Transfer Between Analogies:

How Solving One Analogy Problem Helps to Solve Another

By

Mark T. Keane

University of Dublin,

Trinity College.

1) proof, 2) Include Burns ref...

Proofs should be sent to:

Dr. Mark T. Keane,

Department of Computer Science,

University of Dublin,

Trinity College, Dublin 2,

IRELAND

Abstract

This paper deals with transfer between analogies; with what people acquire from one analogy problem-solving episode that can be re-applied to a subsequent analogy, problem-solving episode. This issue must be resolved if we are to understand the nature of expertise and the appropriate use of analogy in education. There are two main explanations of what subjects acquire from an analogy problem-solving episode. The *schema-induction hypothesis* maintains that subjects acquire an abstract schema of the analogous domains, that can be re-applied to a subsequent situation. The *predicate-mapping hypothesis* asserts that subjects acquire a set of predicate-mappings than can be re-used in a later situation. While there is empirical evidence to support each of these hypotheses, no critical test between them has been carried out. Furthermore, no previous research has examined transfer between analogies; that is, transfer between two distinct, analogy problem-solving episodes. The present study uses a novel paradigm to test transfer between analogies in a manner that constitutes a critical test of the above two hypotheses, using attribute-mapping and relational-mapping problems. The results support the schema-induction account.

INTRODUCTION

Many aspects of analogical problem solving are now much better understood than they were 15 years ago, when research on complex analogies really began (see Gentner, 1983; Gick & Holyoak, 1980; Holyoak & Thagard, 1994; Keane, 1993, for a review). Gick & Holyoak's (1980) seminal empirical demonstration of the role of analogy in problem solving made use of Duncker's (1945) "Radiation Problem" . The radiation problem involves a doctor's attempt to destroy a malignant tumour using rays. The doctor needs to use high-intensity rays to destroy the tumour but these high-intensity rays will destroy the healthy tissue surrounding the tumour. If the doctor uses low-intensity rays then the healthy tissue will be saved but the tumour will remain unaffected too. This dilemma can be solved by a "convergence solution" which proposes that the doctor send low-intensity rays from a number of different directions so that they converge on the tumour, summing to a high intensity to destroy it. Only about 10% of subjects produce this solution if they are given the problem on its own, but when Gick & Holyoak gave subjects an analogous story about a general attacking a fortress -- who divides his army up into small groups of men and sends them along different roads to the fortress so that they converge on it -- the rate of convergence solutions rose to about 80%.

Over the last 15 years, researchers have uncovered many aspects of the process of analogical problem solving. The different sub-processes of analogy have been explored empirically; representation (e.g., Novick, 1988), analogue retrieval (e.g., Holyoak & Koh, 1987; Keane, 1987; Wharton et al, 1994), analogical mapping (e.g., Clement & Gentner, 1991; Gentner & Toupin, 1986; Keane, 1985, 1988, 1995; Spellman & Holyoak, 1992), adaptation (Keane, 1994; Holyoak, Novick & Melz, 1994; Novick & Holyoak, 1991) and induction (Gick & Holyoak, 1983; Novick & Holyoak, 1991). Furthermore, many of these sub-processes have been modelled

Falkenhainer, Forbus & Gentner, 1989; Holyoak & Thagard, 1989; Keane & Brayshaw, 1988; Keane, Ledgeway & Duff, 1994; Thagard, Holyoak, Nelson & Gochfeld, 1990). However, in spite of all of this theoretical progress, there has been little or no empirical work on *transfer between analogies*; that is, on situations in which one analogy problem-solving episode affects a subsequent analogical problem-solving episode.

Transfer between analogy episodes is an important issue for several reasons. First, it should place further constraints on theories of analogy. Second, it also has practical implications for the use of analogies in education. Students are often given successive analogy problems in the course of learning a topic (see e.g., Burstein, 1986; Mayer & Bromage, 1980). So, we need to understand what students derive from each of these episodes, if analogies are to be used effectively in educational contexts.

Table 1 About Here

The Problem of Transfer Between Analogies: Previous Research

Two main accounts of analogical transfer exist in the literature: the schema-induction account and the predicate-mappings account. The *schema-induction hypothesis* maintains that people retain an abstract schema derived from the two domains involved in the analogy. The *predicate-mappings hypothesis* maintains that people retain the specific concept-matches that were made between the two domains. In the following sections, we review each of these accounts and the evidence that supports them. However, from the outset it should be noted that no previous research has examined transfer between muitiple analogy problem-solving episodes. As we shall see, the previous literature has used either single-episode paradigms or multiple-episode paradigms with a single analogue, whereas the present study involves a multiple-episode paradigm with multiple analogues (see Table 1).

The Schema-induction Hypothesis & Supporting Evidence

Gick & Holyoak (1983) proposed that people induced an abstract schema as a bi-product of solving a problem by analogy. They maintained that the experience of solving an analogy problem resulted in the formation of an abstract schema of the analogue and problem domains. So, they argued that after solving the radiation problem by analogy to the general story, subjects had derived an abstract schema of the commonalties between these two domains (see Table 2). Most of the research to support this proposal has used variants of the standard, analogical problem-solving paradigm (see e.g., Gick & Holyoak, 1980; Keane, 1988); what I will call the single-episode paradigm (se Table 1). For example, in Gick & Holyoak's experiments subjects are given a single story-analogue (or a number of analogues) and are asked to solve a single problem by analogy to it (or them).

Table 1 About Here

Gick & Holyoak (1983) found that manipulations using a single-analogue did not produce analogical transfer. The most convincing support they found for schema-induction came for situations in which subjects first noted the similarities between two story-analogues and then solved the radiation problem (see the single-episode, multiple-analogue paradigm in Table 1). Subjects in their two-analogue condition produced more convergence solutions than subjects who were given a single analogue and an irrelevant story (in conditions where no hints were given). They also found that the quality of subjects' abstract description of the two stories (a measure they called *schema quality*) was a good predictor of whether or not they succeeded in solving the problem by analogy (but see Gick & McGarry, 1992; Weisberg & Spenser, 1986; Reeves & Weisberg, 1994). Gick & Holyoak (1983) explained these results by proposing that subjects derived an abstract, convergence schema from the stories that was applied to the subsequent problem; they proposed that mapping from an appropriate schema was

easier than mapping from an analogue. Table 2 shows the convergence schema they assumed subjects derived for the stories and problem.

Novick & Holyoak (1991) found more direct evidence for schema-induction in a multiple-episode, single-analogue paradigm (see Table 1). Using mathematics word problems, they found that solving one target problem-a, with analogue-a improved the subsequent solution of a second problem, problem-b, which was also analogous to analogue-a [1]. Like Gick & Holyoak they found that schema quality was the best predictor of success on this second problem (see also Bassok & Holyoak, 1989; Catrambone & Holyoak, 1989; Reed, 1989; Ross & Kennedy, 1990 for related work). This research shows that people can induce an abstract schema from one analogy problem-solving episode. It also suggests that in the presetn paradigm (a multiple episode, multiple analogue paradigm) people should use an abstract schema derived from an earlier analogy problem-solving episode to guide the solution of a later problem-solving episode.

The Predicate-Mappings Hypothesis & Supporting Evidence

Burns' (1992, 1994) predicate-mappings hypothesis leads to a very different account of analogical transfer. Rather than an abstract schema being derived from an analogy problem-solving episode, it is suggested that people retain specific mappings between concepts in the two domains. If we apply this account to the radiation-problem analogy, it predicts that the mappings between the two domains is retained after solving the problem by analogy: that is, predicate mappings like $intend_{general}$ -> $intend_{surgeon}$, $send_{troops}$ -> $send_{rays}$, $take_{fortress}$ -> $destroy_{tumour}$. In a second problem-solving episode this account predicts that there should be better transfer if the second episode involves the same or similar predicate mappings. So, the subsequent solution of another analogy problem involving a military analogue and a medical problem should be easier. Veale & Keane (1993, 1994) have proposed a related computational account

The predicate-mappings hypothesis has been used successfully to predict transfer effects in letter-string proportional analogy problems. Proportional analogies are often used as test items in IQ tests and have been the focus of extensive study (see e.g., Sternberg, 1977). In letter-string proportional analogies, subjects are asked "If *abc* was changed to *abd*, how would you change *kji* the same way ?" (typically, the problems are notated as *abc:abd::kji:?*). One of the benefits of these problems is that they admit several possible solutions; for example, plausible answers to the above problem include *kjj*, *kjh*, *lji*. However, these different answers rely on different predicate-mappings between the domains of the analogy. For the *kjj* solution, *c* (last element of *abc*) is mapped to *i* (last element of *kji*) and the "successor" relationship between *c* and *d* is mapped to a "successor" relationship between *i* and *j*. So, this solution is based on a *successor ->successor* mapping. In the *kjh* solution, the subjects have to represent the fact that *abc* is an ascending sequence and that *kji* is a descending sequence; so, *b* is the successor of *a* and *c* is the successor of *b*, as *j* is the predecessor of *k* and *i* the predecessor of *j*. This successor-group is then mapped from *abc* to the predecessor group in *kji*, allowing the "successor" relationship between *c* and *d* to map the "predecessor" relationship between *i* and *h*. So, this solution is based on a *successor->predecessor* and a *sequence->sequence* mapping. These analogies have been modelled extensively in the Copycat analogy model produced by Hofstadter and Mitchell (Hofstadter & Mitchell, 1988; Mitchell, 1993; Mitchell & Hofstadter, 1989).

In his empirical studies, Burns first gave subjects analogies like *abc:abd::kji:?*. . He then examined how the solutions subjects proposed to this first analogy episode affected a second analogy episode, like *abc:abd::mrrjjj:?*. Clearly, if one re-applied the successor-successor mappings the solution to the second problem should be *mrrkkk*, whereas if one re-applied the successor-predecessor mapping a likely solution would be *mrriii*. Burns tested this type of a prediction in five different experiments, all of which substantially supported the predicate-mappings hypothesis. Burns' paradigm, like

single analogue (see Table 1). As such, it is quite different to the paradigm used here, although his theoretical account makes predictions in the present study.

Summary

In this study, we test these two competing accounts of transfer between analogy, problem-solving episodes. The materials used are attribute-mapping and relational-mapping problems. In particular, I examine the issue of whether there is transfer from solving an attribute-mapping problem to the solution of a relational-mapping problem. To the best of our knowledge, this is the only instance of a multiple-episode, multiple-analogue paradigm in the literature. The benefit in using this paradigm with these problems is that they constitute a situation that allows a critical test of these alternative hypotheses; the schema-induction account predicts transfer between these problems, while the predicate-mapping account does not.

Transfer Predictions Between Attribute-Mapping and Relational-Mapping Problems

In this study, I examine the issue of transfer from one analogy, problem-solving episode to another; in particular, transfer from an attribute-mapping problem to a relational-mapping problem.

Holyoak & Thagard (1989) proposed the attribute-mapping problem as a demonstration that people can handle analogies that involve pure, structural isomorphisms (see Table 3). In attribute-mapping problems, subjects are asked to say which things in List A correspond to which things in List B (ignoring the meaning of the words); they have to discover a one-to-one mapping between all the individuals and attributes in List A and List B. This mapping task is quite difficult because of the ambiguity in the mappings between the two domains and the number of possible interpretations of the analogy (32 in total). For example, *smart* may match *hungry* or *friendly* or *frisky* and the correct

all but one of these matches. However, many subjects manage to solve the problem producing the unique one-to-one mapping that involves matching *Steve -> Fido*, *Bill -> Rover*, *Tom -> Blackie*, *smart -> hungry*, *tall -> friendly*, and *timid -> frisky*. Keane et al. (1994) demonstrated order and similarity effects these problems based on predictions made by the Incremental Analogy Machine (IAM).

Table 2 About Here

Keane (1995) showed that order effects found in attribute-mapping problems generalised to structural isomorphs which he termed relational-mapping problems (see Table 2). However, relational-mapping problems are generally more difficult than attribute-mapping problems because more entities are involved in the mapping. For example, the solution to the relational-mapping problem used here has three more mappings than the attribute-mapping problem; it is solved by the mappings *Joe -> Lisa, Steven -> Jenny, Mark->Laura, Ronan->Ruth, Conor -> Mary, Paul -> Ali, motivates -> hugs, is-beside -> employs, fears -> sees*. The important point for the present study is that these problems have certain abstract features in common but they do not share any specific, predicate mappings. Consider what the two hypotheses predict for the situation in which subjects first solve the attribute-mapping problem and then the relational-mapping problem.

According to the schema-induction hypothesis, after solving the attribute-mapping problem subjects should have some abstract schema for the problem; for instance, that the problem involves matches between semantically-unrelated entities and that these matches must be co-ordinated to form a one-to-one mapping between the two lists. Such a schema would surely aid subjects in solving the relational-mapping problem, where they again have to match up semantically-unrelated entities and co-ordinate these matches.

In contrast, according to the predicate-mappings hypothesis, very different information should be retained from the first problem-solving episode. After solving the attribute-mapping problem subjects should retain a record of the predicate-mappings established (i.e., *smart -> hungry*, *tall -> friendly*, and *timid -> frisky*). These mappings would not help to solve the relational-mapping problem because it is solved by a very different set of mappings (e.g., *motivates -> hugs*, *is-beside -> employs*, *fears -> sees*). In short, the schema-induction hypothesis predicts transfer from the attribute-mapping problem to the relational-mapping problem but the predicate-mappings hypothesis does not.

TRANSFER BETWEEN ANALOGY PROBLEM-SOLVING EPISODES

In the present experiment, I tested the above proposals by giving an experimental group the relation-mapping problem to solve after they had solved the attribute-mapping problem. A parallel control group, received the same relational-mapping problem, after an irrelevant task. If the schema-induction hypothesis is true then the experimental group should do better on the relational-mapping problem than the control group. The predicate-mapping hypothesis predicts no difference between the two groups.

Method

Subjects & Design

Forty-eight undergraduates attending Trinity College Dublin took part voluntarily in the experiment. The design was a between-subjects design with two conditions: the experimental condition (n = 28; who solved the attribute-mapping problem and then received the relational-mapping problem) and the control condition (n = 20; who received an irrelevant task and then the relational-mapping problem). An additional 22 subjects participated in the experiment and attempted to solve the attribute-mapping problem, but failed to solve it. They were excluded from the experiment because they had not acquired the relevant predicate-mappings for the attribute-mapping problem.

Materials

We used the two types of problem shown in Table 2: attribute-mapping problems and relational-mapping problems (also see Appendix). The sentences making up the lists for each problem type were randomised with the constraint of keeping attributes (or relations) about the same individual (or pair of individuals) together. Order effects in the problems were controlled by counterbalancing different orderings of the sentences between and within conditions.

Procedure

Subjects in the experimental condition solved the attribute-mapping problem and were presented with the relational mapping problem to solve. In the control condition, subjects received an irrelevant task of the same duration as the attribute-mapping task and then the relational-mapping problem.

When solving the problems all subjects were shown the two lists of sentences and were instructed in writing that their "task is to figure out what in the left set corresponds to what in the right set of sentences". A single column below List A listed the names of the individuals and attributes/relations in that list (in the order in which they appeared in the list of sentences). Next to each was a space for subjects to write the corresponding name or attribute/relation from List B. Subjects were first shown the instructions and problem and were asked to read them carefully. Subjects were given 15 minutes to solve each problem and were tested individually and in small groups.

Measures

The dependent measure was the proportion of incorrect-mappings produced by subjects to a problem (the attribute-mapping problem has six correct mappings and the relational-mapping problems has nine such mappings).

Figure 1 About Here

Results & Discussion

Figure 1 shows the mean number of incorrect-mappings produced by subjects in the two conditions of the experiment. The pattern of results shows that prior experience of solving the attribute-mapping problem results in transfer to the relational-mapping problem.

A chi-squared test revealed a reliable difference between the frequency of subjects solving the relational-mapping problem in the experimental condition 71% (20 out of 28) than in the control condition 40% (8 out of 20; $chi^2(2) = 10.28$, $p = .001$). This difference was maintained in the mean number of incorrect mappings produced by subjects in both conditions. Subjects produced reliably fewer incorrect mappings in the experimental condition (M=.15, SD =.26) than in the control condition (M =.42, SD =.39; $t(46) = -22.95$, p = .005).

These results suggest that the predicate-mapping hypothesis should be rejected and the schema-induction hypothesis adopted. People acquire some general schema of about how to solve the attribute-mapping problem by analogy. This general schema is then re-applied to the relational-mapping problem and even though this problem differs in several respects the schema acts as a significant guide to enable people to solve the problem. Without a relevant schema, problem solving performance is significantly worse.

GENERAL DISCUSSION

The present study involves a novel test of two alternative hypotheses about transfer between different analogy problem-solving episodes. One's initial intuition might be that no transfer could occur between the problem-solving episodes used here; exactly the prediction made by a predicate-mappings hypothesis. However, we have found significant transfer from the solution of one mapping problem to another. These results

that subjects derive some abstract structure characterising the first analogy episode that is re-applied to the second episode. This finding is consistent with a large number of other studies in the literature (see e.g., Novick & Holyoak, 1991; Reed & Evans, 1987; Ross & Kennedy, 1990). This link between analogy and schema induction is important because it suggests that analogy has a role to play in forming the schemata that turn novices into experts (see Chi, Feltovich & Glaser, 1981; Eysenck & Keane, 1995, Chapter 16 for a review).

Where does the present finding leave the predicate-mappings account ? To date, the predicate-mappings hypothesis has only received support in the context of letter-string, proportional analogies. While the account is a plausible one and has received ample support in proportional analogy problems, its applicability to transfer in more complex analogical problem solving remains questionable. It remains to be seen whether it can generate successful predictions for more complex analogies.

AUTHOR NOTES

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FOOTNOTES

[1] Note that between the first problem solving episode and the second subjects were asked do a similarity assessment task like that used by Gick & Holyoak (1983). That is, subjects were asked to characterise the similarities between the story-analogue and the problem. After this task, they were given the second problem to solve.

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Table 1 Different Types of Paradigm Used to Examine Transfer in Analogical Problem Solving

Single-episode paradigms	
	Single analogue
	Episode 1: analogue-a *is-mapped-to-solve* problem-a
	Multiple analogue
	Episode 1: (analogue-a, analogue-b...) *is-mapped-to-solve* problem-a
Multiple-episode paradigms	
	Single analogue
	Episode 1: analogue-a *is-mapped-to-solve* problem-a
	Episode 2: analogue-a *is-mapped-to-solve* problem-b
	Multiple analogue
	Episode 1: analogue-a *is-mapped-to-solve* problem-a
	Episode 2: analogue-b *is-mapped-to-solve* problem-b

Table 1 The Convergence Schema Proposed by Gick & Holyoak (1983) to Characterise The General Story and Radiation Problem

Initial State:		
	Goal:	Use force to overcome a central target
	Resources:	Sufficiently greater force
	Constraint:	Unable to apply full force along multiple paths simultaneously
Solution Plan:		Apply weak forces along multiple paths simultaneously
Outcome:		Central target overcome by force

Table 3 Examples of Mapping Problems Used in Experiment 1

Attribute-mapping Problem

A	B
Tom is tall.	Fido is hungry.
Tom is timid.	Rover is friendly.
Bill is smart.	Rover is hungry.
Bill is tall.	Blackie is frisky.
Steve is smart.	Blackie is friendly.

Relational-mapping Problem

A	B
Conor is beside Paul.	Lisa hugs Jenny.
Conor fears Paul.	Mary employs Ali.
Mark motivates Ronan.	Mary sees Ali.
Mark is beside Ronan.	Laura hugs Ruth.
Joe motivates Steven.	Laura employs Ruth.

APPENDIX: MATERIALS

Attribute-Mapping Materials

Your task is to figure out what in the left set of sentences corresponds to what in the right set of sentences.

THE MEANING OF THE WORDS IN THE SENTENCES IS IRRELEVANT.

A	B
Tom is tall.	Fido is hungry.
Tom is timid.	Rover is friendly.
Bill is smart.	Rover is hungry.
Bill is tall.	Blackie is frisky.
Steve is smart.	Blackie is friendly.

<u>For Working</u>

Tom

Bill

Steve

tall

timid

smart

Relational-Mapping Materials

Your task is to figure out what in the left set of sentences corresponds to what in the right set of sentences.

THE MEANING OF THE WORDS IN THE SENTENCES IS IRRELEVANT.

A	B
Conor is beside Paul.	Lisa hugs Jenny.
Conor fears Paul.	Mary employs Ali.
Mark motivates Ronan.	Mary sees Ali.
Mark is beside Ronan.	Laura hugs Ruth.
Joe motivates Steven.	Laura employs Ruth.

<u>For Working</u>

Conor

Paul

Mark

Ronan

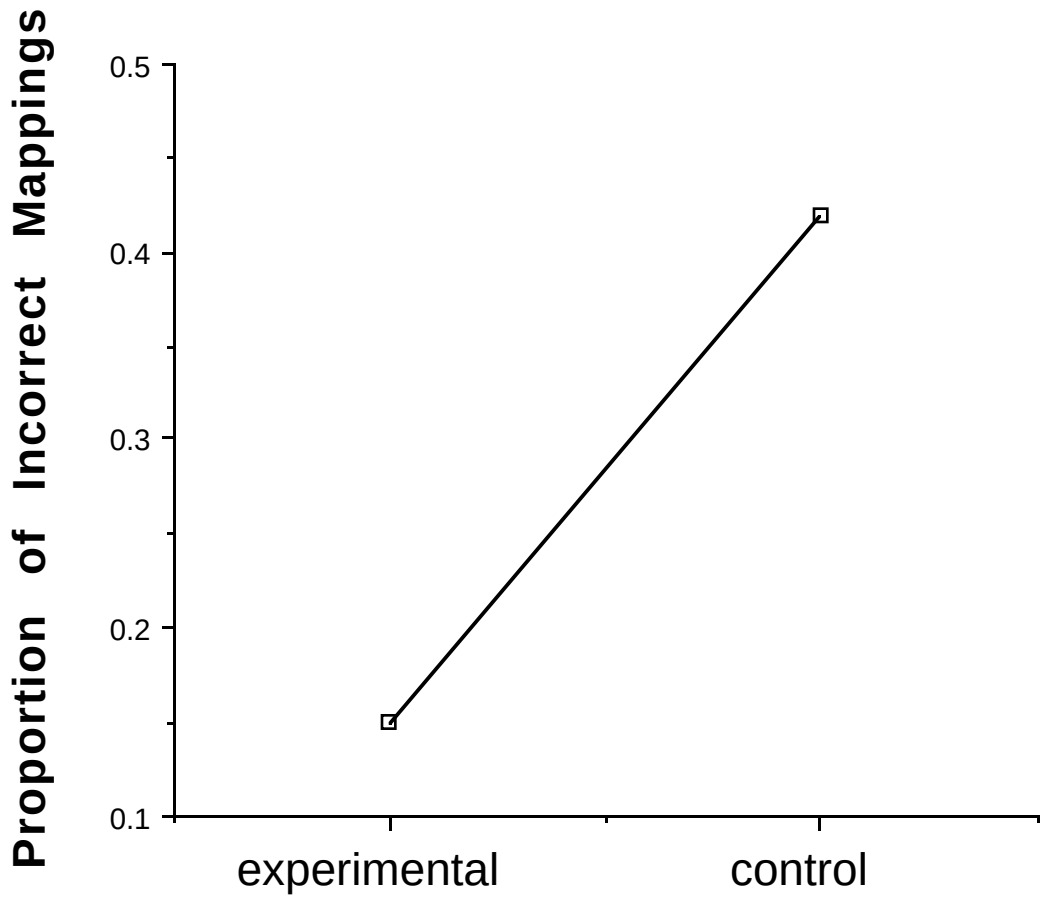
Joe

Steven

is beside

fears

motivates


Proportion of Incorrect Mappings
0.5
0.4
0.3
0.2
0.1
experimental
control