Student Generated Analogies in Science: Analogy as Categorization Phenomenon

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Abstract: Past research on analogies has tended to focus on analogies generated by a textbook, teacher, or researcher that are then interpreted by a student. Such research identifies how students learn from analogies—but not how students create or use their own analogies. Models of analogy comprehension that have been derived from this research, in particular structure-mapping, cannot be extended to analogy creation. However, features of student-generated analogies show striking similarities to features of *categorization*, including prototypes, family-resemblance, and a folk-theory basis. In this paper, I present a thread of analogies from a 5th grade science classroom and argue for a view of analogies as a categorization phenomenon.

Introduction

When students are explaining their scientific ideas and predictions to others they frequently draw analogies to explain themselves (Dunbar, 2001), where by analogy I mean a description of one phenomenon in terms of another. Understanding these analogies is crucial if one is to understand student reasoning in science. There is a wealth of research on analogies, including several computational models (including Gentner, 1988; Falkenhainer, Forbus & Gentner, 1986; Holyoak & Thagard, 1989; Glucksberg and Keysar, 1990), but the majority of this research concerns the comprehension of analogy and not its creation (exceptions include Hofstadter & Mitchell, 1994). The creation of analogies (e.g., a student's comparison of a falling cup of water to a toy cat swinging in a basket—see below) is a very different process from the comprehension of an existing analogy (e.g., other students in the class interpreting that analogy). Recent reforms in science education have called for an increased focus on student ideas. Such a shift will lead to an increase in student generated analogies in the science classroom and necessitate a better understanding of these.

Categorization research has emphasized the creation and structure of categories that the participants have—how learners form categories, instead of how they understand categories presented to them. This research has much to offer the study of analogy creation and usage. In section 1 I summarize current categorization research. In section 2 I present a thread of analogies generated spontaneously in a 5th grade science classroom and argue that these analogies define and negotiate a category. I then contrast this categorization model of student-generated analogies with models of analogy comprehension (particularly Gentner's (1988) structure-mapping) and show that these models of analogy comprehension do not account for the creation of analogies.

I. The Modern View of Categorization

Research on categories has had major shifts in the past 30 years, beginning Rosch's research on prototypes. Here I briefly review the features and theories of categorization; below I will show that these features are present in analogical reasoning in students. These features include prototype effects, a folk-theory basis and multiple members.

The classical view of categories held that there were rules of membership and if an item met these rules then it was a member of the category (or, there are properties that define a category and all members must share these properties). In this view categories, therefore, were seen as binary with no internal structure: an item either was or was not a member of that category, and the research paradigm for categorization was to define the rules or properties. Rosch's (1973) research challenged the classical view, arguing instead that categories had graded structure: some category members are more representative of the category than others, some items are of indeterminate membership (is a stool a chair?), and some non-members may be still seen as "closer" to the category than others. Rosch developed a research paradigm for identifying these prototypes, attending to features such as the following (using the category "bird" for illustration):

1. Direct rating. (How birdlike is this?)
1. Reaction time. (Show a picture and ask: Is this a bird?)
1. Producing an example. (Draw a bird.)
1. Asymmetry of similarity. (Are ducks like robins? Are robins like ducks?)
1. Asymmetry of generalization. (Robins get the flu, do ducks? Ducks get the flu, do robins?)

In this paradigm, a prototype will receive a high rating, show low reaction time, and resemble the example produced. Additionally, studies show (Rips, 1975) that people will more readily compare a non-prototype to a prototype and will more likely generalize from the prototype to the non-prototype than vice versa. Initial theories on categorization in this vein argued for a category membership as degree of similarity to the category prototype.

Further work showed that categories are not defined solely by family resemblance to a prototype, but have "an intellectual as well as an ecological basis" (Neisser, 1987 p3). Barsalou (1983) studied "ad hoc" categories, such as "foods not to eat when on a diet." Members of these categories had the graded structure and typicality effects that Rosch found, but did not show family resemblance to the prototype. Instead the categories were goal-oriented; for example, a chocolate cake has little resemblance to peanut brittle, but abstaining from these satisfies the goal of eating as few calories as possible. Murphy and Medin (1985) found that "categorization assumes a (folk) theory on the part of the person who is engaged in that particular cognitive process. This theory 'guides' him in selecting the relevant features and the relevant feature correlations; in other words, noticing features and feature correlations is not an 'objective' process based on similarity, but is instead theory-dependent." (Shen, 1992) Lakoff (1987) holds that prototype effects result from cognitive models, "which can be views as 'theories' of some subject matter." (p 45) The "effect of these beliefs is to make some similarities between objects decisive and other simply irrelevant." (Neisser p 3)

Additionally, researchers have shown (Namy and Gentner, 1999) that students' abilities to categorize properly are greatly enhanced when multiple members of a category are shown. Without presentation of multiple category members, young students, in particular, tend to categorize based on superficial similarities.

If analogies are, as I claim, assertions of categorization, they should display similar properties:
they should be based on theories and/or goals
they should show the prototype effects of generalization and similarity, and
they should often appear in sets of several analogies rather than singly in as a base-target pair.

In the following section I will follow a thread of analogies in a 5th grade science class that displays these properties.

II. Analogies in the Classroom

The following passages are taken from a "Science Talk" (Gallas, 1995) in 5th grade classroom in Maryland. The students are posed the following question (NASA, 1999): a cup full of water is inverted on a cookie tray and the tray is rapidly pulled out from underneath the cup (see Fig. 1). What happens to the cup-water system? Most students believe the water will "go everywhere" and report as much. This belief is most apparent when the experiment is performed and the students are surprised by the result (the cup and water fall at the same rate, and the water does not leave the cup until they hit the ground). This surprise is evidence that the students expected this cup-water system to behave differently, meaning they expect this cup-water system to belong to a class of things that spill, i.e. like most other overturned cups. None of the students explicitly states this.

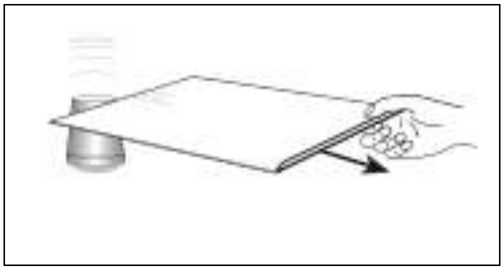

Fig. 1: The Experiment: A tray pulled out from under a cup

However, one student predicted this correct outcome and explained her prediction with an (unsolicited) analogy.

> Teacher: …let's see what some– I see a lot of other hands up. Um, Miranda?
> Miranda: I predict that when it falls off it's going to stay in the cup until it gets down to the floor and then it'll splash.
> Teacher: So you have a prediction that when I slide it off of the tray the water is going to stay in the cup. Now that's very different from what they're saying.
> Miranda: 'Cause at home when I have like something in a basket and when I go like that real quick [student swings arm around, miming that the basket is swung overhead and quickly pulled down] it stays in. So when – and when I pull it down like this [motions pulling basket straight down] like upside down on the way down it stays in until it gets to the bottom and then it comes out.
> Teacher: So you're using now this example of something that you've done at home where you have an object in a bucket— or a basket, you said— and what do you do? You—
> Miranda: I go like this and then I pull it down and it stays at the top until I stop and then it comes out. [Motions swinging overhead and pulling down, lifts hands to show that it stays at the top of the basket.]
> Teacher: So you swing this – what's in the basket? What object is in the basket?
> Miranda: Sometimes I put like, like a little toy cat that I'm playing roller-coaster with and put it in there and I pull it down and it stays in the back [motions that the cat is up at the top] until I stop and then it comes out.

Miranda explains her prediction about the water by spontaneously creating an analogy in which the cup corresponds to a basket and the water corresponds to a toy cat. This analogy, I assert, positions this cup and this basket as belonging to a category (1). That category we can call "containers that do not spill their contents when overturned" (2). Miranda's analogy claims that this not-obvious category exists. The reasoning and analogies that follow illustrate several features that have been identified in research in categorization: a folk-theory basis, prototypes, and multiple members.

A Folk-theory Basis and Prototypes

Categories are not just defined by resemblance to a prototype but are often structured around a folk "theory" of the world (Murphy & Medin, 1985, Barsalou, 1985, and Lakoff, 1987). Further clarification of Miranda's analogy by another student illustrates this principle:

> Teacher: …Ok now has anybody else, want, can relate to this also? Looks like a lot of you can. Let's hear some of your ideas. Let me come over to – thank you Alyssa.
> Alyssa: Um. Um what she's also talking about it's the air- it's like pushing the cat up against the— the bottom of the basket which is holding it back from going out.

And Miranda agrees with this theory,

> Miranda: And it'll be the same thing with the water the air will push the water up [raises hands up to show the push] until it falls down and then it will go everywhere. Because when it comes down the air is pushing upwards [raising hands] and that keeps the water in there- because I've also done that in the bathtub when you've got your cup, I'll like I'll fill it with water, put my

hand, and drop it the water stays in until it hits the bathtub and then it goes everywhere. [Mimes dropping the water.]

What is startling in the above passage is that Miranda claims to have done something that is quite similar to the case in question (involving cups, water, and dropping), but her initial analogy to explain her reasoning came from a much less similar experience. Several findings from category research can be brought to bear to understand this seeming illogicality. First, if a generated analogy is an assertion of category membership, one might expect the choice of analogy base (3) to be a category prototype and not a visually (or structurally) more similar event. When listing members of a category, the first members that are listed are category prototypes. In this case the category is "containers that do not spill their contents when overturned," and so Miranda would be expected to choose a prototypical member of this category and not an analogy that is "closer" to the target. Second, categories are often folk-theory based, and if the theory at play is one of air pushing then the cat-in-basket analogy is a better exemplar, as is illustrated by other students who later in the conversation contend that air can push a cat (because "it's just one thing") but not water. It could be argued that air pushing was not Miranda's original theory and may not have come into play in her original reasoning. Elby (conversation) suggested perhaps Miranda was invoking a "carrying" phenomenological primitive (diSessa, 1993) (the cat stays in the basket because it is "carried along" with it) in which case the cat-in-basket is still a better exemplar than the bathtub exemplar. Even when we (as researchers) are unsure of the mechanisms/theories that define students' categories, we should expect them to reason about category prototypes, and not other category members, because of the asymmetry of generalization and similarity: if you determine a principle that applies to the prototype, it is easier to extend it to non-prototypes, and those non-prototypes are easier to determine if you have determined a prototype. This implies that the analogies students draw should not be expected to be "near" analogies, but rather analogies to category prototypes.

<u>Multiple Spontaneous Analogies</u>

Following discussion of the mechanism of air there are still questions and the class is divided on whether or not the cup-water system will behave like the cat-in-basket system. Students then begin to come up with multiple spontaneous analogies as a means of negotiating the category:

…[When I have] a bucket full of water and I swing it around… when I throw it, the bucket of water still stays until it hits something.

…at Trick-or-Treat I had like a bunch of candy and I swung it around… and none of the candy came out.

…when me and Johnny play Monopoly there's like this little hat that we play with when we roll the dice and like, we always put the dice in and flip it back to each other with the dice in it and we always catch it and it stays— and the dice stay in.

It is both intuitive and empirically proven that knowledge of multiple category members improves students' ability to properly categorize a novel item (Namy and Gentner, 1999). The above listing of analogies can be seen as "fleshing out" the category in order to better categorize the novel water-cup system.

These passages demonstrate that features that have been identified in categorization are also apparent in analogies that are spontaneously generated by students in a science classroom, and the research on categorization can shed light on the ways in which students are reasoning.

III. Why Not Structure-Mapping?

The most well known theory of how analogies are interpreted is Gentner's structure-mapping theory and its associated computational model, the Structure Mapping Engine (Falkenhainer, Forbus & Gentner, 1986). This theory has had success in explaining and predicting phenomena in the interpretation of analogies and it seems only natural to apply the theory to student-generated analogies in science. The central idea in structure-mapping is that

> an analogy is a mapping of knowledge from one domain (the base) into another (the target), which conveys that a system of relations that holds among the base objects also holds among the target objects… In interpreting an analogy, people seek to put the objects of the base in one-to-one correspondence with the objects in the target so as to obtain the maximum structural match (Gentner, 1989).

Although Gentner has shown that structure-mapping accounts for analogy *interpretation*, it is tempting to extend the theory to analogy creation. While structure-mapping can account for many properties of student-generated analogies, including the folk-theory basis, it cannot account for prototype effects and multiple spontaneous analogies.

Dunbar (2001) has noted a similar difference, particularly between the analogies that occur in a psychology experiment and those occurring naturally. This distinction he terms “in vivo” versus “in vitro” analogies. *In vivo* refers to analogies as they are created in a natural setting (a science lab, in the case of Dunbar’s research) and *in vitro* refers to analogies that are presented to a participant in the psychology lab. His findings suggest that there are significant differences in the nature of these two types of analogies, theorizing that this could be due in part to *in vivo* analogies resulting from a memory search, while *in vitro* analogies require participants to choose between different sources. His suggestion is consistent with the idea that structure-mapping, while accurate *in vitro*, may not be accurate *in vivo* for student-generated analogies.

There is evidence from the above transcript that structure-mapping alone cannot account for student-generated analogies. While individual analogies may be understood as structure-mapping, multiple spontaneous analogies are better accounted for as a whole by categorization. By the time a student in the cited discussion compares a cup and water to dice in a hat, he has heard four other analogies. His analogy indicates that he has understood these properly. Having mapped the target (cup-water) onto the base (cat-basket) then, in the structure-mapping model, there is no need for the multiple analogies. In the categorization story, however, identifying multiple members of a category is beneficial in understanding the category.

Choosing a base, in the above conversation, is more than a matter of finding a similar structure, but choosing a category prototype. A structure-mapping account of analogy generation cannot account for this, while the categorization story does.

Studies in metaphor interpretation may support this view of analogy creation. Some studies (Bowdle and Gentner, 1999) show that a well-known metaphor is interpreted rapidly and shows categorizational effects while a novel metaphor does not and is structure-mapping-like in its interpretation. (For example, interpreting: life is like a road versus life is like a newspaper would be well-known versus novel.) In creating an analogy the analogy is, for its creator, well understood and may be expected to mirror the interpretation of well-known metaphors.

IV. Summary

The reforms that are being instated in science education call for a greater attention to student ideas and reasoning (NRC, 1996). Past research on analogies—including analogies in the classroom—concern themselves with participants and students *interpreting* analogies and not *generating* analogies, reflecting a model of education in which students receive and interpret knowledge from the teacher, but do not contribute their own knowledge to the instruction. The reforms in science education demand more attention to this latter type of analogy: what a student means when he states that *x* is like *y*. In this paper, I have argued that when looking at such student-generated analogies, their properties and bases, a pattern consistent with categorization emerges. Student-generated analogies are based on folk-theories, are often generated in multiples, and refer to category prototypes.

Endnotes

(1) Murphy and Medin (1985) distinguish a category from a concept, saying: “We use *concepts* to refer to mental representations of a certain kind, and *categories* to refer to classes of objects in the world.” I am taking a similar stance, suggesting that categories may be based on concepts and these can be revealed by analogies.

(2) I do not mean to impute propositional structure by so naming the category—rather, I need a way of referring to this category. The reader should not interpret “containers that do not spill their contents” as a definition of the category.

(3) In an analogy statement “*A* is like *B*,” *A* is the target and *B* is the base.

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