint or in total. The identical performance was seen for those who were in analogy plus principle condition and the analogy-only condition.

Experiment 3 had a similar design as the previous one, however but with visual diagrams instead of a verbal statement of the principle was presented. Three conditions were analog-only, analog-plus-diagram and diagrams only. There was no significant difference between the analog-plus-diagrams condition and the analog-only condition. Results showed no indication that spatial diagrams constituted an effective addition to the basic story analog any more than the verbal statement used in Experiment 2. When the diagrams were presented alone in the context of a "pattern recognition" task, it is unlikely that subjects assigned any semantic interpretation to them, and surely none even approximating the convergence schema. But once subjects had been explicitly told to consider the prior diagrams, they were able to interpret them by means of a mapping process. This can be known as analogical bootstrapping where antecedent conditions given are used to interpret the antecedent diagram, which can be used to decode the consequence diagram.

The 4th Experiment aimed at comparing effectiveness of two vs one prior analogs in producing analogical transfer. The two-story analogs were varied as to one from a similar domain and another from a dissimilar domain. The third condition was given an analogous and a disanalogous control story. Subjects asked to attempt to solve the target problem first without a hint, and then with the hint, this is called the two-pass procedure. It was seen that though there was not a significant difference in similar and dissimilar analogs coming up with a complete convergence solution, two analogy subjects did significantly better than one analogy plus control. The quality of schema was assessed, and no difference was found in schema quality induced and the relationship between schema and transfer performance for similar and dissimilar analogs conditions. Most of the subjects who failed to come up with the convergence solution had poor schemas.

The fifth Experiment studied the effect of adding the verbal statement, used previously in Experiment 2, to two prior analogs. There were two conditions, with-principle conditions read 2 analogous stories except the verbal statement of convergence principle was added. Participants were asked to read the stories and then answered questions, after the story was collected rest task was to be done from memory; two-pass procedure was used. It was seen that addition of a verbal statement had a clear positive effect on transfer from a pair of analogs. Addition of principle also had a strong influence on schema quality. The results of Experiment 5 again provided clear evidence of the formation and use of schemas in analogical problem solving; furthermore, they demonstrated that a verbal statement of the solution principle can aid in the induction of a schema from two analogs and substantially improve noticing and application of the information in a subsequent transfer task. The diagrams previously used in Experiment 3, where they failed to facilitate abstraction of a schema from one analog, were now presented along with two analogs. Provision of a diagram resulted in a higher frequency of initial solutions (57 vs 37%) as well as of total solutions (92 vs 79%). Provision of the diagrams improved the quality of the schemas derived from both similar and dissimilar analogs, of subjects who received diagrams, 55% wrote good schemas and only 22% wrote poor ones; of those who did not receive diagrams, only 28% gave good schemas while 39% gave poor ones.

Multi-constraint theory. Holyoak and Thagard (1997) proposed a theory of analogical reasoning and problem solving. The theory predicts how individuals use analogies to solve the problems what factors govern the analogies people construct. It highlights how people are constrained by three factors when they try to use or develop analogies. The first factor is problem similarity i.e., there has to be a reasonable

degree of similarity between already understood problem (source domain) and the current problem being solved (target domain). The second factor is the problem structure where in people must establish a parallel structure between the source and target problems which can help them to map elements from the source to comparable elements in the target. It is important to figure out these correspondences or mapping because it corresponds to working out the relationships of the analogy. The third factor is the purpose of the analogy. It is deeper than merely the general purpose of trying to solve the problem. it is about matching between person's goal and the goal stated in the problem. Many studies have shown that problem solving has also focused on how people may use the analogies in a more unconscious and implicit manner.

Factors influencing problem solving.

Expertise

By definition, experts are people who have become acknowledged as being extremely knowledgeable or skilled in a particular field by devoting a large amount of time to learn, practice and apply knowledge. Whereas, novices are people who are beginners or who do not have extensive training of experts. Experts are believed to possess ore knowledge about their fields and hence they usually solve problems with a higher success rate than novices. Along with lot of knowledge, it is also important how they organize their knowledge. As compared to novices, experts spend more time analyzing the problems. They try to understand the problem rather than merely and immediately solving it. They may be slow at the start but they engage in strategic planning which helps them to come up with the solution. Novice and experts differ substantially in their knowledge base or schemas.

Chi et al (1982) presented 24 physics problems to a group of experts and novices and asked them to sort the problems in the groups based on their similarities. Experts engage in using structural similarities while solving problems while non-experts just use the surface similarities to sort a solution to their problems. Experts spend time in trying to understand the problem rather than immediately solving it. However, it might slow them down in the beginning but this approach effectively pays off while approaching the problem.

Considering the aspect of memory of the novices and experts, they differ with respect to their memory for information related to their area of expertise. The memory skills of experts tend to be very specific. Experts also tend to divide a problem into several sub-problems which they solve in specific order. This helps them to come up with an effective solution. Experts are believed not to get distracted by the surface similarities as compared to the novices. They tend to differ in the speed as well i.e., experts

are much faster than novices while solving the problem accurately. Their operations become more automatic and a stimulus situation also quickly triggers a response.

Intelligence.

There are concepts like global planning (encoding the problem and formulating a general strategy for attacking the problem) and local planning (forming and implementing strategies for the details of the task). Spending more time on global planning increases the likelihood that the overall strategy will be correct. In various studies it has been observed that more intelligent individuals take longer during global planning and less time for local planning. More intelligent people seem to spend more time planning for and encoding the problems they face.

Age

Age is yet another factor that influences problem-solving. Holyoak, Junn and Billman conducted a study of development of analogical problem-solving skill. They found that even preschoolers were able to use analogies to solve problems however, they faced difficulty doing the mapping when objects lacked perceptual and functional similarities. Children were able to use analogs the same way as adults used to solve the problem but the younger children's abilities were more fragile. The factors that limited the performance for 11-year-old participants were the same for adults too. They failed to notice that the two situations might be analogous. However, when they were hinted, they were able to carry out mapping as much as the adults. The 2nd experiment was designed to provide a more detailed assessment of the factors that influence the success or failure of the younger children in using analogies. Kindergarten and first graders were considered for this experiment. All eight children in the original condition generated the cane solution whereas only five in each of the other conditions came up with the cane solution. The 3rd experiment assessed whether children could use a story analog to derive the more complex rolled paper solution. It was seen that 7 out of 12 subjects who received the analog either one or two stories came up with the rolled paper solution as contrasted to zero of the twelve subjects. The results indicated that the subjects in the analogs condition came up with the solution even before being given a hint.

Practical implications. When we are faced with a difficult situation, a useful heuristic helps us to find a similar or related situation and thus an analogy could be built. This reasoning and problem-solving help us to understand a variety of situations like how students should be taught in schools. The teachers can be aware of the kinds of noticing and mapping difficulties the young children are likely to encounter and how people choose professional role models. In 1988, Evans conducted an experiment to study whether the

effectiveness of metaphors hold up in actual university classes. In one of his experiments, the subjects were either taught with metaphors or without metaphors and it was found that those who were taught with metaphors were able to make better inferences than those who were not taught using metaphors. Analogies have the potential to be very powerful tools in engineering design. For example, they compared the designs of scaffolding and angioplasty to indicate the ability of designers to stretch their knowledge to be able to solve complex design problems. An angioplasty stent's intent and function are similar to scaffolding erected to support walls in mines as they are being built. A stent supports the walls of the artery as surgeons operate. This example makes clear to students that inspiration can be found in other designs whether they are directly similar or only similar in terms of form or function.

Howe et al in 2013 investigated priming of analogical problem solutions with true and false memories. Children and adults were asked to solve nine verbal proportional analogies, three of which had been primed by Deese–Roediger–McDermott (DRM) lists where the critical lure (and problem solution) was presented as the initial word in the list (true memory priming), three of which were primed by DRM lists whose critical lures were the solution to the verbal proportional analogies (false memory priming), and three of which were un primed. Age differences in solution rates (knowledge base) in order to examine developmental differences in speed of processing, were controlled. The results showed that adults completed the problems significantly faster than children. Furthermore, both children and adults solved problems primed with false memories significantly faster than either those primed with true memories or un primed problems. For both age groups, there was no significant difference between solution times for un primed and true primed problems. These findings demonstrate that priming of problem solutions extends to verbal proportional analogies, false memories are more effective at priming problem solutions than true memories, and that there are clear positive consequences to the production of false memories.

Methodological issues

Problem solving experiments have behavior-related dependent variables as compared to other cognitive psychology topics which use dependent variables like reaction time or accuracy. Generally, verbal protocol is the behavior measured. This is done through the think aloud procedure where a participant is asked to verbalize every thought as they try to solve the problem given and this verbalization is recorded verbatim by the experimenter. There are various other issues with the controls and methodological designs.

Data discussion

The aim of the current experiment was to study problem solving as a function of analogous stories. In the current experiment we had expected that the development of the convergence solution to the radiation problem will not be independent of the analogous stories presented in the story comprehension task.

In 1983, Gick and Holyoak conducted a series of experiment and the 4th experiment had similarities with the current experiment. In their experiment they had three conditions (two analogies condition, two dissimilar analogies condition, one analogy plus control condition) however, the current experiment had only two condition (two analogies condition, one analogy plus control condition). Participants in their experiment were asked to the stories they read before answering the questions while this step was eliminated in the current experiment. The participants in the current study were not asked to rate the stories however, Gick and Holyoak asked their participants to rate the stories on 7-point scale. The design of the Gick and Holyoak's experiment was a simple random design. They observed schema quality as a mediator of transfer performance while the current experiment assessed schema quality as an ancillary observation. Gick and Holyoak's experiment used the 2-pass procedure whereas the current experiment eliminated the 2-pass procedure and gave the participants hint before providing the radiation problem.

Individual data discussion

For the current experiment we had hypothesized that the development of an analogous solution i.e., the convergence solution, to the target problem in not independent of the number of analogies provided as a part of a prior story comprehension task. Based on this, we had expected that the 1st participant (P1), who is presented with two analogies, will come up with a complete solution and the 2nd participant (P2), who is present one analogy plus control story, will come up with partial/no solution.

As represented in table 8.1, it can be seen that the two analogies participant came up with no solution while the one analogy plus control participant came up with a complete solution and hence the data were not in line with the expectation. P1 was unable to solve the radiation problem, that is, come up with a complete solution as she failed to mention any of the three necessary points i.e., convergence of rays simultaneously from multiple directions. While P2 mentioned these three points as the solution, it can be said that she was able to come up with a complete solution. The data were not in line with the expectation as participant in the two analogies condition failed to come up with a complete solution while participant

in the one analogy plus control condition came up with a convergence solution to the radiation problem. When the participant in the two analogies condition was asked whether the story or stories helped her to come up with the solution, she agreed that both the stories i.e., the general story and the fire chief story did help her and yet there was no one-to-one mapping seen between the elements when the participant engaged in the think aloud procedure. It was also observed that the participant seemed disinterested in the experiment and this could also be one of the reasons the participant did not engage well in the schema induction and hence the schema that was drawn had a poor quality. The participant was unable to draw similarities between the general story and the fire chief story, that is, failed to mention anything with respect to large forces, multiple resources, or buckets and small troops. The poor schema quality might have, in turn, affected the transfer performance. The result obtained here can be understood by taking into consideration the experiment conducted by Gick and Holyoak in 1983 where they found that 90% of the participants who had a poor schema were unable to come up with a complete solution.

The participant in the one analogy plus control condition was presented with the general story followed by the identical twin story. She was unable to draw any similarities between the two stories because there were no similarities to be drawn. Schema quality would therefore be automatically be poor. She came up with a complete solution to the radiation problem. On being asked whether the story or stories helped her to come up with the solution, she said that the 1st story, that is, the general story helped her a lot. She could understand the correspondence and highlighted it when she was questioned as to how did the story help. On being asked, which story or stories helped her to come up with the solution she said that the general story helped her and not the identical twin story. As the participant used only one of the two stories. It can be said that the participant engaged in reasoning by analogy. While engaging in the think aloud procedure the participant answered with the help of hand movements indicating 'from all sides' with the explicit mention of word 'together'. However, on being probed the participant mentioned the 'lower intensity rays coming from all sides at once' which indicated that she came up with a complete solution.

Group data discussion

In the current experiment it was hypothesized that the development of analogous solution, i.e., the convergence solution, to the target problem is independent of the number of analogies provided as a part of a prior story comprehension task.

Table 8.3 highlights the percentage of solvers and non-solvers in the two analogies and one analogy plus control conditions. It can be seen that 23 participants (48%) were able to solve the radiation problem

in the two analogies condition as compared to 5 participants (10%) in the one analogy plus control condition. There were 25 participants (52%) in the two analogies condition, as compared to 43 participants (90%) in the one analogy plus control condition, who were unable to solve the radiation problem. This indicates that there were more solvers in the two analogies condition as compared to one analogy plus control condition and that the non-solvers were more in the one analogy plus control condition as compared to two analogies condition.

The graph in Fig 1 represents the solvers and non-solvers in both two analogies condition and one analogy plus control condition. The height of the bar for the two analogy solvers is higher than the height of the bar for the solvers in one analogy condition. We had expected that the participants in the two-analogy condition will be more likely to solve the radiation problem as compared to participants in the one analogy condition. The data is in line with the expectation.

To compute the data, chi square test of independence was used. Chi square test of independence is used to determine whether two categorical variables are independent or are related. The dependent variable in the current experiment is the proportion or the percentage of participants, that is they are categorized as solvers and non-solvers and hence a non-parametric test has been used. In the current experiment chi square was used to compare the observed frequencies with expected frequencies. A df was calculated (df = 1) for the current data and the p value was 0.005. The chi square value of 16.34 was obtained which was greater than the $_{crit}$ value of 7.88 ($p<0.005$, df=1). Therefore, the null hypothesis, that the development of analogous solution, i.e., the convergence solution, to the target problem is independent of the number of analogies provided as a part of a prior story comprehension task, can be rejected.

The group data is in line with the hypothesis that the development of an analogous solution i.e., the convergence solution, to the target problem in not independent of the number of analogies provided as a part of a prior story comprehension task as 48% of participants were able to solve the radiation problem in the two analogies condition as compared to 10% who were able to solve the radiation problem in the one analogy plus condition.

This could be because the participants in the two analogies condition were presented with the general story and the fire chief story that facilitated the participants to come up with a convergence solution either both or one of the both stories. The participants in both the conditions were given a hint to use one or both the stories while coming up with the solution and this too could have aided the participants. However only 10% of the participant in the one analogy plus control condition were able to come up with the solution to the radiation problem, as they were presented with either general or fire chief story and

identical twin story (distractor story). As the two stories in this condition were disanalogous it might have distracted the participants to come up with a convergence solution. The experiment was based on Gick and Holyoak's experiment of 1983 and it can be seen that the results obtained in their 4th experiment are similar to the results obtained in the current experiment. Their results had 80% and 53% which clearly stated that two analogies were better than one analogy plus control condition. Similarly in the current experiment the solvers in the two-analogy condition (48%) were more than the solvers in the one analogy plus control condition (10%).

References

Ashcraft, M. H., & Radvansky, G. A. (2013). *Cognition: Pearson New International Edition* (5th ed.). Pearson.

Evans, G. E. (1988). Metaphors as Learning Aids in University Lectures. *The Journal of Experimental Education*, *56*(2), 91–99. https://doi.org/10.1080/00220973.1988.10806471

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology*, *12*(3), 306–355. https://doi.org/10.1016/0010-0285(80)90013-4

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology*, *15*(1), 1–38. https://doi.org/10.1016/0010-0285(83)90002-6

Holyoak, K. J., Junn, E. N., & Billman, D. O. (1984). Development of Analogical Problem-Solving Skill. *Child Development*, *55*(6), 2042. https://doi.org/10.2307/1129778

Holyoak, K. J., & Koh, K. (1987). Surface and structural similarity in analogical transfer. *Memory & Cognition*, *15*(4), 332–340. https://doi.org/10.3758/bf03197035

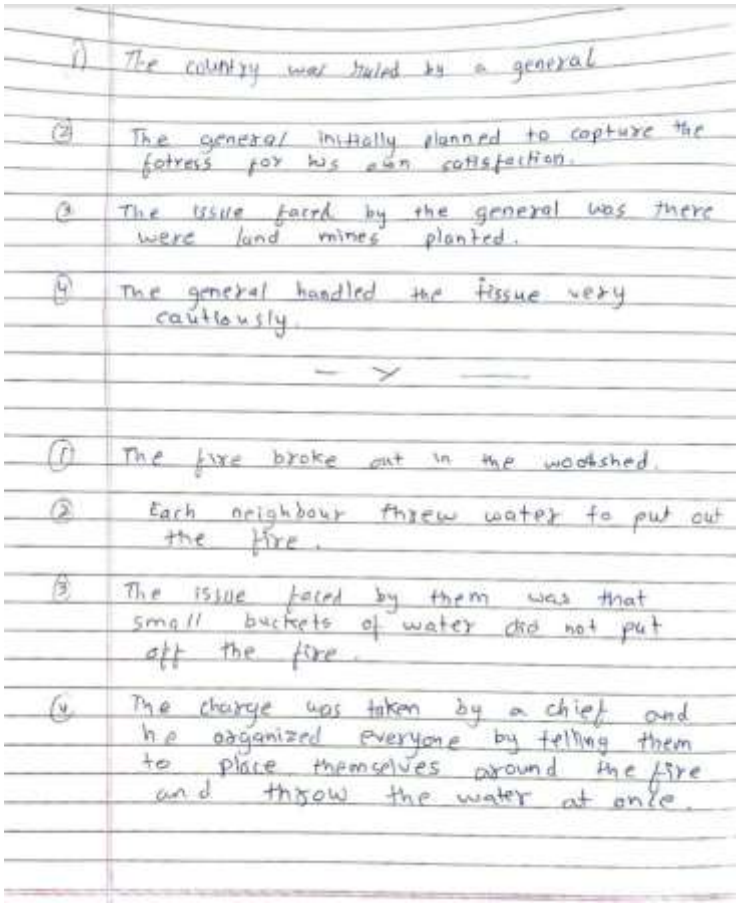
Sternberg, R. J., & Sternberg, K. (2011). *Cognitive Psychology, 6th Edition* (6th ed.). Cengage Learning. https://www.pdfdrive.com/cognitive-psychology-6th-edition-e188961648.html

Howe, M. L., Threadgold, E., Norbury, J., Garner, S., & Ball, L. J. (2013). Priming children's and adults' analogical problem solutions with true and false memories. *Journal of Experimental Child Psychology*, *116*(1), 96–103. https://doi.org/10.1016/j.jecp.2013.03.006

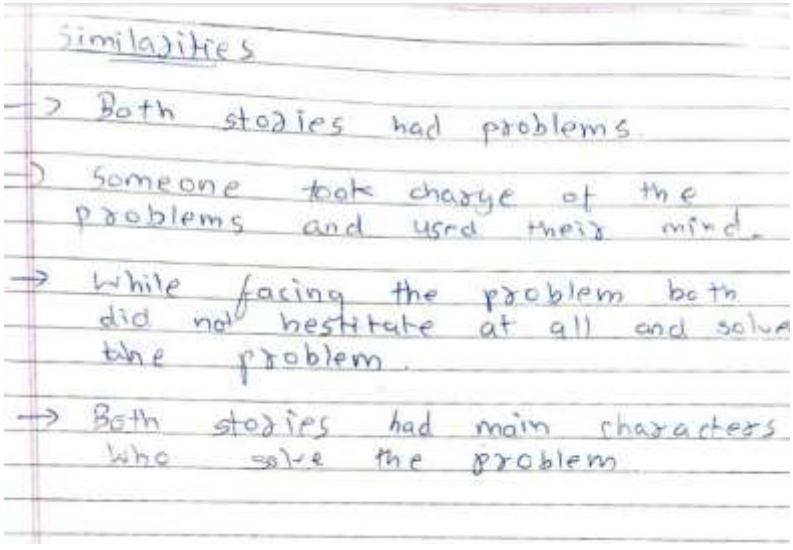
Appendix

A] Story comprehension task

P1-Two analogies condition

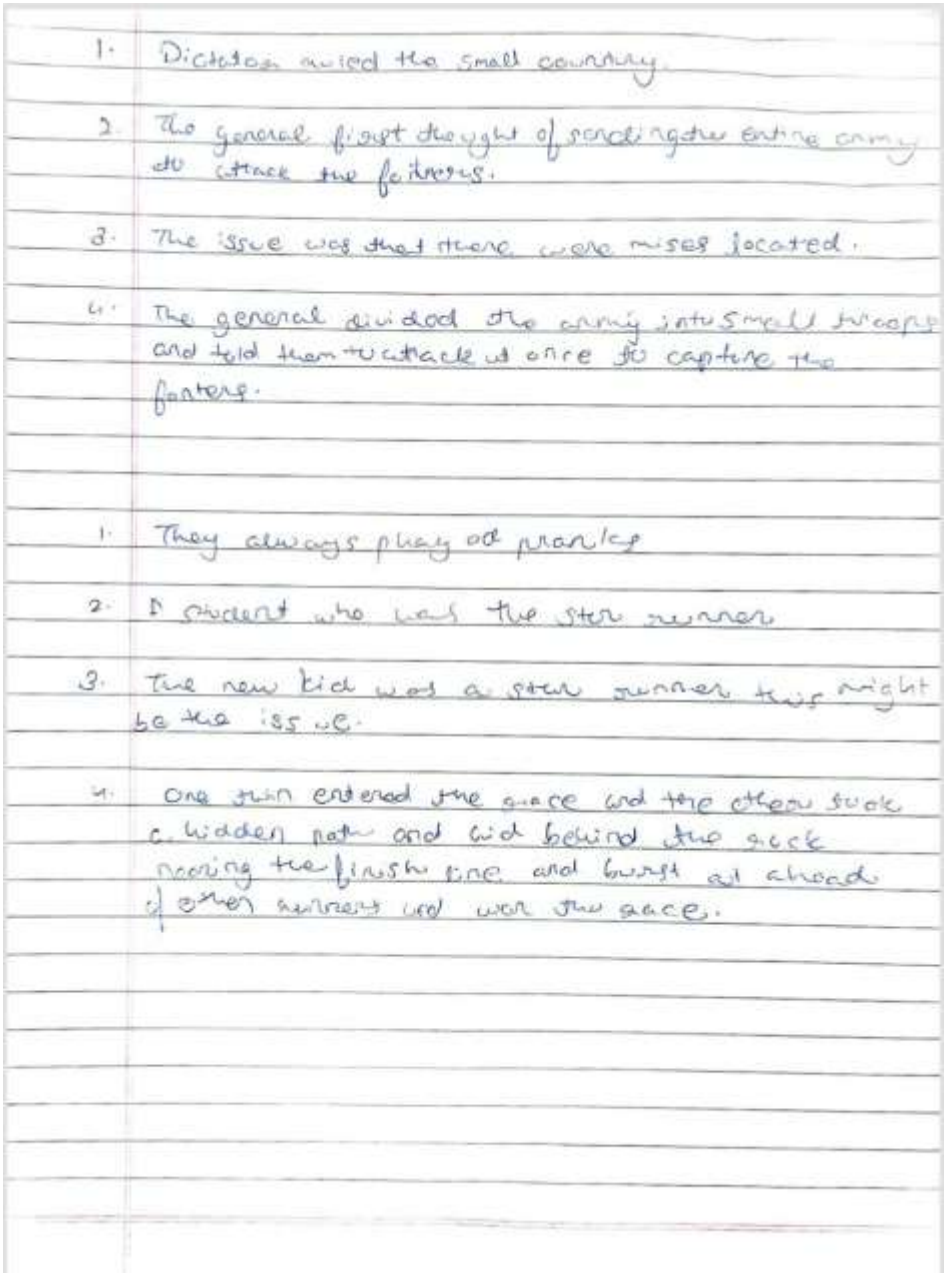


Schema induction task (P1)



Story comprehension task

P2 One analogy plus control condition



1. Dictator ruled the small country.
2. The general first thought of sending the entire army to attack the fortress.
3. The issue was that there were mines located.
4. The general divided the army into small troops and told them to attack at once to capture the fortress.

1. They always play at practice
2. A student who was the star runner
3. The new kid was a star runner that might be the issue.
4. One team entered the race and the other took a hidden path and hid behind the rock nearing the finish line and burst at ahead of other runners and won the race.

The participant in the one analogy plus control condition was unable to point similarities

C] Think aloud

Think aloud procedure of participant in the two analogies condition

While coming up with the solution the participant said “to destroy the tumor what I think I will pass the high intensity rays at the tumor and see if actually the tissues are getting damaged. If they are getting damaged, I will not do the operation but if only a few tissues are getting destroyed I will continue with the high intensity rays”

Think aloud procedure of participant in the one analogy plus control condition

While coming up with the solution, the participant said “actually, if all the high intensity rays cannot be projected at one time then may be, we can project it from different areas together so that the tumor will be destroyed but it can harm the tissues and we cannot do that so may be low intensity rays from all sides can be projected at the same time so that the low intensity rays do not harm the tissues”

C] Post-task questions

Two analogies condition

What did you think was the purpose of the current experiment?

The participant thought the experiment was about how one should not hesitate and be in the presence of the mind and solve the problem.

Did you have any prior knowledge of this study? Or about the solution to the radiation problem?

The participant did not have any prior knowledge about the study or the radiation problem.

How helpful were the story/stories from the earlier phase in arriving at your solution to the radiation problem?

The participant said that both the stories were very helpful.

In what way did you feel the earlier story helped you in arriving at your solution, highlight the specific story?

The participant said that both the stories had problems and it taught her that one should not be afraid about the situation rather be more alert.

Did you experience any fatigue, boredom that could have affected your performance?

The participant did not experience any boredom or fatigue.

Do you think that engaging in the think aloud procedure impacted your performance in any way?

The participant said that it did not affect her in anyway.

One analogy condition

What did you think was the purpose of the current experiment?

The participant thought the experiment was about a solving a problem and how one relates things in order to solve problems.

Did you have any prior knowledge of this study? Or about the solution to the radiation problem?

The participant had no prior knowledge and knew nothing about the solution to the radiation problem.

How helpful were the story/stories from the earlier phase in arriving at your solution to the radiation problem?

The participant said that the first story, that is, the general story was very helpful.

In what way did you feel the earlier story helped you in arriving at your solution, highlight the specific story?

The participant mentioned about the troops in the general story and how that was related to the rays.

Did you experience any fatigue, boredom that could have affected your performance?

The participant said that nothing as such affected her. However, she also mentioned that she was a bit nervous in the start.

Do you think that engaging in the think aloud procedure impacted your performance in any way?

The participant agreed that the think aloud procedure impacted her performance. She highlighted that it actually helped her to be quicker to come up with the solution.

D] Data Tables

8.1 Individual Data Table: Number of analogies and development of the convergence solution to the target problem.

Condition / **Solution**	**Two Analogies**	**One Analogy plus Control**
Complete / Partial / No Solution	complete solution	no solution

8.2

Group Data Table Number of participants producing the convergence solution to the target problem in the Two Analogies vs One Analogy plus Control Conditions.

Condition / **Roll no.**	**Two analogies**	**One analogy plus control**

1	0	0
2	0	0
3	1	0
4	1	0
5	1	1
6	1	0
7	1	0
8	0	0
9	1	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	1	0
16	0	1
17	1	0
18	0	1
19	0	0
20	1	0
21	1	0
22	1	0
23	0	0
24	1	0
25	0	1
26	0	0
27	1	0
28	1	0
29	1	0
30	0	0

31	1	0
32	0	0
33	0	0
34	1	0
35	1	0
36	0	0
37	1	0
38	0	0
39	1	0
40	0	1
41	0	0
42	1	0
43	0	0
44	1	0
45	1	0
46	0	0
47	0	0
48	0	0
Number of participants providing a complete solution	23	5
Number of participants providing No solution	25	43
Total number of participants	48	48

1-complete solution, 0-No solution

8.3 Group Data Summary Table:

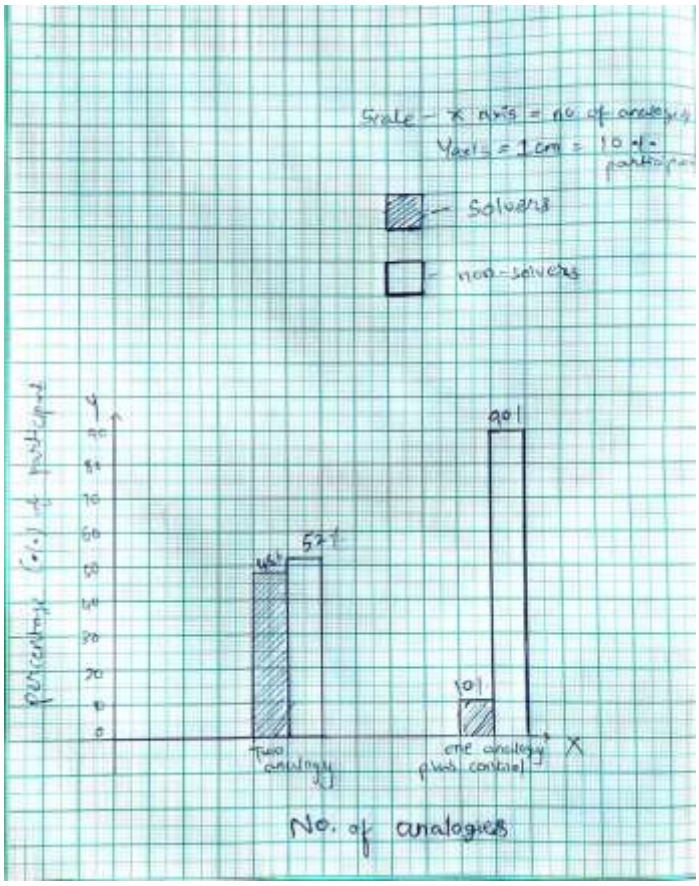
Number and percentage of participants arriving at the convergence solution to the target problem as a function of the number of analogies provided in a story comprehension task.

Condition / Solution	Two analogies	One analogy plus control	Total
Solvers	23 (47.9%)	5 (10.4%)	28
Non-solvers	25 (52%)	43 (89.5%)	68
Total	48	48	96

8.4 Group Data Table: The Calculation of the $\chi 2$ value (Test of Independence). Chi square contingency table indicating the relationship between number of analogies and development of the convergence solution to the target problem.

Condition / Solution		Two analogies	One analogy plus control	Total
Solvers	*fo*	23	5	28
	fe	14	14	
Non solvers	*fo*	25	43	68
	fe	34	34	
Total		48	48	96

Fig 1 graphical representation of the number of solvers and non-solvers in the two analogies and one analogy plus control conditions.



E] Chi-square calculation

Chi-square for data was calculated as below.

$$x^2 = \sum \frac{(fo - fe)^2}{fe}$$

$$= \frac{(23-14)^2}{14} + \frac{(5-14)^2}{14} + \frac{(25-34)^2}{34} + \frac{(43-34)^2}{34}$$

$$= \frac{9^2}{14} + \frac{(-9)^2}{14} + \frac{(-9)^2}{34} + \frac{9^2}{34}$$

$$= 5.78 + 5.78 + 2.38 + 2.38$$

$$x^2 = 16.34$$

a