

The InVivo/InVitro Approach to Cognition: The Case of Analogy

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Abstract

A new way of investigating Cognition -the InVivo/InVitro method- is proposed that combines naturalistic and experimental methods into a single approach. Using the InVivo approach we have investigated analogical reasoning by scientists reasoning “live” at lab meetings and politicians at political meetings. We found that the types of analogies that scientists use change with their goals and that politicians frequently use emotional analogies in trying to persuade their audiences to vote for their ideas. Furthermore, unlike subjects in many cognitive experiments, scientists and politicians frequently used structural features in their analogies. Using the InVitro approach we returned to the Cognitive laboratory to determine what aspects of naturalistic contexts lead people to use structural information when using analogy. We found that by asking people to generate analogies and by using complex scenarios people use structural information. We have obtained similar results in other areas of reasoning such as hypothesis testing and causal reasoning. We conclude that the InVivo/InVitro approach makes it possible to discover new features of cognition that are of both theoretical and real-world relevance.

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Cognitive Scientists have used many different approaches to understand the human mind, ranging from experiments, computational modeling, to brain scanning. Each of these approaches has yielded a vast amount of data and theory regarding the basic processes involved in cognition.^{1,2,3} While there has been a large degree of consensus on what is known about the nature of cognitive processes, many critics have claimed that what we know of human cognition is based on arbitrary tasks bearing little relationship to the cognitive processes that people use in naturalistic settings.⁴ Over the past six decades various researchers such as, Brunswik,⁵ Neisser,⁶ and Suchman⁷ have proposed different ways of investigating cognition that have been claimed to give a more accurate understanding of “real” cognition (See Cole⁷). Most of these “alternative approaches” converge on investigating cognition in naturalistic situations, often eschewing experimentation altogether (see Box 1). Here we outline an alternative approach to cognition that incorporates naturalistic and experimental approaches into one method. Borrowing from Biology, we argue that research can be kept theoretically sound and relevant to real-world performance by investigating cognition in naturalistic contexts (InVivo Cognition) *and* by conducting controlled experiments on the Cognitive phenomena uncovered in the naturalistic settings (InVitro Cognition).^{9,10,11} Here, we show

how the InVivo/InVitro approach led to a new understanding of important components of Analogical Reasoning.

Analogy

Analogies such as the atom being like the solar system, the internet like a highway, or a political party like a family abound in virtually all cultures and societies. Many researchers have argued that analogy is important in all aspects of human life ranging from politics, to relationships, to science.¹² An intense research effort over the past twenty years has resulted in a vast amount of empirical data and important computational models of analogical thinking.^{13, 14} Analogies contain two main components – the “target,” which is the problem or issue that the reasoner is currently attempting to understand (such as the internet), and the “source” which is the familiar piece of information that is used to understand the issue (such as highways). By seeing similarities between a source and a target, the reasoner can import knowledge from a familiar situation and apply it to a new situation. Good analogies are those where the source and the target have very similar underlying structures. The power of analogy is that the analogizer can see the similarities of the underlying structure, despite differences in superficial features. Accounts of analogy have stressed the importance of underlying structures and relations in analogies (see Box 2 for a description of Classical Analogy research). However, over the past twenty years, researchers have shown that while people are very sensitive to underlying structural features of analogy, they tend to use superficial features when asked to recall potential source analogs or retrieve similar situations while solving a problem.

We decided to investigate the use of analogy in non-experimental contexts. We wanted to discover what similarities people note and under what circumstances will their reasoning be based on superficial or structural similarities. That is, we examined analogy use “InVivo.” We began this research by investigating analogy use in science. Our investigation of analogy in science is part of a larger project on scientific reasoning.^{5,6,7} We have been investigating reasoning as it unfolds “live” at laboratory meetings. We have videotaped and audiotaped leading molecular biologists and immunologists as they think and reason at their laboratory meetings. We then analyzed, sentence by sentence, the types of thinking and reasoning that the scientists used when formulating theories, analyzing data, and designing experiments. We have investigated leading laboratories in the United States, Canada, and Italy. Each laboratory we have followed from three months to a year. Using this “InVivo” approach, we were able to capture science as it happens, which includes some scientific discoveries, and to investigate analogical reasoning in a naturalistic context.

For our initial investigations, we analyzed the use of analogy at 16 laboratory meetings in four laboratories.^{5,6,7} We found over 99 analogies and scientists used anywhere from 3 to 15 analogies in a one-hour laboratory meeting. What we also found is that the majority of analogies that scientists used were biological or within-domain analogies (Fig 1). Molecular biologists and immunologists used analogies from the biological or immunological domains and not from domains such as economics, astrophysics, or personal finances. This shows that scientists as well as participants in cognitive experiments use superficial features in their analogies. When scientists were using analogy to fix experimental problems, the sources and targets did indeed share

superficial features. For example, a scientist might draw an analogy between two different experiments using a gene on the HIV virus. The gene, the proteins used, and the temperature used might be identical, but the incubation time might be different. In these situations, while there were many superficial features in common, there was usually one key superficial feature, such as incubation time, that differed between the two experiments that could have led to a strange result. When the difference was noted the scientists changed the key feature: By using analogies to very similar situations, the scientists were able to fix experimental problems. Analogies based on superficial similarities can be useful. (see also Bassok & Medin¹⁵ for discussion of why superficial analogies are useful).

Insert Figure 1 about Here

When scientists switched goals to formulating a hypothesis, the types of analogies used also changed. The distance between the source and the target increased and that the superficial features in common between the source and target also decreased. Here, the scientists used structural and relational features to make an analogy between a source and a target – rather than superficial features. While only 25% of all analogies that scientists used were based on structural rather than superficial features, over 80% of these structural analogies were used to formulate hypotheses. The scientists based their hypotheses on the similarity of the underlying genetic sequences of the source and the target. For example, if a gene in clams and a gene in the malaria producing parasite plasmodium had a similar genetic sequence, the scientists might postulate that this

genetic sequence has the same function in plasmodium as in clams. While there is no superficial similarity between clams and plasmodium, there is an underlying structural similarity. It is important to note that even though the scientists were basing their analogies on sources and targets within the domain of biology, the analogies were based upon underlying sets of structural relations rather than any superficial similarity between clams and plasmodium. These results indicate that that while scientists use many analogies that share superficial features between the source and the target, they can and do produce analogies based on deeper structural features. Analogy use appears to be flexible and change with the goals of the analogizer.¹⁰

Why do these scientists use structurally based analogies? One possible reason is that these scientists were experts in a domain. Numerous researchers have shown that experts may be more likely to base their analogies on structural features, compared to undergraduate students in psychology experiments.¹⁶ To address these issues we decided to investigate analogy use in another naturalistic context and then to return to the lab to conduct our own InVitro experiments on analogy.^{17,18} We investigated the use of analogy in a referendum on independence that took place in Quebec in 1995. The electorate was presented with the choice of voting to keep Quebec within the country of Canada or voting to make Quebec a new country. We analyzed politicians and journalists use of analogy in newspaper articles during the final week of the referendum campaign. We took every newspaper story that appeared in three Montreal newspapers during the last week of the referendum campaign and searched for all uses of analogy. We found over four hundred articles referring to the referendum and then searched for every analogy used. This analysis resulted in the discovery of over two hundred analogies.

The analysis of the sources that were used revealed that only 24% were from politics. Put another way, over 75% of the analogies were not based on superficial features. Instead, the analogies were based on higher order relations and structural features. The range of source categories was fascinating, from agriculture, to the family, sport, magic, and religion. These analyses revealed that politicians and journalists frequently used sources from domains other than politics (see also Box 4). We extended the research to analyze political meetings and rallies “live.” Again we found that over 70% of the analogies used were from non-political domains. Politicians were not basing their analogies on superficial features. In both science and politics analogies based on higher order relations are common.

Back to the lab: InVivo investigations of analogy

Our InVivo work on scientists and politicians shows that analogies based on structural features are common in naturalistic settings. We wanted to find out why it has been so difficult for participants in classic analogical reasoning experiments to use structural features, yet these types of analogies are commonplace in naturalistic situations. While expertise is obviously very important, there were other hypotheses for this difference in performance. One possible reason is that the scientists and politicians were generating their own analogies rather than being asked to use various source analogs provided by the experimenter. We have used a “Generation Paradigm” in which people were asked to generate sources for a given target.¹⁹ The task that we used in these experiments was one of asking subjects to generate analogies to the zero-deficit problem. The zero deficit problem refers to the enormous deficit that the government had to cut.

We asked subjects to generate analogies that would justify cutting the deficit. First we explained the deficit problem to subjects. They were told that psychologists had found that analogy is a powerful way of changing opinion and that they should generate analogies that could be used to change opinion on the deficit issue. Subjects were asked to generate as many analogies as they possibly could. What we were interested in was whether they would generate analogs that shared superficial features only, shared structural and superficial features, or shared only structural features with the deficit issue.

Insert Figure 2 about here

Subjects generated relatively few analogies that were dependent on superficial features. As can be seen from Figure 2, most of the analogies generated (80%) were non-financial or non-political. The analogies were from a wide variety of domains such as agriculture and fables. Many of the sources that subjects used were idiosyncratic. Overall, what these generation studies reveal is that people can and do use analogical sources that do not have superficial features in common with the target. Figure 2 also shows that when the task was changed to the more commonly used task of “what does this remind you of?” our InVitro results mirror those of traditional research on analogical reasoning - people responded using superficial features. In summary, when generating analogies, people use structural information and when recalling analogs they use superficial features. By using both InVivo and Invitro approaches to Cognition we have been able to elucidate what features of the task given to participants will lead them to access superficial or structural (relational) features.

Further insights from InVivo Cognition

Our observations of analogy use by politicians and scientists showed that when they were generating analogies, they rarely gave an explicit mapping between the source and the target. In the naturalistic contexts, the source analog was described in detail, but corresponding elements for the target, and the mappings between the source and target, were not explicitly provided. This is different from analogies used in most laboratory experiments, where elements from both the source and the target are provided explicitly, and people are directly asked to draw mappings. In naturalistic environments, politicians and scientists assume that their audience will draw mappings and make inferences.

Again, traditional analogical reasoning research has demonstrated that it is difficult for subjects to spontaneously draw inferences. We investigated this question in a series of experiments where participants read the description of a target problem, followed by a potential source analog.²⁰ No mappings were explicitly made and no instructions to use this source were given. Even with minimal instructions, people engaged in analogical mapping and drew inferences. When we tested their memory for the target information, people erroneously recognized analogical inferences as having been presented, when in fact they had not. This work shows that not only can people make mappings and draw inferences when the analogy is not explicitly made, this process has an important impact on their representation of the target problem. Again, using findings from our InVivo work, we have been able to demonstrate complex analogical reasoning processes in InVitro experiments.

The InVivo/InVitro method provides a richer understanding of Cognition

Overall, our InVivo/Invitro research on analogy has showed that analogy is frequently used in naturalistic contexts and has revealed that analogical thinking and reasoning can be as sophisticated as many accounts of analogical reasoning suggest they should be, but is not readily apparent in empirical studies of analogy. By using the InVivo/InVitro approach we can see that the tasks given to subjects are crucial determinants of how people will use analogy. People in the laboratory can take advantage of structural features when the tasks that are given to them more closely resembles the analogical reasoning situations that people encounter in naturalistic contexts. When asked to generate analogies, or are given complex scenarios to read, people will use the underlying structural features that traditional models of analogical reasoning predict that they should use. This reveals that analogical reasoning, even in the psychological laboratory, is more successful than traditional research has demonstrated.

The InVivo/InVitro approach to cognition can be applied to many different domains. In one recent set of InVivo/InVitro investigations, we investigated the ways that scientists design experiments and whether they show classic confirmation bias such as only conducting experiments that will confirm a hypothesis. We found that in immunology laboratories scientists show little confirmation bias and are constantly worried by the threat of error and incorporate numerous different types of controls in their experiments. In our InVitro work we found that when people are given real-world scientific situations to reason about they show little evidence of confirmation bias, but naïve subjects with no scientific background to hook their hypotheses onto will fail to conduct certain types of experiments that will disconfirm their hypotheses.^{21,22} As with our

work on analogy, we have found that with different tasks and more realistic scenarios that tap pre-existing knowledge structures, people engage in more normatively correct reasoning.

How does the InVivo/InVitro approach differ from the Ecological and Situated approaches to Cognition? The InVivo/InVitro approach shares much with Ecological and Situated approaches, in that one part of this approach is to investigate Cognition in naturalistic situations. The InVivo component suggests new methods, theories and models that can be investigated InVitro using standard experimental and computational methods. We have shown that it is possible to go back into the laboratory and obtain the same types of results that we have observed in naturalistic settings. Unlike a number of situated cognition investigations, we have not concluded that all previous work on Analogy is misguided. Rather we are showing that both experimental and naturalistic approaches can be brought together to build new models of cognitive processes. What this method has shown is that rather than human thinking and reasoning being a catalog of errors, reasoning is often successful and works under clear constraints that both naturalistic and experimental approaches can jointly identify.

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Box 1: Ecological Psychology & Situated Cognition

One important assumption of both Ecological Psychology and Situated Cognition is that mental representations are not the central component of Cognition. Instead, theorists such as Gibson ^a, and Suchman ^b have argued that much of what guides human cognition is in the environment rather than in the head. According to this view, the goal of Cognitive research should be to understand human beings in relation to specific contexts, rather than in an abstract task. Suchman ^b argues that a real understanding of the ways that humans interact with computers is not to discern the mental model in the user's head, but to investigate the interactions with the context. Researchers in Ecological Psychology and Situated Cognition have proposed a variety of different ways of investigating cognitive activity. For example, Brunswik ^c proposed that a person should be followed around in naturalistic contexts and asked to make perceptual judgements about objects that she is looking at. Other researchers such as Bronfenbrenner ^d have proposed that we must investigate human beings in their natural contexts. More recent work by Lave and Wegner ^e again points to naturalistic situations as being the appropriate way to understand human beings. For example Lave has found that shoppers are capable of complex mathematical thought that is supported by the environment in which they shop. This type of mathematical behavior is impossible in standard experimental situations. Similarly Hutchins in his investigations of navigation has argued that cognition is embodied in the environment and not the head.^f All these approaches provide important challenges to traditional Cognitive Science methods and models.

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Box 2: Classical Analogy research

Classic experiments on Analogical thinking that have been replicated and extended by many researchers are those of Gick and Holyoak^a and Gentner and Ratterman.^b In Gick and Holyoak^a subjects were given Duncker's radiation Problem to solve. In this problem, subjects are told that a person has a stomach tumour and that doctors have a powerful laser beam that can burn the tumour out. Unfortunately, the laser beam is so strong that it will also burn the healthy tissue and the diseased tissue. Subjects are then asked to find a solution that spares the healthy tissue but destroys the diseased tissue. Some subjects were given an analogically similar story that possessed a solution. They first read a story about an army attacking an evil general living in a fortress. The fortress had a series of roads that converged at the center of the fortress. The general had placed mines on all the access roads to the fortress such that a large army would be blown up. The attacking general broke his army up into small groups that were not heavy enough to be blown up by the mines and sent each small group along each of the roads. The soldiers converged and captured the evil general. If subjects notice the underlying analogy, they should be able to map the solution over to the radiation problem. Gick and Holyoak found that few subjects spontaneously proposed a convergence solution, even when given the fortress story. Only when subjects were given hints that the fortress story was relevant did they begin to use the convergence solution. In versions of the task where the source and target share superficial features subjects readily see the connection and will spontaneously map the convergence solution from the fortress story onto the radiation problem. In many experiments, Dedre Gentner and her colleagues have also

found that people tend to rely on superficial features. For example, Ratterman & Gentner^b gave subjects a series of stories to read. A week later the subjects were given stories to look at. Some stories had the same underlying structure, others shared only superficial features. Subjects had to say which stories they were reminded of. Subjects chose the stories sharing superficial features. Other researchers such as Novick^c have found that subjects will choose structural features when they have training in a domain. She has shown that when solving mathematical equations that have the same underlying structure, subjects with experience at using these types of formulas will use structure rather than superficial features in deciding which type of procedure to apply.

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Box 3: Analogy and Emotion

While analogy has often been treated as a cold abstract process whereby one mental structure is mapped over to another, recent research has found that analogy is used to map emotional states from one domain to another. . Blanchette and Dunbar^{a&b} asked subjects to rate the emotionality of the different topics that politicians used in their analogies.

What we found is that the politicians frequently used very emotional analogies such as the birth of a child or a divorce. Interestingly, the politicians used positive sources when arguing for their own side and negative analogies when arguing against the opposing side. Other researchers, such as Paul Thagard^c analyzed the use of analogy in generating emotions. He argues that empathy is the result of analogical reasoning where one person essentially aligns her representation of herself with that of another, which enables her to experience the same feelings. Analogy is also involved in humor where many things that make us laugh are in fact unlikely mappings between one domain and another. It would appear that politicians have figured this out for centuries in fact Julius Ceaser wrote a book entitled *De Analogia* about the correct use of language! Unfortunately, along with a number of other books that Caesar wrote, this book has been lost.

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Outstanding Questions

- a. Do standard experiments and computational models provide an accurate picture of Cognition?
- b. What are the roles of superficial and structural features in analogy?
- d. How do scientists use analogy?
- e. Why do subjects in experiments rely so heavily on superficial features? Is this result a consequence of the methods used?
- f. What other aspects of cognition might the InVivo-InVitro approach shed light on? Why?
- g. Can a cognitive process such as analogy work in conjunction with other mental processes such as those involved in emotion?

Figure 1: Goals and types of analogies produced by scientists live at lab meetings

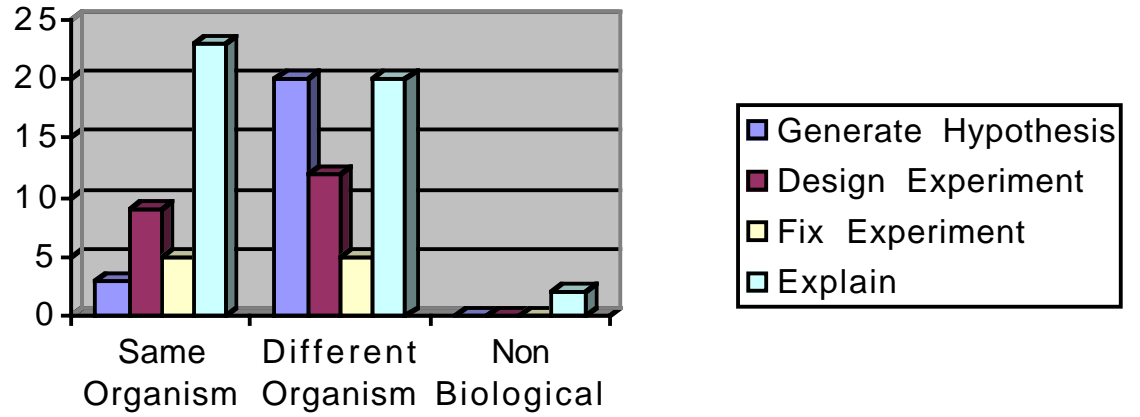


Figure 2: Types of sources used as a function of generating analogies or being asked which source they are reminded of.

