Chapter 4: Phenomenological Coherence

Introduction

The central thesis of this dissertation is that student generated analogies in science can best be interpreted as assertions of categorization. This description of analogy began with an analysis of a single classroom, first introduced in the previous chapter. In this chapter, I will highlight particular *phenomenological* aspects of this and other analogies and the negotiation of these analogies. I will explore the consistency of these aspects with a categorization framework. Alternative theories of analogical reasoning will be contrasted with a categorization description. In following chapter, I will address the implications that these phenomenological properties have on cognitive structure and how a theory of cognitive structure that consists of a manifold ontology of mind can, in turn, provide a more formal definition of analogy and account for the phenomenology described here. The phenomenological features that will be detailed below are: multiple analogies that serve to enumerate a category, multiple analogies that serve to analogy "hop," far-transfer analogies introduced before near-transfer analogies, constructing the base of an analogy rather than recalling the base from memory, a variable representation of that base, and analogies as offering an *alternative* to another way of understanding this phenomenon.

Models of analogy from the literature

To understand these phenomenological aspects of generated analogies, one might first turn to an established model of analogy. As noted in Chapter 2, these models, first developed in the 1970's, have evolved to the commonly accepted models of structure-mapping (Gentner, 1983) and MAC/FAC (Gentner and Forbus, 1991). The initial theories of analogy, commonly referred to as feature-matching theories, were based on similarities between features, properties and behaviors of the primary and secondary subjects of the analogy (Johnson and Malgady, 1980, Miller 1979, and Tversky 1977). It has since been widely recognized that the claim of "similarity" is vague and underdetermines the correspondences and nature of analogical reasoning (Lakoff 1987). Similar claims were made in categorization: while members of a category were assumed to have certain features in common, defining these features was problematic. Some features, such as "seat" for the category of objects called "chairs" appear to have names that showed them not to be meaningful prior to the knowledge of the object as a chair. "Large" for the object "piano" has meaning only in relation to categorization of the object in terms of a superordinate category. And "you eat on it" for the object "table" is a functional attribute that requires knowledge about humans, their activities and the world (Rosch 1978). Similarly, analogies are not based on superficial attributes and feature-matching between subjects, but apply to a more abstract structure of the subjects. Gentner (1983) developed a theory, structure-mapping, to address the fact that analogies are not feature comparisons, but much more structural.

Structure-mapping theory argues that interpreting an analogy involves both alignment and projection. The process is described in Bowdle and Gentner (1999):

> Structure-mapping theory assumes that interpreting a metaphor involves two interrelated mechanisms: alignment and projection. The alignments process operates in a local-to-global fashion to create a maximal structurally consistent match between two representations that observes one-to-one mapping and parallel connectivity (Falkenhainer, Forbus and Gentner, 1989). That is, each object of one representation can be placed in correspondence with at most one object of the other representation, and arguments of aligned relations are themselves aligned. A further constraint on the alignment process is *systematicity*: Alignments that form deeply interconnected structures, in which higher-order relations constrain lower-order relations, are preferred over less systematic sets of commonalities. Once a structurally consistent match between the target and base domains has been found, further predicates from the base that are connected to the common system can be projected to the target as *candidate inferences*.

There are several shortcomings of structure-mapping theory when trying to understand student-generated analogies. First, such a model is designed to explain "interpreting an analogy" and not the process by which that analogy was created.[1] Additionally, while structure-mapping can illustrate *what* an analogy is, it is not clear *why* a student would map knowledge from one domain onto another, under what circumstances analogies are generated, or how the analogy will evolve in the classroom. Structure-mapping is a powerful model for how an analogy, once introduced and understood may be formalized and used to draw further inferences, but it is not a model for how analogies are generated and the kind of work this generation does.

Analogies as categorization

To address the phenomena mentioned above and understand the role of generated analogies, I will argue for a categorization framework; that is, I assert that the role of Miranda's analogy between a falling cup of water and a toy cat swinging in a basket (first mentioned in chapter 3 and explored in detail below) is not to establish a one-to-one mapping between this particular cup of water and a particular instance of swinging a basket overhead. Rather, the cat/basket serves to represent a more abstracted, general category – that of, perhaps, containers that do not spill their contents when overturned (though certainly not so well-defined in Miranda's mind, and lacking the propositional structure that such a characterization implies). By constructing this category, she has introduced an alternative cognitive model, allowing for a new set of causal mechanisms to be explored. As this category is negotiated, adapted and understood, additional analogies are introduced as a means of negotiating and understanding this category. This idea echoes and expands upon claims made in cognitive science regarding the

[1] In some references, structure-mapping is portrayed not as a model for how we interpret analogy, but generate (Falkenhainer, Forbus and Gentner, 1989 p 2): "Structure-mapping decomposes analogical processing into three stages…: 1. Access: Given a current target situation~retrieve from long-term memory another description, the base, which is analogous or similar to the target."

interpretation of metaphor. When the base of an analogy (termed the vehicle in the context of metaphor) is used as both an exemplar and as an ad hoc name for a category, Glucksberg et al. (1997) call this linguistic move "dual reference." As an example of dual reference, the phrase "a responsibility is a shackle" can be used to refer to the concrete,

> physical device that is made of metal, often has chains, can be locked around someone's arms and legs, and so forth, and it can also be used to refer to the abstract, general category of constraining entities. We refer to such abstract, general concepts as attributive categories. (Glucksberg et al 1997 p 334)

The authors claim that "nouns can be used to make dual reference whenever a superordinate category has not been lexicalized and a category exemplar is available that is prototypical of that category." I will expand upon this idea to include more than nouns in metaphorical scenarios and focusing on the generation of analogies

Again, in this chapter I will focus on the phenomenological aspects of generated analogies in science – in particular, the pattern of multiple analogies, chains of analogies, near and far transfer analogies, analogy bases constructed as opposed to recalled, and the variability of representation of the base in such analogies. In the following chapter I will focus on the underlying cognitive structure, cognitive models and ontology of mind that is consistent with this analysis.

Multiple Analogies

The first phenomenological aspect of student-generated analogies that I present is that of multiple analogies. In each of the following transcripts, an analogy is generated and then, in the negotiation of that analogy, further analogies are brought up. None of the following analogies is at odds with the initial analogy, nor are they extensions or modifications of that analogy, rather they are consistent with the initial analogy and, I argue, serve to aid in understanding the category – the *kind* of thing – that the initial analogy asserts. Below I present these multiple analogies and demonstrate the consistency between multiple analogies and a categorization framework of student-generated analogies in science. This chapter consists primarily of kind of checklist of phenomena that student-generated analogies have in common with categorization; in the following chapter I will account for this correlation in a more theoretical manner by addressing a theory of mind that can account for and explain these phenomena.

Multiple analogies: Example 1

In Chapter 3, I first introduced the following analogy from a 5th grade classroom in a rural Maryland public school. In this transcript, the students have been visited by the science resource teacher and 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. 4.1). What happens to the cup-water system? The students will later observe

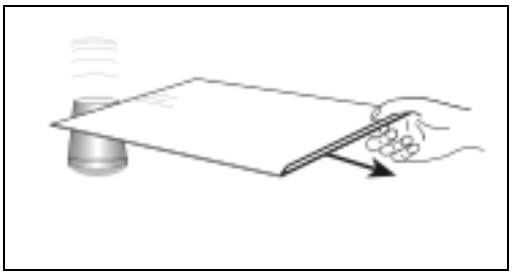

Fig. 4.1: The Experiment: A tray pulled out from under a cup

that the water does not leave the cup as it falls to the ground – the cup falls at the same rate as the water and the water will only spill out once it reaches the ground. However, perhaps not surprisingly, the students initially predict that the water will spill from the cup or spread across the tray. A student then offers a different prediction and introduces the analogy (transcript 2, lines 8 – 36) that the cup of water is like a cat in a basket and will not spill when overturned

The claim that I will continue to make throughout this dissertation is that Miranda, with her analogy, is making the assertion that the cup of water belongs to a category or class of phenomena that is typified by the toy cat swinging in the basket, rather than mapping the structure of swinging a cat in a basket to the phenomenon of the overturned cup of water. Consistent with this story are the multiple analogies that ensue. Following Miranda's introduction of the analogy to a toy cat swinging in a basket, the following analogies are introduced, consistent with Miranda's analogy: throwing buckets of water (transcript 2, lines 134 - 144)

Teacher:	It could turn sideways like that. And that would make a difference. Okay let's get – a lot of you have been very patient. Cody?
Cody:	Um because when I was um having bucket full of water and I swing it around and then when I throw it the bucket of water still stays in there- the water, and… Yeah and then when I throw it the bucket of water still stays until it hits something.

throwing a bag of Halloween candy (transcript 2, lines 179 – 189) and tossing dice in a hat,

Isaac:	Um I pre- I don't- um I agree with Miranda but I don't think air has anything to do with it. Because um yesterday at Trick-at-Treat I had like a bunch of candy and I swung it around that's like when I was bored and stuff –
Teacher:	In your bag?
Isaac:	Yeah. And none of the candy came out. I like kept on swinging it and also when me and Johnny play monopoly there's like this little hat that we play with when we roll the dice [Teacher: Mmm hmm.] 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.

and twirling Easter candy (transcript 2, lines 200 – 207)

Teacher:	…Alexandra?
Alexandra:	Um when Miranda said how when she dropped the cat in a um basket- I've done that with um my Easter candy but with more candy in it and when I turned it over when I got up here and it dropped it all went everywhere.
Teacher:	But when you were swinging it, it didn't fall out until you got up here and then stopped and then it all fell out. [Alexandra nods.]

In the structure-mapping model of analogy, the role of multiple analogies is not clear: if students understand the target and base and their relationship to one another, the analogy has served its purpose and reiterations of this structure-mapping with additional analogies should not be necessary. However, multiple analogies are consistent with categorization, as categories typically consist of multiple members and these serve to better define and negotiate the category they are constructing. Researchers have shown, perhaps not surprisingly, that students' abilities to categorize properly are greatly enhanced when multiple members of a category are shown (Namy and Gentner, 1999) and these multiple analogies can be understood to be negotiations of the category Miranda is asserting.

What is surprising about these multiple analogies is that, although they are consistent with Miranda's cat/basket analogy, they are not always introduced by students who agree with Miranda's prediction: neither Cody, who introduced the bucket of water analogy, nor Alexandra, who brought up the Easter candy analogy, believe that the water will stay in the cup, and Isaac agrees with Miranda's prediction but, without a rationale for why, disagrees with the suggested mechanism of this prediction. These students are not discussing the "mapping" of a base onto a target: they are not relating their analogies to the cup of water, they have not put items in a one-to-one alignment or made candidate inferences, as structure-mapping suggests. Rather they are exploring the phenomenon of the toy cat in the basket in its own right by mentioning other members of the category that it represents – that is, other items that do not spill from their containers – as a means of negotiating the category to which the base of the analogy belongs.

A particularly telling moment in the multiple analogies as categorization story is when Alexandra claims (transcript 2, lines 200 – 207):

Alexandra:	Um when Miranda said how when she dropped the cat in a um basket- I've done that with um my Easter candy but with more candy in it and when I turned it over when I got up here and it dropped it all went everywhere.
Teacher:	But when you were swinging it, it didn't fall out until you got up here and then stopped and then it all fell out. [Alexandra nods.]

What does Alexandra mean when she claims to have "done that?" What is *that*? No one ever explicitly discusses the abstracted "category" of "overturned containers that do not spill their contents"– and yet *that* cannot refer to the concrete example that

Miranda mentioned: Alexandra does not claim to have spun a basket overhead. Instead, Alexandra, indeed the whole class, recognizes that Miranda is using the toy cat in a basket as an instance of a more general category, one that Alexandra represents with her Easter candy and refers to by her claim to have done "that." In another use of "that" to refer to the class of phenomena that her initial analogy constructs, Miranda, in line 55 (transcript 2), says:

> Miranda: And it'll be the same thing with the water the air will push the water up until it falls down and then it will go everywhere. Because when it comes down the air is pushing upwards and [it keeps/I keep?] 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.

To claim "I have also done that" signifies there is a "that" to refer to – the category of phenomena to which the cat/basket, cup/water and Easter candy/basket belong. The use of "that" is often indicative of categorization: imagine that you are telling someone about training for and running a marathon and she replies "I've done that." One would assume she means she has run *a* marathon – not the same marathon as you, but rather recognizes the (slightly) more abstract category of marathons in general. For a more abstract case, consider the example from the previous chapter, in which a friend and I were discussing *Moneyball* (a story about baseball management) and he mentions that he is reading a similar story and brings up Björk (an Icelandic pop star). Though I don't have a transcript of our conversation, one can imagine saying, "That's a really popular story to tell these days." In this case, "that" would mean an abstracted type of story – a category to which *Moneyball* and Björk belong. Miranda's analogy, then, is to instantiate this category of containers that do not spill when overturned – construct it as a category and assert that the cup of water is a member. The other students understand this, come up with other members of the category that Miranda has constructed, and debate whether or not the cup of water is, indeed, a member of this category and Alexandra's comment to say that she has "done that with um my Easter candy."

If the use of the word "that" seems scant evidence for categorization to be at play, this is only due to the fact that categorization is so ubiquitous it frequently escapes our notice. Every conceivable noun describes a category, and every time I identify a window as being, in fact, a window, I am making a categorical assertion. Verbs, too, can be seen as categories; the claim "I leap" makes a categorical assertion about the *kind of* activity I am doing, ignores the subtle differences between *this* leap and *other* acts of leaping – just as running-a-marathon or swinging-something-overhead-so-that-its-contents-do-not-immediately-fall-out can be a category. While running-a-marathon is a relatively exact category (in this context), the nuances of many categories can be quite complex. Consider all of the ways in which "leap" can be used: "a leap of faith," "look before you leap," a "flying leap," or "leap frog." Or, as Hofstadter (2004, p. 505) explains,

> such lists go on and on virtually forever, and yet the amazing fact is that few people have any inkling of the vastness of their mental lexicons (see Becker

1975). To be sure, most adults use their vast mental lexicons with great virtuosity, but they have stunningly little explicit awareness of what they are doing.

And just as lexical items and phrases describe categories, there are categories for which we have no simple labels. As with the *Moneyball*/Björk analogies, there are "stories about someone who has an entirely different perspective on the 'system' and revolutionizes it despite naysayers to great success." And in these categories, multiple members serve to negotiate and define the category. As a second example of the role of multiple analogies as defining and negotiating a category, I present another transcript of student conversations of science.

Multiple analogies: Example 2

The following transcript, first introduced in Chapter 1, is from an undergraduate physics course for elementary education majors, Inquiry into Physical Science. The students have been investigating the electrical properties of Styrofoam and metal, and noticed that Styrofoam is easy to charge (simply rub with wool) and metal is not, but metal can easily give you a shock and there are ways to charge metal once you have a charged object. They have been asked to explain the differences between these two materials by describing "what life is like" for a charge in each. In doing so, multiple analogies are introduced. (In this transcript, by class convention, the two types of charges are referred to as "top" and "bottom.") Hana begins the discussion with an analogy between the charges and fish (Transcript 1, lines 1 – 17):

Hana:	I kind of see the charge in metal as like, fish in a fish bowl? Like they never really stop moving, they're always kind of floating around wherever they kind of feel like going and that's just how I see it in my head, like them always moving around. And I don't know what hap- I don't know how to describe it really I don't really know what happens once another charge is brought closer then.
Instructor:	Does this make sense to you then?
Hana:	Yeah.
Instructor:	So this is – so this is like two kinds of fish. [Hana: Yeah.] And in metal they can move around. They're kind of stuck inside the bowl, but within the bowl they can move around.
Hana:	But I also think that they can leave the bowl at some point because –
Instructor:	Well we get shocked right?

This idea of continual motion of the charges is mentioned in another analogy (Transcript 1, lines 20 – 33):

Kelli: That same idea I was thinking except more like ping pong balls that bounce all around and that's why if there's top and bottom charges they're moving around a lot and they're kind of attracting and repelling and attracting and repelling each other the tops and bottoms that go all over the place – but once the extra bottom charge is added it's almost trying to like reneutralize itself and the tops are attracting to the extra bottoms. And then they're trying to kick out the other extra bottoms so they can get back into their whole little [Student: Balance.] balance. Bouncing around.

Instructor: So this- I think what you're offering is an explanation of why I get a shock. Is that – am I wrong?

Kelli: No, you're not.

In both analogies, the students are, first, introducing an imagistic analogy that describes the motion of the charges and then, in the case of Kelli's analogy, explaining how, mechanistically, this is consistent with observed phenomena. However, a student notes the following (transcript 1, lines 46 – 52):

Christie: We were thinking that – like they were saying that in metal it's always moving, so if it's always moving it has more room to move and that would mean to say that the molecules are less tightly packed together or less dense and we were thinking of Styrofoam as more dense than – I'm just trying to figure out first if that's right and how it relates.

A second group of multiple analogies stems from Christie's comment, "If it's always moving it has more room to move and that would mean to say that the molecules are less tightly packed together or less dense and we were thinking of Styrofoam as more dense...". The students are all in agreement that charge seems to move more freely in metal than in Styrofoam (as in the analogies to fish in a fish bowl or ping pong balls bouncing all around), but this seems to imply that there is "more room to move" – meaning that metal should be less dense than Styrofoam. Lea, picking up on the fact that metal is more dense than Styrofoam, constructs an analogy that incorporates both: the Styrofoam is like cotton while the metal is like ice skating, in which the density of the medium allows for easy movement (transcript 1, lines 53 – 60). This category, media whose density allows for movement, is non-intuitive: crowds are hard to walk through, syrup is hard to walk through. In understanding and negotiating this category, other analogies are mentioned: a sponge, whose lack of density is a trap for water versus the dense countertop that allows water to flow easily (transcript 1, lines 61 – 66):

Instructor: Lea I want to add – I think you're sort of what I when I hear you talk I'm thinking of like, pouring water into a sponge versus pouring water onto a hard surface. [Lea: Yeah.] Like this sponge is actually less dense and there's room for it to absorb the water

and the you know if you pour it onto something hard there's no room for it to absorb.

And later another analogy, consistent with the previous two is mentioned – stepping stones that, when far apart, inhibit easy passage but when densely packed are easy to negotiate (transcript 1, lines 113 – 121).

Lydia: I was going to say I think the pie plate is more dense but I do think that it's inside not outside because if there's more space to travel then the molecules can't get from one space to another easily but it's all real close together so it can sort of hop along inside.

Instructor: Oh so it's like stepping stones [Lydia: Kind of.] like in the Styrofoam it's really far to the next stepping stone so it's like can't get there I'm stuck here. [Lydia: Right] but in the metal the stones are really close together so I can kind of walk across. [Lydia: Yeah.]

I will revisit this analogy in the following section for the manner in which it differs from those that came before. In the above transcript there are several analogies mentioned:

- charges are like fish in a fishbowl (lines 1-4)
- charges are like ping-pong balls (lines 20-24)
- metal is like ice-skating (lines 56-57)
- Styrofoam is like a sponge (line 63)
- charge flow is like steam escaping a shower (lines 98-104)
- metal is like a set of closely spaced stepping stones (line 120)

Some of these analogies are mentioned relatively independently, but, as in the case of Miranda's analogy and the multiple analogies around it, some analogies in the transcript above further develop a category that the original analogy has constructed.

Chains of Analogies

A second manner in which multiple analogies are used is not to flesh out a category, but as a means of "stepping" from one analogy to another. In this section, I will present examples of analogies that are not consistent with one another but can each be seen to be a slight "tweak" on the one that came before. Such analogies are consistent with findings from categorization – in particular family resemblance, described below.

It is important to note that research indicates categories do not have a fixed representation or set of criteria for membership. Our categories are constantly reshuffled and recast depending on the context. At times, the concept of leaping is very much related to movement, at other times to lack of support, and no dictionary definition can capture the full character of the way this word is used in everyday language. As noted in chapter two, "there is no one property that all games share, but rather there are family resemblances between games, so that "chess and Go both involve long term strategy… chess and poker both involve competition. Poker and old maid are both card games"

(Lakoff, 1987 p. 16). Similarly, "leap-frog" and a "flying leap" indicate a kind of forward motion off of the ground, while a "flying leap" and "look before you leap" are situations in which you lack support. This family resemblance is indicative of two things: one, as mentioned above, that no one characteristic defines a category, and two, there is a hierarchy of categorization. Rosch referred to the most accessible level – the easiest to learn, recognize, recall, and shortest to name – the basic level and underlying this level are more fine grained categorizations: such as games dividing into card games.

If analogies, then, are assertions of categorization, we might expect multiple analogies as a way of negotiating the category, and chains of analogies (as with Go, chess, poker and old maid) as family resemblances are followed within a category, subdividing that category into a finer grained one. The analogies in the previous section are relatively consistent with one another as a particular category becomes increasingly defined. In this section, I present analogies that follow chains of "family resemblance" to tease apart distinctions and more narrowly define a particular categorization.

Chains of analogies: Example 1

The first transcript below is from a research group meeting of the Physics Education Research Group. Paul, a graduate student, is interested in authentic classroom activities and is discussing his definition of authentic. Key to this definition is that authenticity is a property not only of the activity but also but also in the way that the students relate to that activity and the coherence of this to the scientific community of practice (that is, do the students know what they're doing? Would scientists agree?). This is at odds with definitions of 'authentic" activities that situate authenticity as a property of the curriculum itself. In this transcript, analogies to authenticity are suggested, and multiple analogies are pursued. These analogies are both along the lines of honing in on and refining a particular analogy (akin to the multiple analogies above) and "family resemblance" analogies that are more "horizontal" than "vertical" chains. The transcript begins with David recapping Paul's concerns with the standard definition of authentic curricula, and Rachel's introduction of an analogy between "authentic" and "fun" (transcript 3, lines 1 – 9):

David:	It's not a responsive definition of authentic. Authentic is defined pre-experience. And so what your [Paul's] sense is what's going to be authentic is about watching the student and and what is authentic for this group – may be different from what's authentic science for *this* group. And you don't like defining authenticity in a way that isn't responsive. So the content isn't responsive but also the sense of what is authentic isn't responsive.
Rachel:	So ontologically authenticity is like fun. Which would be –
David:	Oh that's great.
Andy:	Oh that is beautiful!

The analogy is understood by the group and further explained in lines 17 – 29 (transcript 3):

Andy: – it emerges from an activity but it's really ultimately lives inside –

Rachel: Right and I mean you could say – I mean you couldn't look at a thing on paper and declare that it was fun until you could see people do it and see them have fun.

David: And it may be fun for some people and not fun for other people.

Andy: You could – an experienced teacher could make guesses about what's more likely to result in fun blah blah blah.

Rachel: Sure, sure. But really ultimately you don't know until after [inaudible]…

David: Or anyone – what what my kids think of as fun might not be the same as what Rachel thinks of as fun [trails off].

However, a weakness of the analogy is identified: Paul has argued that authenticity must not only be recognized by the students' relationship to the curriculum, but a (hypothetical) community of practice must have a similar understanding of the relationship between the students and this curriculum. This weakness is identified and alternative analogies are proposed (transcript 3, lines 38 – 70):

Leslie: Is there a community of fun practice? [Laughter.]

Rachel: Or norms? [Laughter.]

Leslie: Like with the community of practice the scientist is someone who's outside deciding whether or not it was science but with fun there isn't – so it's a negative analogy – but with a community – yeah there's no community of practice.

David: I don't know what you mean – there's no authentic community of practice?

Leslie: You only have to ask a person who's having fun if they're having fun. But this (definition of authenticity) implies that you have to ask the scientists whether they're doing science.

David: Ahhh – right. Gotcha.

Andy: Not only does it have to be meaningful it has to be meaningful in the right way – but – yeah I'm having fun but it's – you know – low-brow fun instead of highbrow fun. Guffaw guffaw! Gotcha. [Laughter.]

David: So can we patch that? Is there, is there another…

Rachel: Good clean fun?...

Leslie: I have a multiple analogy if that's okay? I'm thinking it's more like worship – like, you know if you're worshipping but a religion is going to also decide if what you did was worship.

Andy: Oooh.

David: Right. Right that's good.

Andy: It's gotta pass both tests. That is good. Good clean fun works, too. You decide if it's fun, *I* decide if it's good and clean! [Laughter.]

Leslie: Or pornography?

The analogies above construct a particular ontology (as Rachel identifies) – or category – of adjectives: those that are not inherent properties of the object they describe, but, like "fun," are a measure of both the activity and the participant. This does not quite describe the sense in which Paul is speaking of authenticity. In his description of an authentic activity, Paul also relies on the coherence of the students' understanding of the activity with the community of practice's understanding of that activity. To patch the analogy, two alternative analogies are suggested. One is a more "vertical" analogy: replacing fun with "good clean fun" (line 60). I say vertical because this is similar to looking at games and then honing in on "card games" because the category "games" is too vague and lacks the detail that "card games" has. An alternative "patch" is to move more "horizontally" – as if moving from "games of chance" to "card games" as Leslie (I) does by suggesting "worship" or "pornography" as alternative analogies.

The multiple analogies presented above do not serve the same role as the multiple analogies presented in the previous section. Instead of serving to negotiate and understand the category that the analogy constructs, they alter this analogy – however they do so in a manner consistent with categorization. One possible "tweak" to a category is to further parse it – categories have hierarchies (as with "chair" which is a base level category – and "easy chair" or "desk chair" or "recliner," which are subdivisions of this category). Taking the idea of "fun" into "good clean fun" is such a move. An alternative move is one of "family resemblance" in which categories are related to one another within a hierarchy (as with "easy chair" and "desk chair") – it is this move that Leslie makes in moving from "fun" to "worship."

Chains of analogies: Example 2

Furthermore, these analogies, unlike the multiple analogies that are consonant with the cat in the basket, are in response to something problematic – a small piece of the story doesn't work out. This is the story in the final analogy presented in the analogies regarding charges in metal (transcript I, lines 113 – 121) in which the metal is like closely-spaced stepping stones. Implicit in the analogies that the other students have suggested is that the charge will then travel on the outside of the metal: ice-skaters travel on top of ice and water travels on countertops – implying charge will travel on the outside of metal. This is very much a structure-mapping story, in which the structure of the base makes implications for the target: items in the base and the target are placed in a one-to-one alignment and inferences are projected from that alignment. Charge traveling on the outside of the metal is an inference that structure-mapping can predict and explain. In this regard, structure-mapping tells a story that is an important piece of the work that analogies do in science classrooms and in science, and address a part of analogies that I do not: how they are used to draw inferences and establish a sense of mechanism. My claims are not regarding Lydia's interpretation and understanding of these implications, but how they in turn construct new analogies. This implication is one that Lydia challenges. (I note that) The "tweak" to the analogies is then suggested by the instructor, who moves from a countertop analogy to a stepping-stones analogy.

Chains of analogies: Example 3

The following transcript from a third grade classroom presents another example of this "family resemblance" property of multiple analogies. In this classroom, the teacher, Trisha Kagey, has asked the students: if you are running with a beanbag and want it to fall on an *X*, should you release it before, when, or after you reach the *X*? In the discussion that follows, several analogies are introduced, many of which are slight modifications of the one that preceded it. Below I present transcripts from the chain of analogies:

- the beanbag is like a baseball bat (line 59)
- it is like a leaf being dropped from a bus (line 74)
- it is like a rock being dropped from a bus or a bike (lines 36 and 76)
- the leaf is like a feather, and a rock is different (line 136)
- the rock is like a tree and yet made from the things that are different (188)

The first analogy is mentioned (in transcript 4, lines 35 – 46) after Adam argues for his prediction with Newton's Laws. I present it here for completeness: this analogy is not a part of the "chain" of analogies that ensue but the teacher's instructions and the student's analogy may play a role in the other students' expectations about what kind of knowledge to bring to bear on the question:

Teacher:	…but trying to just explain it to someone using your experiences – see if you can use it that way. Explain to – like you're explaining to a kindergartner. They're not going to be able to understand that law.
Adam:	Like um – if – like if something – if you're riding your bike, um – it's in motion. And you're going to keep going until you get stopped by like – um, a rock or something. And, and – or going uphill. And so if you're on a bike, and you get – you can get stopped by something else, like a rock or something.
Teacher:	So if we're thinking of your analogy to a bike, or your explanation with a bike, what's stopping it, and this is –
Adam:	Um, no. Well, in the situation of dropping the beanbag. Like, um, it's thing is the ground, and because the beanbag is running against the ground, um – it's getting slower. Because like the beanbag is um – getting – I don't know how to explain this.

Connor, in lines 55 – 62 (transcript 4), does not address Adam's prediction and explanation, but instead offers his own analogy:

Connor:	I would think the bean bag would – might fall behind where you want it to fall because when I put – when I played baseball – they always said don't throw the bat because it might hit the catcher and not one of the um person because we're using metal bats, and – so

we drop it, you drop it and then you – . Well, when I drop it, it usually swings backwards; it wouldn't be behind the plate instead of the front of the plate.

Connor's analogy changes as he considers it further (transcript 4, lines 71 – 78):

Teacher: Why do you think it fell behind?
Connor: Well actually it didn't mostly. It got on the side or in front because – well because you're supposed to drop it because you don't need a bat while you're running the bases. Once you drop it, I'm just thinking also, what Adam is – well a bus – well if you were on a bus and you had uh, this little leaf that you found, and the window was open, and you drop it, it will go – it'll be going backwards.

It is interesting to note that the original analogy that Connor introduced should lead him to predict that the beanbag falls ahead of you when you drop it – and the analogy he then offers that is consistent with his prediction is a scenario that he has not likely done. This phenomenological aspect of analogies will be explored later in this chapter. In terms of the chain of analogies that is being constructed, Connor has moved from the very similar running-drop to dropping from a bus. In lines 83 – 94 (transcript 4), another student challenges Connor's analogy and he tweaks it further:

Lauren: Because I think that's cause – you're talking about a leaf that's falling? That's because the – it's sort of – the bus is going back, so it's making like the air move. And the leaves are really, really light, so the reason they are going backward is because – . Um, well it's going so fast – a bus is like going so fast that it's probably making the air go that way. So that way the leaves are going that way.
[Many talking in disagreement.]
Connor: What if you did it with a rock? The same thing will probably happen with a rock. Because you are probably like a bus, that you make the air come – no one moves, don't you notice that um, objects like in cars or something – when you're going really fast on your bike that are – that um, you sometimes, [inaudible] and leaves your ankle on your back step and actually move.

The distinction between the "little leaf" and the rock are considered in lines 146 – 150 (transcript 4), and an analogy between the leaf and a feather are drawn:

Kamran: But, if you – cause you know a feather is – it, it, it goes with the air just simply its a light. That's why – same with a leaf. A leaf is very light. And if you – a leaf falls [Inaudible.] goes to air. It doesn't go, 'leaf – boom.' It doesn't go like that.

And then (transcript 4, lines 188 - 190) the idea of the leaf is tweaked into considering the weightiness of a tree:

> Kamran: Yeah, because the weight pulls it right down. If a tree – it's heavy, and it's heavier than all the leaves it has, so the leaves will make it fly.

Through these analogies, we see the students following a chain of reasoning that begins with a particular phenomenon – that of the running drop – and steps through a series of family resemblances to arrive at two subcategories of the running drop phenomena. Kamran's comment (line 188) explores some confusion in the distinction in these categories, saying "the weight pulls it right down. If a tree – it's heavy, and it's heavier than all the leaves it has, so the leaves will make it fly – flies here. And the tree, it will just go down."

These two sections have demonstrated that a feature of student-generated analogies in science is multiple analogies. At times these analogies that come up in student conversations are independent of one another, but often they are related and this property is one that is neither predicted nor explained by current models of analogy. The predominant model of analogies – in particular analogies in science – is that of structure-mapping. This model is admittedly designed to explain analogies that have been constructed and the role that they then play. However, as shown above, it cannot account for multiple analogies. Categorization, which inherently involves multiple members and has been demonstrated to relate items not through any set of formal rules but rather through family resemblance, more coherently captures the manner in which spontaneously generated analogies in science are constructed and negotiated. In the following two sections, I will focus on the choice of the base for the analogies that students generate: first focusing on the base as a construction as opposed to a recollection, and then considering the role that similarity to the target of the analogy playas in the selection/construction of this base.

Construction of the base

Depiction of the base in research on analogies

Analogies are often depicted as a mapping from a well-understood base to a less-understood target, and implicit in this depiction is that the base is something that was previously known, experienced, considered, and then, during the act of the analogy, recalled. The following quotes (with italics added) about analogy reveal this assumption, in which the analog (or base) is "retrieved," "stored in memory," "accessed," and "in memory," but not "constructed" or "created":

- "A theory of analogical reasoning must explain how an analog is *retrieved*." (Vosniadu and Ortony, 1989 p 7)

- "Given a current target situation, *retrieve from long-term memory another description*, the base, which is analogous or similar to the target." (Falkenhainer, Forbus and Gentner, 1989 p 2)
- "Mental experience is full of moments in which a current situation reminds us of some prior experience *stored in memory*" (Gentner, 1989 p 199) and,
- "the chronological first step in an experiential learning sequence is *accessing the potential analog*." (p 200)
- "Analogical problem solving involves three steps, each of which raises difficult theoretical problems. The first step involves accessing a plausibly useful *analog in memory*…" (Holyoak and Thagard, 1989 p 242)

Not all researchers describe analogy in this way. Anderson and Thompson (1989, p 267) note that the base of an analogy can come from someone's "own past… the behavior of another…or it might come from adapting an example given in a textbook. The source for the analogy can be either an explicit experience or a generic or schemalike representation." However, explicit reference to generated analogies as having a base that is constructed rather than recalled is rare.

Prototypes in categorization

Categorization research has a similar history, beginning with theories of category representation as static things stored in memory and recalled for the purposes of judging category membership. Though there is no single theory of prototypes and the graded structure of categories, it was originally argued that a category was represented by a single representation, which was an amalgam of all exemplars stored in memory. Judging whether or not a new item belongs in a category involves comparing it to this amalgam. And this involves recalling all known instances of the category to construct a "typical" exemplar that is "a unified representation rather than separate representations for each member." (Murphy, 2002 p 42) To address concerns with this initial theory, the idea of "feature combination" was added, in which features that are averaged together are first combined, so that "

> people keep track not just of individual features but configurations of two or more features. For example, perhaps people notice how often bears have claws *and* eat garbage, or have fur *and* are white – that is, combinations of two features. (Murphy 2002 p. 45)

Concerns with the computational demands these theories make on memory and recall, schema were introduced. A schema is "a structured representation that divides up the properties of an item into dimensions (usually called *slots*) and values on those dimensions (*fillers* of the slots). Features of exemplars were then stored with a given weight into particular slots. An alternative to this (typically called the "prototype view") is the exemplar view, in which every instance in memory is used in the construction of a category rather than the average of these. While both the prototype and the exemplar

view proved generative and had great explanatory power, their representation of mind was problematic and the categories they sought to describe proved to be quite narrow, as Barsalou's research in *ad hoc* categories and point-of-view categories shows.

Construction of the prototype

Barsalou's (1983) studies of "ad hoc" categories addressed categories that cannot be interpreted as fixed cognitive structures, such as "foods not to eat when on a diet," or "things to do at a convention." These categories, which maintained the phenomenological properties of more conventional categories (such as a graded structure), could not be explained simply using the exemplar and prototype theories. Surely, Barsalou argued, one does not store information on such detailed categories but rather constructs it. In later research (Barsalou, 1987) extended this idea, asking participants to take the point of view of a professor, Chinese person, or "redneck" in judging membership in categories. Again, these categories displayed a phenomenological consistency with conventional categories but, again, could not be stored representations. Barsalou argues that "rather than being retrieved as static units from memory to represent categories, concepts originate in a highly flexible process that retrieves generic and episodic information from long-term memory to construct temporary constructs in working memory" (Barsalou 1987). This is not meant to imply that there is not stable knowledge in long term memory, but rather that the concepts in working memory – the ideas that are pondered, discussed, articulated and reasoned with – are temporary constructs and, as such, sensitive to context and goals and inherently unstable. This interpretation of categorization Murphy (2002) contrasts with the prototype and exemplar views, referring to it as the "knowledge view," in which "part of categorization and other conceptual processes may be a reasoning process that infers properties or constructs explanations from general knowledge." (Murphy, 2002, p 60-61)

It is this picture that is missing from most analogy research. In part, this is because the focus of analogy research on how people understand a given analogy – in which case the base of the analogy is present, and one must recall information about that base. It is also due in part, perhaps, to the analogy of the mind to a computer in which context and knowledge construction is irrelevant. However, when paying attention to the analogies that students create when discussing scientific ideas, these analogies are not always drawn to a well-understood base. Rather, the base may be a construction, as with our representations of categories.

Construction of the base in student-generated analogies

In the transcripts above, bases that are clearly not recalled from memory are most profound in the beanbag transcript. In line 64 of this transcript, Connor has predicted that the beanbag will fall backwards and has drawn an analogy to dropping a baseball bat. When the teacher asks "Why do you think it fell behind?" He, surprisingly, notes "Actually it didn't mostly." And then he selects a more appropriate analogy: "if you were on a bus and you had uh, this little leaf that you found, and the window was open, and you drop it, it will go – it'll be going backwards." While it is possible that he has dropped a "little leaf" from a bus window, he does not claim to have done so and it is reasonable to imagine he hasn't. And in line 91, his suggested analogy "What if you did it with a rock?" is based more on a sense of theory than a past experience. Instead of recalling this experience from memory, he is constructing it from "a reasoning process

that infers properties or constructs explanations from general knowledge" (Murphy, 2002 p 61) – as has been argued happens in the construction of representations of categories. Kamran, in line 154 (transcript 4), makes this searching for a representation from principles (rather than from memory) clear as he reasons through possible analogies: "A rock is different, a rock has – it's also like, it's solid, but it's not that a leaf isn't solid, or a feather isn't solid. A feather – but you have to – it's very small, and it's very like thin, so you kind of say like solid. But anything hollow, like if you have a paper box…"

A second example of such construction of the base of the analogy comes from the Physics 115 course. Students were asked to make sense of several phenomena of circuits. In one course, an analogy was suggested: imagine a vacuum cleaner sucking up beads, and the light bulbs were like small filters in the tube of the vacuum cleaner. In another course, the analogy was drawn to a hose that is already full of water (so that it takes no time for the bulbs to light) that has small holes in it (which represented the light bulb). In each case, the students are seeking to explain their reasoning via an analogy that they have constructed rather than one they are simply recalling. Again, this underscores the fact that students are not mapping from a well-understood base onto a less-understood target. The consistency of the constructed bases of analogies will be explored in the following chapter, in which I will show that these analogies are constructed from the schemas or p-prims that the students have activated; for now it is important to note that, consistent with the spontaneous construction of categories, the base of an analogy can be a spontaneous construction.

A final example of the constructed base of analogies comes from two undergraduate students who are trying to solve a problem in their quantum mechanics homework assignment. In this problem, they are asked to find the total angular momentum, which the first student, Ben, believes you can answer from first principles. Anselm argues that understanding a simple case does not necessarily mean that you will be able to solve the more difficult problem, and explains this using a constructed (as opposed to a recalled) analogy (transcript 5, lines 15 – 27)[2].

Ben:	We should be able to figure this out from today's lecture.
Anselm:	No you shouldn't.
Ben:	He's gonna explain in detail probably Wednesday how you actually get to J [the total angular momentum].
Anselm:	But see you're doing the wrong thing. 'Cause you're assuming that if you have the example: "suppose there's a charge here, what's the electric field due to it?" You can figure out – suppose you have Bugs Bunny, and he's charged, what's the electric field around his ears? Alright? Because you have a simple example when they're both the same, you're not going to be able to figure out exactly what you're supposed to do when the rules weren't the same.

[2] Ray Hodges, who was a TA in the room with the students at the time, aided in this interpretation of these comments.

I will revisit this transcript below for its evidence of a variable representation of the base of the analogy – here I would just like to note that Anselm's analogy, "suppose you have Bugs Bunny, and he's charged, what's the electric field around his ears," is not a problem that these students have been assigned in the past and tried to solve. Rather, Anselm is constructing this as a representation of a category of problems that cannot be solved from first principles. The category is an ad hoc construction and its representation, Bugs Bunny's electrically charged ears, are similarly an ad hoc construction. Constructed, I argue, by categorizational reasoning; and clearly not a map from a known base to an unknown target.

Near and far transfer analogies

Research on prototypes and research on transfer

The initial research on categorization established a graded structure of categories, in which some members are recalled more quickly and with greater frequency than others, are judged to be better exemplars of the category and are recognized as category members more rapidly than others. Theories behind these effects are varied and will be explored in the following chapter but, as explained in the above section, it is not due to simple feature matching, but seems to be rooted in reasoning processes and explanations.

Analogy research has shown that near-transfer analogies are far more easy to achieve than far transfer analogies – where near-transfer refers to analogies that are within-domain or have similar features, while far-transfer analogies are those that bear little superficial resemblance to one another. As explained in the previous chapter, however, this may be an effect of the particular style of research being conducted and the lack of meaningful context in which the analogies are situated. And, contrary to this research, "far transfer" analogies do occur in student discourse and are not uncommon.

If one interprets analogies as categorization, then perhaps the ideas of near and far transfer are not relevant. Instead, one would expect the base of the analogy to be, instead of superficially near, prototypical of the category. In this section I will present evidence that the base of analogies are not chosen for the similarity of features or "nearness." Arguing that the choice is, instead, prototypical requires appeals to theoretical considerations that will be addressed in the next chapter.

Examples from student-generated analogies

Returning to the cup/water and cat/basket set of analogies, Miranda (line 59) 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. In line 25, to explain why she believes water will not spill from the cup as it falls, Miranda offers the analogy of spinning her toy cat overhead in a basket. Later, in line 59, Miranda says: "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." If the base of the analogy is arrived at through a process of retrieval from memory, as many models of analogy imply, one would expect near-transfer before far-transfer, as the similarity of features would be key

in retrieving the analogy. If, instead, the base of an analogy is a construction from this categorization, one would expect a base that is prototypical of the category it is asserting; near and far transfer are not significant questions in this framework. Rather, that the cat/basket analogy is chosen first, is much more convincing and is referred to repeatedly in the classroom can be understood by its prototypicality (or centrality) in the category it serves to describe. Additionally, concerns that Miranda is "making up" the analogy to the cup in the bathtub (this concern has been voiced in discussions with others regarding the analogy) are not important: given that Miranda chooses these two analogies, regardless of whether they are experienced or fabricated, she does so in this order and the class responds to them in this way.

Miranda serves as a particularly powerful example because she refers to two analogies and chooses the "further" analogy first and it is this analogy that holds sway in the classroom and is repeatedly referred to by the teacher and students. Far transfer analogies are not at all uncommon. Other examples from analogies above are:

- comparing a cup of water to a toy cat in a basket
- envisioning electrical charges in metal as fish in a fish bowl
- drawing an analogy between motion of charged particles in Styrofoam and the motion of water through a sponge
- drawing an analogy between motion of charged particles in metal and using stepping stones
- comparing dropping keys on an *x* to hitting a rock on your bike, and
- explaining your approach to solving a total angular momentum problem to solving a problem of the electric field around Bugs Bunny's ears.

While many of the above analogies are creative and intriguing, none are outside of the bounds of "normal" conversation in science, and in many cases a superficially "closer" analogy could seem *too* close and a more strange statement to make than the far transfer analogies. In the next chapter I will argue that these analogies – the "far" analogies – are appropriate and, indeed, expected over near transfer analogies because of their relationship to the category that they serve to represent.

Variable representation of the base

In an effort to understand analogies, the majority of research from cognitive science and education has focused on the comprehension of analogies provided by the researcher or teacher, or the application of a desired analogy (for example, in Holyoak and Thagard's study of transfer). Such studies limit the variability of representations of concepts that researchers can observe. The study presented here originates in research on student inquiry in science classrooms. These classrooms place a premium on student reasoning and explanation of ideas, and, as such, allow for student-generated analogies (which are far more rare in a classroom with a focus on content goals over process goals).

In this section I will present two different kinds of analogies: one set of analogies are presented to explain different ideas about the mechanisms of a scientific phenomenon; the second set are analogies used to explain the speakers' conceptions of the epistemological *type* of scientific phenomena – that is, what is the nature of knowledge that applies to this phenomenon. In each case, the representation of the concept to which the analogy is drawn is chosen from among many possible

representations, and categorization, because of its fluid nature and flexibility, can explain this choice of representation.

Variable representation: Example 1

In the following transcript, there are multiple possible representations that the base can take, and the one that is taken depends on the conceptions of the target. While not entirely in discordance with structure-mapping (the process of alignment could be considered choosing the representation), a categorization framework shifts the importance and nature of analogy; when someone says "a is like b" they are not saying: "the structure of this one thing, b, has a lot in common with the structure of this other thing, a." Instead, the assertion of analogy is more akin to "*a* belongs to a class of things typified by *b* – it's the same *kind* of thing." Where a "kind of thing" defines a (often ad hoc) category and more may be brought to bear on *a* than just the relationships that exist in *b*.

This first transcript below is of non-science faculty at the Governor's School of North Carolina. In the lounge of the faculty dorm, they are discussing what happens to a rock in space as it receives energy from the sun: will it heat up indefinitely or only to a certain point? And if it only heats up to a certain point, why does it stop there? This rock is referred to as "David" because of a previous conversation about the differences between humans and statues (namely, Michelangelo's "David") in space. Marc is content to say that David will reach a certain temperature and stay there, and explains this using an analogy. Note that Marc prefers a "water" analogy of light, and is able to take on a "money" analogy of light that is contradictory to Vic's "money" analogy of light. This demonstrates that, one, the choice of base in an analogy is one of ontology and, two, the base can shift representation according to the ontology ascribed to the target (transcript 6, lines 471 – 498).

Marc:	Okay– let's – let's say David is in a shadow, right? Okay- he enters the sun. The sun bombards him with all this energy right? So in a second it's now at 5 degrees. Can it radiate heat that fast? No. So in the next second it's 10 degrees. It's now radiating a little bit more heat but there's more energy coming in. So it gets to 15 degrees. But at some point it's radiating enough heat to stabilize at 20 degrees.
Steve:	But why?
Cameron:	What?
Marc:	Or let's think of think of like a, think of like a basin, ok? Think of a tub. With the drain open, okay? The drain is open. Now if I open the spigot [Uh huh.] – if I open it too slow then the tub doesn't fill. But if I open the spigot fast enough there's water filling up the bottom, and yet some is also draining out, right? [Right.] If I open the spigot up fast enough it doesn't matter if the bottom is open, the top will overflow but at some point if I reach the right point the tub could stay at a certain level, even if water's going in and water's going out, right? If they came in at the same rate [Steve: Right, but –] the tub would fill up.
Steve:	But that's – what's David's drain?

Vic: That's – this is my question. What's David's drain?
Tom: Well, what's the sun's drain? The sun is clearly radiating heat and energy.
Marc: Yeah I mean that's just the –
Steve: The sun is radiating *light*.

The conversation continues, and over the next three minutes Marc suggests that things radiate – it's just what they do; like a drain and like the sun, the rock gives off "radiation and stuff." To explain why we can no longer see the radiation when the rock re-radiates, Marc offers that the light changed from a visible form to a non-visible form. But how "ROYGBIV" (the colors of the rainbow) become "infra-ROY" bothers Vic. The analogy of light as water and a rock as a tub contrasts with the analogy that Vic invokes to point out a problem in Marc's re-radiation explanation in the following transcript (transcript 6, lines 1038 – 1054).

Vic: Wait wait wait – every – everybody is payin' me money. Everybody is paying me money in different forms – in dollars, five-dollar bills, twenty- dollar bills. [Marc: Okay.] I'm savin' all of my one dollar bills that I don't give away – I do not spend any of my dollar bills on anything ever. Which means that I am gradually accumulating one-dollar bills – even if I'm spending it in fives and tens and twenties. So what do I do when I end up with a thousand dollars in one-dollar bills that I don't know what to do with?
Marc: I'm gonna change that analogy [Others: Groan.] – or I could keep it! I could keep it! Okay? I'll keep it. Fine – you know what I'm gonna do with those one dollar bills?
Vic: Tell me.
Marc: Well – those dollar bills become – you, you spend 50 cents of it in terms of heat and you throw the other 50 cents of it away but we can't see those 50 cents because we're only attuned –
Tom: You're losing the analogy.

The choice of this analogy is a largely ontological choice: Marc has a "water-like" ontology of light and one can imagine that, just as turning a cup of water into two half-cups of water needs no mechanistic explanation, turning red (a high energy wavelength) into infrared (a lower energy wavelength) does not require further explanation – it happens "by the virtue of your existence." Marc is making a claim about the *kind of thing* that light is – it belongs to the class of things that water belongs to. This class could be described as a conserved quantity that does not come in discrete chunks and flows easily from one "container" to another. Vic has a different conception about the *kind of thing* that light is – one that is organized in discrete quantities and matches the category that currency might belong to: net wealth does not count quarters as different from dollar bills, but in terms of actual objects, they are physically different and do not "mutate" into one another. That this analogy is a statement of categorization (the *kind of thing* that light is) is evident in the objection that Tom believes Marc "loses the analogy" when he

violates this ontology. Marc, though he wants to "change that analogy" is able to take it on by representing money in as a "fluid" ontology. It is reasonable that money could be conceptualized in the manner Marc intends: when conceiving of someone's bank balance, it makes sense to think of money as belonging to the ontology of fluids: if I deposit a quarter my bank will certainly allow me to withdraw a penny. And gas stations routinely charge to the tenth of a cent (or at least to the nine-tenths!). Structure-mapping and other interpretations of analogies that assume a particular conception to the base of an analogy miss the point that the claims are being made to signify a *class* of objects, and that a base and target can have multiple representations and belong to several different classes (or categories).

Variable representation: Example set 2

In this section I present three transcripts: the first two are conventional analogies – the "tree in the forest" conundrum (albeit with slightly different features), and "apples and oranges" – and the third is a novel analogy regarding Bugs Bunny and electric fields. The first two analogies are intended to establish the categorization model and provide a means of interpreting the third analogy: if the first two are instances of categorization, as I believe is apparent, then so must be the third. And, as with the variable interpretations of "money" (as fluid and divisible or "hard" currency), the base of these analogies may be interpreted in many ways. Furthermore, to echo a prior claim, the third analogy is novel and cannot be argued to be a well-understood base that is recalled from memory but rather is constructed on the fly to represent an ad hoc category.

The first transcript is from a conversation in a 5th grade classroom. The class has been discussing light and heat and the relationship between the two. After reasoning that light "contains" heat because sunlight feels warm, Lisa notes that the light from overhead fluorescent lights does not make you hot (transcript 7, lines 86 – 102).

Lisa:	I think that sometimes, well, most of the times, light is not always containing heat. Like, like this light up here, it's not con – it's not, its not –
Dashawn:	Burning?
Lisa:	Yeah, like making you hot.
Kyle:	Yeah it's not making anything hot.
Anna:	But it's just – what if you go up there and touch it? It would – ?
Brian:	That's because your finger is an object. When it hits something it's hot.
Teacher:	Oh, I see. So you get, there's a reaction when you touch light.
Brian:	But it's also a question like, um, if a door slams – if a locker door slams and no one's around to hear it, does it make a noise? Because you don't know if – if you don't touch it and the light is making heat and making the air hot. You won't know.

A variant on the standard philosophical question "if a tree falls in the forest and no one hears it, does it make a sound?" is raised here as an analogy to explain that not only does light need to "hit something" to make it hot, but "it's also a question" of if, in the absence of a measurement, heat may not be a meaningful concept. It is an argument about the kind of thing that heat is. This analogy could be interpreted in a structure-mapping

framework in that it maps elements from the secondary onto the primary; one could align the locker with the light, the slamming with the light hitting a finger, and the heat with the sound. But categorization highlights a very different aspect of this analogical reasoning, namely the ontological goal of expressing the *kind* of thing that heat is. The analogy is *not* drawn for the purpose of comparing two items and making a projection, but to make a sophisticated claim about the nature of light and heat.

An epistemological analogy is drawn in the following transcript. The two students are undergraduate quantum mechanics students working on a problem set together. They encounter one problem (determining "J," the total angular momentum) and have trouble making headway from first principles so they try to work backwards from the answer. Ben can kluge together numbers that are present in the problem to arrive at the answer, but the way in which he assimilates these numbers is nonsensical, as he notes in the transcript below (transcript 5, lines 65 – 74).

Ben:	All right, look at this – look at this. If you take all the positives and add them together, you get eight-ninths.
Anselm:	Oh, oh.
Ben:	You take the negative, you get one-ninth.
Anselm:	Yeah that's –
Ben:	But you're mixing apples and oranges. It's dumb!
Anselm:	Yeah that's so messed up, yeah that's not the answer. If I just ignore the fact that I'm in the three-halves one-half and I'm in the one-half one-half and I just add them all together…

Here the assertion of "you're mixing apples and oranges" is clearly not a matter of structure-mapping, but categorization. The "apples" are not aligned to a specific element present in the physics problem. Rather, "apples and oranges" has come to represent a category of dissimilar things erroneously compared, and Ben's statement is a categorical assertion of the type of thing that he was doing. This claim is not new. Glucksberg and Keysar (1990) argued that the interpretation of a metaphorical statement was a process of categorization. As a means of accounting for this theory of metaphor interpretation as categorization, it has been argued (Gibbs, 1992, Bowdle and Gentner, 1999) that conventional metaphors, such as apples-and-oranges, are interpreted as categories, but that interpreting novel metaphors is structure-mapping. In accordance with Bowdle and Gentner's research and the categorization theory of metaphor, the creation and assertion of the conventional metaphor "you're mixing apples and oranges" seems clearly an instance of categorization and not structure-mapping. However, I claim that categorical assertions are also made with novel analogies. Bowdle and Gentner (1999) have argued against that, at least in the interpretation of novel analogies, but perhaps generated novel analogies could be considered assertions of categorization. In the following transcript a novel analogy is used in a similar way to the "apples and oranges" and the "tree in a forest" conventional analogies. The base of the analogy is clearly novel, not well-understood, and invented on the fly, but its role in the analogy is no different from that of the conventional analogies. The elements of the base of the analogy do not clearly map onto elements in the target, and the claim posed by the analogy is not instantiated by

projection but by categorization. Again, a categorization model of analogy is far more capable of understanding the role of the base than a structure-mapping model.

The students in the previous transcript continue to work on the problem of total angular momentum (transcript 5, lines 15 – 26). Ben believes that they should be able to determine the answer because they know the constituent angular momenta and have some background in adding these to find the total. Anselm argues that this does not necessarily mean they can solve this more complicated problem, and draws a novel analogy to explain himself, that of the problem first introduced above of the electric field around Bugs Bunny's ears. Anselm's analogy is to say that this problem of adding angular momenta is like finding the field around an oddly shaped object – not because of any similar structures (the charge and Bugs Bunny don't correspond to any particular items in the angular momentum case) – but because you cannot always find the answer to complex problems using knowledge about simple problems. Knowing the field of an electron doesn't mean that you know the field around an oddly shaped object, like the ears of Bugs Bunny. In this analogy, the *structure* of the problem (calculating total angular momentum from components) is only very weakly similar to the structure in the Bugs Bunny scenario (determining the field around an oddly shaped object); the similarity, and thus the analogy, lies in the fact that they are a similar *type* of problem. Furthermore, the base here is created "on the fly" – the idea that we have a stored representation of Bugs Bunny as an odd shape for the electric field to take seems highly unlikely. Far more plausible is the spontaneous construction of an ad hoc category of *things that are more complex than their simple parts*. The analogy is not from a well-understood base to a poorly-understood target, but instead the base is constructed *spontaneously* to represent an ad hoc category – that of problems you cannot solve from first principles – and asserts membership in this category. In defense of structure-mapping, it could be argued that the elements being aligned were not the particular elements of the problem at hand (the charge, the Bunny, and the constituent angular momenta), but rather the problems *themselves* are elements in a larger structure. But such a claim would bring us back to the problem of representation. The Bugs Bunny analogy can be represented as a structure in itself, or as an element in a larger structure, and choosing which representation is the one to use is a problem that structure-mapping does not address.

Previous Claims of Analogy as Categorization

The claim of analogy as a categorization phenomenon is not new. The greatest proponents of this theory are Glucksberg and Keysar (1990). Why have their arguments failed and what does this dissertation bring to bear that others have not? First, I argue that past claims are overwhelmingly with regard to the *interpretation* of analogies and the claim I am making is about the assertions made by a *generated* analogy. Interpreting analogies allows for a much more narrow range of representations than generating analogies does. Second, as noted by Gentner, Bowdle Wolff and Boronat (2001) the "category-based approach is 'localist:' it assumes a metaphor conveys a categorical relation between a particular pair of terms. Thus this approach addresses single metaphors and not extended systems of metaphors."

As demonstrated above, I am not making "localist" claims with regard to analogies. Rather, I will argue in the following chapter that analogies assert categories

based on schemas: categories are defined only within a particular cognitive model, and this cognitive model carries with it a quite extended schema. Previous arguments for a categorization model of analogy used a far more classical model of categorization. The following section addresses a final phenomenological property of analogies – one that is not particularly demonstrative of the categorization framework at first glance, but within a particular ontology of mind, together with a current understanding of categorization, is particularly revealing of the reasons why we use analogies and the cognitive work that they do and is strongly supportive of a categorization framework

Analogies as Negative Assertions

In this final section on phenomenology, I demonstrate that analogies are asserted as an alternative to another way of understanding a particular phenomenon. In part, this is a *definition* of analogy that distinguishes analogy from other forms of similarity, but it is a definition that arose from the data.

In observing what seemed to be analogies and an effort to understand the cognitive work that these insightful moments of analogy did for the students, it became clear that what I understood to be analogies are the statements of similarity that are an *unexpected* similarity. This is a matter of convention, but one that, as I will demonstrate in the following chapter, is a rather powerful convention that is consistent with a particular ontology of mind and understanding of student reasoning.

Violations of expected schemas

In *Women, Fire and Dangerous Things,* Lakoff (1987), who argues that our categories derive from and are defined within cognitive models, notes that one indication of cognitive models is the use the term "but" – as in, "she's a mother but she has a job." Such a statement makes far more sense than "she's a mother but she doesn't have a job" – which sounds strange. He argues that, to understand these statements and why one sounds so strange, we must turn to the idea of the cognitive model. "Mother" exists in a complex model of nurturance and work, and "working mother" is defined relative to this model (Lakoff, 1987 p 80):

> A *working mother* is not simply a mother who happens to be working. The category *working mother* is defined in contrast to the stereotypical housewife-mother. The housewife=mother stereotype arises from a stereotypical view of nuturance, which is associated with the nurturance model. According to the stereotypical view, mothers who do not stay at home all day with their children cannot properly nurture them. There is also a stereotypical view of work, according to which it is done away from the home, and housework and child-rearing don't count. This is the stereotype that the bumper sticker "Every Mother Is a Working Mother" is meant to counter.
>
> The housewife-mother stereotype is therefore defined relative to the nurturance model of motherhood. This may be obvious, but it is not a trivial fact.

I mention this because the analogies that have been presented in this chapter all have this "but" quality to them. As in, "the cup is overturned but it doesn't spill" – which makes far more sense than "the cup is overturned but it spills." As Lakoff says, this may be obvious, but it is not trivial. In the following chapter I will explore why this is not trivial – how it can inform us about cognitive structure and our cognitive models of the world,

and then I will revisit this again in considering what it means for education. Here I present it as a final phenomenological property of analogies – student generated analogies in science are "defined in contrast" to expectations, just as "working mother" is defined.

Examples from student-generated analogies: Analogies as negative assertions

The analogies presented in this chapter are as follows:

- an overturned cup of water does not spill like other overturned cups of water, but keeps the water inside, like a toy cat swung overhead in a basket (transcript II),
- density of an object enables/enhances the motion of charged particles as opposed to hampering it, just like a countertop lets water flow while a sponge doesn't, or stepping stones must be closely spaced to allow you to step (transcript I),
- "authenticity" is not a property of an activity, but is a more "interactive" adjective – one that is not solely an attribute of curriculum, but arises from the interaction of the student and community with that curriculum, just as worship is an activity that requires a practitioner and a community of practice (transcript 3)
- dropping a beanbag is not like (at second glance) dropping a bat, but can be understood as dropping a leaf from a bus, or
- it is not like dropping a leaf from a bus, it is like dropping a rock from that bus (transcript 4),
- a quantum mechanics problem is not one to be solved from first principles, just like you could not use a simple field equation to find the field around Bugs Bunny's ears (transcript 5),
- a rock is not just a container of heat but also gives off heat, like sinks not only hold water but also have a drain (transcript 6),
- light cannot be received at one frequency and given off in a different frequency, just as one cannot be received a quarter and turn it into dimes and nickels, or
- light can change from red to infrared, just as one can have a dollar's worth of wealth and spend only fifty cents (transcript 6),
- in order to determine if light contains heat you must put your finger in the light, just like the question of sound in the absence of a listener (a door slams and no one hears it – transcript 7), and
- numbers normally can be added together or multiplied unproblematically, but when these numbers mean something (as in a quantum mechanics problem) adding these numbers might be akin to mixing apples and oranges – it doesn't make sense (transcript 5).

In each of these analogies, they are (perhaps implicitly) not only a claim of similarity – the cup of water is like the cat in the basket – but equally, if not *more* significantly, they are a claim of dissimilarity. They arise as contradictions to what is expected. Numbers usually can be added unproblematically (of course, this is only true in a mathematics classroom and rarely, if ever, true when applied to life); overturned things usually spill; objects are usually seen as generators of energy or receivers of energy but not both – not a tub with a drain; whether or not something happened is not usually contingent upon someone being there to observe it. The way in which this plays into a categorization framework will be explored in greater detail in the following chapter. For now, I just would like to note that this property of analogies is not explained by structure-mapping and other theories of analogies. When it is accounted for, it is added on in an ad hoc

manner – by assuming that context or goals is significant and needs to be accounted for – but accounted for in a somehow distinct way (Gentner and Markman, 1997). In their model of analogy, this phenomenology is not inherent to the analogy, but part of the context. In the following chapter, I will argue that it is fundamental to analogy and to the role that analogy plays. Furthermore, it allows for a definition of analogy that distinguishes analogy from routine categorization and similarity.

Conclusion

This chapter, which details the similarities between student-generated analogies and properties of categorization, may seem to disregard the adage: "Correlation does not imply causation." Categorization and analogy are both related to similarity, so they *should* have some phenomena in common – but that does not imply that they are the same thing, arise from the same cognitive mechanism. The following chapter is designed to address causation by introducing an ontology of mind that can account analogies as arising from the same cognitive mechanism as categorization – the only distinction being that analogies offer an alternative categorization to what is expected. The correlation between analogies and categorization are summarized below.

Analogies that students spontaneously generate in science classrooms are often presented in multiples: analogies that are all members of a more general class of phenomena, in which the generated analogies are in agreement with one another, or analogies that are tweaks from one to the next, representing a class of phenomena that bear a family resemblance to one another. These analogies are often "far transfer" analogies that bear little superficial resemblance to their target. They may be constructed on the fly as opposed to recalled from past experience. And the base of the analogy may have a variable representation that changes as the analogy is negotiated. These phenomenological properties of student-generated analogies reflect properties that are representative of categorization phenomena: categories have multiple members and are often related not by strict rules or similarity of features, but a family resemblance that links the various members of the category. Categories are represented by a category prototype, which can account for the prevalence of "far transfer" analogies. They are not stored representations that are recalled, but rather are constructed in a flexible process.

Gibbs, in his article refuting Glucksberg and Keysar's (1990) theory of analogy as a categorization phenomenon, claims (Gibbs, 1992):

> Most metaphorical expressions instantiate, sometimes in spectacular ways, preexisting metaphorical mappings in long-term memory whereby knowledge from a target domain is partially understood in terms of a dissimilar source domain… Metaphors do not simply arise out of temporary, ad hoc categorization processes perhaps to meet particular communicative purposes. Instead, metaphor is a fundamental characteristic of how people categorize and makes (sic) sense of their experience. Verbal metaphors…reflect particular instantiations of metaphorical categorization schemes in long-term memory.

These claims take into account the systematicity of metaphor and polysemy (one word with multiple, related meanings) and are designed to address the more common metaphorical expressions and not spontaneously generated ones.

However, I would like to argue that these claims *cannot* be extended to spontaneously generated analogies. In light of the above analogies from scientific discourse, such as Bugs Bunny, light-as-currency, and dropping rocks from buses, these claims of metaphorical expressions as "preexisting metaphorical mappings" are clearly not true of analogies in general, and particularly not true of student-generated analogies in science, in which they are often investigating phenomena for which they have limited experience and hence no established metaphorical mapping.

Perhaps this inconsistency between the findings from studies of metaphor and the study presented here of student-generated analogies in science is due to inappropriately conflating the two – established metaphor and spontaneously generated analogy. Metaphors, such as the parallels between the ways in which we discuss arguments and the ways in which we discuss war, are ubiquitous in the English culture and apparently "preexisting," while a student inventing a language for discussing quantum mechanics or falling cups of water must be somehow distinct from using a common language to discuss arguments. However, if I conflate these here – metaphorical expressions and student generated analogies – it is because the literature is unclear on the division between metaphorical expressions that are pre-existing and those that are more akin to student-generated analogies in science. At best, the literature virtually *defines* analogy to be structure-mapping and puts metaphor on a distinct footing because of this definition – but such a definition rules out many of the instances of analogy that are discussed here. This does not negate the fact that metaphor and analogy are a fundamental characteristic of how people categorize and make sense of experience – but such an idea need not imply that metaphors and analogies (that is, the mapping of two domains) and their associated categories (that is, the set of phenomena that are consistent with a particular analogy) are fixed representations. Instead, I will argue in the following chapter that what *is* stored in long-term memory are particular schemas that may be combined in any number of ways and give rise to what appear, at times, to be stable categories.

In a purely phenomenological sense, the properties of analogies outlined above are consistent with properties of categorization. Categorization does not require that there be stored representations of concepts or categories that we recall, but rather that "concepts originate in a highly flexible process that retrieves generic and episodic information from long-term memory to construct temporary constructs in working memory" (Barsalou 1987). In the following chapter, I will outline an ontology of mind that is consistent with the findings from categorization and can account for the analogies described here.