Chapter 3: Origins of the Study & Methodological Considerations

Origins of the Study

The following passages are taken from a "Science Talk" (Gallas, 1995) in 5th grade classroom in rural Maryland. It is early November and the science resource teacher, Bruce Booher, has come to lead a discussion. The students have worked with Mr. Booher in the past and this format of science instruction is not unfamiliar to them. The question that he has chosen comes from an experiment suggested on a NASA website regarding zero gravity. 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. 3.1). What happens to the cup-water system? The students will later observe 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. Most students, however, believe the water will "go everywhere," "spill," or "splash" as the tray is removed and report as much. Their answers do not give any rationale or mechanism by which this will happen. However, one student predicted the correct outcome and explained her prediction with a spontaneous analogy (transcript 2, lines 8 – 36).

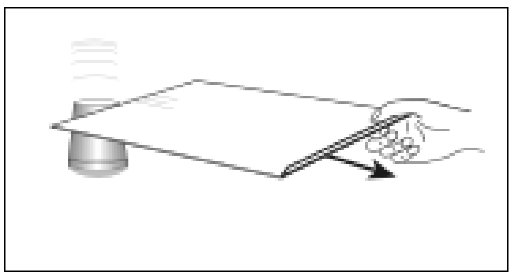

Fig. 3.1: The Experiment: A tray pulled out from under a cup

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.

Wholly aside from the fact that this analogy leads to the correct prediction, this analogy shows the beginnings of deep scientific reasoning. As I will show in later chapters, mechanistic analogies to phenomena with which you have experience are ubiquitous in the scientific literature. Furthermore, once this analogy is brought up the tone of the conversation changed; student hands shot up, and mechanistic reasoning and scientific explanations were brought up. In an attempt to understand this moment – what, exactly, was the significance of Miranda's analogy, what are the assertions that it makes, the cognitive work that it does, why it was brought up, how it was negotiated, how the other students react to and negotiate the analogy – there are few models of analogical reasoning to turn to, fewer still on spontaneously-generated analogies; studies on analogical reasoning suggest that comments like Miranda's should be rare, are indicative of expertise, and more likely with prompting by the teacher. Furthermore, most models of analogy are stem from variable process/regularity approaches to explanation and not causal or meaning-based models. In this chapter I will outline previous studies on analogical reasoning, their philosophical assumptions, the strengths of these approaches and their shortcomings. I then outline the tradition in which my own study is based and explain the theoretical nature of this dissertation and its methodology.

History of Research on Analogies

Past research

Owing, perhaps, to the behaviorist tradition in psychology, the success of experimental methods in more objective sciences, or stemming from the more recent analogy of the mind to a computer with its fixed rules and stability, studies in learning, particularly in cognitive science, have tended to focus on quantitative studies in laboratory settings. The history of analogical reasoning is no exception.

The most well known example of experiments on analogical reasoning is that by Gick and Holyoak (1980 p 307-308). In their study, participants were presented with Duncker's (1945) "radiation problem." The problem begins with an anecdote:

> A general wishes to capture a fortress located in the center of a country. There are many roads radiating outward from the fortress. All have been mined so that while small groups of men can pass over the roads safely, a large force will detonate the mines. A full-scale direct attack is therefore impossible. The general's solution is to divide his army into small groups, send each group to the head of a different road, and have the groups converge simultaneously on the fortress.

The students were told to memorize the above passage and then asked to solve the following problem:

> You are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that may be used to destroy the tumor. If the rays reach the tumor all at once and with sufficiently high intensity, the tumor will be destroyed, but surrounding tissue may be damaged as well. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue?

Few students were able to solve the problem without explicit instruction to use the story that they had memorized. Once prompted, over 90% of students could solve the problem correctly using the convergence principles from the fortress story. This study has been widely cited as evidence that students find analogical reasoning difficult and that transfer is a rare phenomenon. Furthermore, it established a paradigm for investigating analogical reasoning: present participants in the study with two analogically similar scenarios and see if they notice/draw the intended analogy.

This methodology has been reiterated in future studies of analogical reasoning with similar results. In one study, Gentner, Ratterman and Forbus (1993) gave subjects a series of stories to read and followed up one week later with another set of stories. Some stories were structurally similar to stories in the first set, while others shared superficial features – about a similar topic or involving a similar kind of animal, say. The subjects were then asked which of the original stories these reminded them of and they chose the stories that shared superficial features. Again, the authors argued that subjects are not drawing analogies between deep structural similarities. However, Markman and Gentner

(1993) report a study in which they ask participants to look at two pictures and find the "same thing" in the two photos; they found in this case that items that occupied similar *roles* were more often chosen as similar than superficially similar items.

Novick (1988) reports a similar finding in the context of mathematics to Markman and Gentner's findings – that analogies based on structure are possible – but that such analogies are more likely if the participant has sufficient expertise in the subject. (Which echoes findings by Chi, Feltovich and Glaser (1981) in which expert physicists tend to group problems based on principles rather than surface similarities, while novice physics students grouped the same problems using superficial characteristics.)

These studies, and those with similar methodologies, are powerful for their clear findings; they tell us quite definitively that in these scenarios, under these circumstances, subjects behave in this way. Indeed, this methodology, in the tradition of scientific based reasoning (SBR), is hailed in a National Research Council report, *Scientific Research in Education* (2002).

Limitations of past methodology

What, then, are the limitations of such research for understanding spontaneously generated analogies in science? While it has its strengths of clear and exact findings, I claim that such focused, constrained, laboratory-based studies (1) establish too strong constraints on what counts as analogical reasoning, (2) strip analogies of the crucial context in which they are constructed, and (3) fail to capture a causal explanation of analogical reasoning. I detail these below, and then introduce a qualitative alternative to such studies of analogical reasoning. I conclude by introducing the methodology employed in this thesis.

(1) Constraints

Consider the story by Hammer et al.'s (Hammer, Elby, Scherr, Redish, 2004) of a student discussing the size of mirror necessary to see your entire body in it. This student, Sherry, determines that

> you need a mirror the same size as your body, because your whole body has to be able to fit in it. Other students in her group used ideas about reflection to argue that the mirror would need to be half that size, but Sherry defended her reasoning. The next week she told her group about a discovery at home: She owns a mirror roughly half her height, and it shows a reflection of her whole body. She had known the answer to the question all along – she saw it every day.

In their article, this anecdote is brought up to call into question the notion of transfer. I mention it here to suggest that even when students are not drawing appropriate analogies – such as between the tumor and the fortress in Gick and Holyoak's– they may be drawing deep analogies nonetheless. Sherry, the authors suggest, may have been drawing a tacit analogy to doors or paintings instead of the more correct analogy to windows. The participants in Gick and Holyoak's study may be drawing analogies to bullets, sound in rooms, or light coming in through windows (it certainly seems just as bright by the window as it does in the center of the room). Gick and Holyoak may claim that participants did not draw the desired analogy between the tumor and the fortress, but they may not claim that students did not draw an analogy.

(2) Lack of context

Similarly, Gentner, Ratterman and Forbus's findings demonstrate that similarity – or, more accurately, reminding – is based initially on superficial characteristics when done in the context of a laboratory, but these stories lacked context and immediacy. Recently I was explaining to a friend the story of *Moneyball* (Lewis, 2003), in which a baseball manager ignores baseball's cultural wisdom of choosing draft picks in favor of statistical analysis by Harvard graduates. My friend replied that he was reading a similar story about Björk in the New Yorker (Ross, 2004) and commented that this seems to be a trend in nonfiction writing – to tell the story of someone who has an entirely different perspective on the "system" and revolutionizes it despite naysayers to great success. In this real-life context, comparing *Moneyball* to superficially similar stories (say, "Casey at the Bat," Thayer, 1997) would have been unnatural and bizarre, while comparing *Moneyball* to Björk was creative and insightful, but also natural and a logical conversational step. In a laboratory setting, with few stories to choose from and no reason for the stories to be told in the first place, our cognitive behavior can be unnatural and bizarre. It is important, then, to pair our laboratory based studies of cognition with studies "in the wild."

Why has it required conscious and deliberate effort to integrate context into studies of learning and cognition? As Lemke explains:

> We blame the early Moderns of Rene Descartes' 17th-century Europe for cleaving Mind from Body and Society from Nature (e.g. Shapin & Schaffer 1985, Latour 1993). From them we inherited a chain – cognition in the mind, mind "in" a material brain, brain in a mindless body, body in a natural environment separate from society, society made up of persons not bodies, persons defined by cultures, cultures created by minds – a chain that binds us still and runs us 'round and 'round in ever smaller circles.
>
> We rebel, we transgress. We want the freedom to construct a materiality of mind, an intelligence of the body. We want meaning to arise from material processes and Culture to be once again a part of Nature. We want to re-situate cognition in a larger meaning-making system of which our bodies and brains are only one part. We are willing to pay the price, to abdicate our Lordship over Creation, to become partners rather than over-seers. Creation, after all, has been getting pretty unruly anyway.

That is, Cartesian dualism, which proved so powerful for the traditionally "hard" sciences, has left its legacy in the behavioral sciences which may not be appropriate: it places *meaning* outside the scope of scientific research, separating questions of meaning – which are intimately tied to context – from questions of science.

Since the initial studies of analogy reported above, which occurred in the early 1980's, researchers in cognitive science and education have become increasingly concerned with the assumptions noted by Lemke that laboratory-based studies make on the nature of cognition. Gibson (1979), studying perception, emphasized the need to study vision in terms of people behaving in the real world performing meaningful tasks rather than subjects responding to the artificial and acontextual conditions of the laboratory. Lave, continuing this paradigm into the learning sciences, performed a series of classic studies (Lave 1988, Lave & Wenger 1991) observing people – tailors, midwives, and dieters – in real-world settings as they engaged in problem-solving. She found that their strategies in these immediate, concrete, specific, and meaning-rich situations differed from the disconnected problems of school or the tasks posed in a psychology lab. From these studies, she coined the term "situated cognition" to describe cognition as a "nexus of relations between the mind at work and the world in which it works" (Lave, 1988 p. 1), and any claims about how cognition "works" must take into account the world in which it is working.

(3) Causal explanation

A final concern for laboratory-based studies of analogical reasoning comes from Maxwell's (2004) concerns about the types of claims these studies can make about causation. That is to say, he finds fault with what causation *means* when arrived at from a laboratory-based, quantitative study. Concerned with the emphasis on scientific based research (SBR) in the National Research Council's *Scientific Research in Education* (2002) report, Maxwell traces the philosophical traditions of SBR and argues that it assumes a "regularity" view of causation. The regularity view is

> based on an analysis of the contribution of differences in values of particular variables to differences in other variables. The comparison of conditions or groups in which the presumed causal factor takes different values, while other factors are held constant or statistically controlled, is central to this approach to causation.

He further argues that "the central manifestation of the regularity view in the NRC (2002) report is its presentation of causality as primarily pertaining to *whether* x caused y, rather than *how* it did so" (Maxwell, 2004 pp. 125–129). This claim is certainly true in the studies of analogical reasoning reported above: these experiments cite circumstances under which deep analogies are or are not drawn (such as: expertise is important, deep analogies are rare in the context of comparing two items), but make no claims as to why analogies are drawn, what cognitive work these analogies do, the purpose that analogies serve and why students fail to draw analogies in certain situations.

These three concerns – the constraints that laboratory based research places on analogical reasoning, the claims of situated cognition that demand ecologically valid research, and failure of variance theory research to arrive at meaning or mechanism – have motivated researchers to perform qualitative studies of analogical reasoning. These studies are discussed below.

Recent approaches to the study of analogical reasoning

Noting the criticisms of laboratory-based research on cognitive processes that claim "what we know of cognition is based on arbitrary tasks bearing little relationship to the cognitive processes that occur in naturalistic settings" (Dunbar and Blanchette, p 334), and in the tradition of situated cognition research methodology, Kevin Dunbar and Isabelle Blanchette investigated the use of analogy in natural contexts. They explain, "we wanted to discover what similarities people note and under what circumstances their reasoning is based on superficial or structural similarities." They began by video- and audio-taping molecular biology and immunology labs and analyzing the types and frequency of analogy generation in these conversations.

A similar approach was taken in a study of generated analogies in 6th grade mathematics classrooms. A recent article by Richland, Holyoak and Stigler (2004) reports an in-vivo study of analogies with their research in eighth grade mathematics classrooms. As with Dunbar's methodology, Richland *et al.* construct a coding scheme and deep analysis of the kinds of analogies that are generated in the classroom.

The analyses performed on the data from these studies, though situated in a naturalistic context and with strong qualitative components, also continue a quantitative paradigm. These and other studies (for example, Pittman, 1999 and VanLehn, 1998) look at the kinds of analogies, the frequency of these analogies, rely on a large corpus of data to draw statistical claims about *what* happened – again "primarily pertaining to *whether* x caused y, rather than *how* it did so" (Maxwell 2004) or, perhaps more accurately in these cases, *if* x occurred and not *why*. To get at the *meaning* behind analogical reasoning – that is, what are the assertions that analogies make, what cognitive work do they do, how might the mind be organized to allow for this – I rely not on statistical analyses of data or rigorous coding of transcripts (which, of course, are invaluable tools of the educational researcher and a crucial component of many important methodologies), but instead a variety of approaches (primarily phenomenology and case study) and on the philosophy of causality behind process theory.

An alternative to the regularity view (which Maxwell notes as characteristic of variance theory) is that of "process theory" (Maxwell, 2004):

> Process theory… deals with events and the processes that connect them; it is based on an analysis of the causal processes by which some events influence others. It is fundamentally different from variance theory as a way of thinking about scientific explanation… (p. 5)
>
> A realist, process-oriented approach to explanation is compatible with, and facilitates, the key strengths of qualitative research. In particular, it recognizes the reality and importance of *meaning*, as well as of physical and behavioral phenomena, as having explanatory significance, and the essentially *interpretive* nature of our understanding of the former. It also recognizes the explanatory importance of the *context* of the phenomena studied, and does so in a way that does not simply reduce this context to a set of "extraneous variables." It relies fundamentally on an understanding of the *processes* by which an event or situation occurs, rather than simply a comparison of situations involving the presence and absence of the presumed cause. Finally, it legitimates a concern with

> understanding *particular* situations and events, rather than addressing only general patterns. (p. 8)

Maxwell then argues that qualitative research methods, because of their strengths at "identifying causality in particular cases, the importance of context as integral to causal processes, and the role of meaning and interpretive understanding in causal explanation" are a crucial element in education research.

It is in this tradition and due to these concerns that I choose to approach understanding student-generated analogies as they occur in classroom discussions.

Methodology

This thesis is a theoretical account of generated analogies in science, which began with an insight into Miranda's generated analogy above; namely that the thing she seems to be making an assertion of *categorization* rather than a direct one-to-one mapping of this cup to that experience of twirling her basket. Following this insight, I developed an account of generated analogies as assertions of categorization using the events in this classroom research from categorization. This account was then compared with generated analogies in other contexts: different classrooms of various ages, historical accounts of analogy use in science, research group meetings and informal conversations. In these analyses, I compared my story of categorization to the existing accounts of analogy (primarily structure mapping), and I will argue that a categorization perspective is more successful and generative than the others. Further implications of this perspective may then be tested in a more quantitative methodology.

A note on the data

None of the data presented in this thesis was collected for the purpose of studying analogies in science. While collecting data for a project on student inquiry in physical science, and knowing that I was interested in studying analogies in science (because of my own propensity for them), Miranda's particularly powerful student-generated analogy struck me. At the same time, I was reading a book by Lakoff (1987) – *Women, Fire and Dangerous Things: What Categories Reveal About the Mind.* With this one example of student-generated analogies and this one perspective on cognition, I began to develop a rough theoretical perspective for understanding student-generated analogies in science as assertions of categorization around this first analogy. I then turned to a corpus of data from student inquiry into physical science, research group meetings and classrooms to check against my account of analogical reasoning.

The case study methodology

Such a study is indicative of the case study tradition. The case study primarily addresses the *how* and the *why* research questions – in my case, why analogies are generated, how they help students and the cognitive work that they do. The case study aims to provide a detailed description and analysis of the observed case. It acknowledges the importance of studying the phenomenon as a whole and does not consist of a linear model of inquiry, noting that "there are complex relationships within phenomena, [and] taking them apart may result in losing some of their important aspects." Additionally, the "case study is also *naturalistic* in the sense that it studies cases in their physical context, in which the researcher is also interested… the researcher has limited or in some cases no control over the case of study. Case study method also requires the study of a contemporary phenomenon or situation within its real life context" (Louca, 2004, p. 35).

Furthermore it is the evaluation of a single case that Maxwell (2004) and Davidson (1967) argue may be a more powerful method for arriving at causality than the variant theory approaches. Davidson notes that we "can infer cause in single experiments . . . [and that] providing them with conceptual help in doing so is a virtue, not a vice; failing to do so is a major flaw in a theory of cause-probing methods" (Davidson, 1967, p. 465).

One key component of the case study, indeed of all qualitative research, is triangulation of information in which "researchers make use of multiple and different sources, methods, investigators and theories to provide corroborating evidence. Typically this process involves corroborating evidence from different sources to shed light on a theme or perspective" (Creswell p 202). As I continued taping student conversations in physical science, which were replete with spontaneously generated analogies, I had further data to bring into and try out against my theoretical framework. This data primarily comes from elementary school classrooms throughout Maryland, ranging from second through sixth grade. The teachers in this study were part of the project *Case Studies in Elementary Science* and are particularly skilled at listening and attending to student ideas in science, which was significant in providing me with student-generated analogies. In addition, I used data from studies on high school and undergraduate physics students – data initially acquired for other research purposes – along with tapes from research group meetings and faculty conversations. And finally, the framework was compared to analogies by scientists, as reported in studies from the history and philosophy of science, comparative literature and popular non-fiction. The analysis began with a phenomenological analysis, which will be explained in the following chapter and then a more ontological, causal analysis, which I will describe in Chapter 5.

Summary

This is a theoretical dissertation, one that argues for a particular perspective on student-generated analogies and the ontology of mind. As such, quantitative methods – even those that are typically used in more qualitative research (coding, for example) – are not employed here. That is not to say that these are not relevant to a framework of spontaneously-generated analogies. However, as Maxwell (2004) argues,

> I would argue that strictly experimental designs, with no qualitative components, are a comparatively powerful method for understanding only when three conditions obtain. First, there should be a well-developed theory that informs the intervention and research design and allows interpretation of the experimental results (Bernard, 2000, pp. 55–56)… Second, the causal process investigated should be manipulable, fairly straightforward and simple… Third, the situation should not be conducive to the direct investigation of causal processes.

This thesis aims to begin with the first of these criteria by understanding the *why* of student-generated analogies, providing a framework of categorization and consistent with a manifold ontology of mind. Once established, the ability to manipulate the causal processes and whether or not these may be investigated directly may then be asked.