Chapter 8: Summary & Directions for Future Research

Introduction

> You fight your superficiality, your shallowness, so as to try to come at people without unreal expectations, without an overload of bias or hope or arrogance, as untanklike as you can be, sans cannon and machine guns and steel plating half a foot think; you come at them unmenacingly on your own ten toes instead of tearing up the turf with your caterpillar treads, take them on with an open mind, as equals, man to man as we used to say, and yet you never fail to get them wrong… The fact remains that getting people right is not what living is all about anyway. It's getting them wrong that is living, getting them wrong, and wrong and wrong and then, on careful reconsideration, getting them wrong again. That's how we know we're alive: *we're wrong*.
>
> -Philip Roth, *American Pastoral*

When I began my study on analogies, I was interested in a study on *negative* analogies: that is, the places where our analogies are wrong, when the target and the base of our analogies don't quite match, where these mismatches occur, and what that tells us. I was asking this question having recently sat in on a course in literary theory – a field where scholars have argued that we define our terms and our stories negatively: by what they are *not* instead of by what they *are* – and noticing parallels between this idea, based in literature, and my experience in the lab and as a physics teacher. However, the lack of information on student-generated analogies shifted my focus from negative analogies to analogies in general, establishing what analogies are and what kinds of claims they make. Following a summary below, I begin the consideration of directions for future research with a discussion on the literature of differénce and the relationship between this idea and the idea of a negative analogy. I then present a consistency between these ideas of difference and negative analogy and the framework behind student-generated analogies presented in this dissertation. Finally, I conclude with suggestions of a direction for future research – first with respect to negative analogies and then analogies, categories and science education.

Summary

In this dissertation, I began with the argument that student-generated analogies phenomenologically have the properties that have been recognized in categorization research: multiple members, family resemblance, constructed bases with multiple possible representations, and far transfer analogies. Furthermore, these properties are neither predicted nor explained by models of analogy that focus on recall of a base and then an extrapolation of a structure or schema *from* that base. When considering an ontology of mind that allows for this phenomenology, I have argued that a schematheoretical model of mind accounts for these properties: it attributes schemas (p-prims, scripts, and cognitive models) as the building blocks of mind that become activated and then select and construct concretizations. It has been argued (i.e., Lakoff 1987) that our categories are defined within and derivative of our schemas, and I argue that the base of an analogy is such a category – a representation, constructed in the moment, of a set of schemas. The assertion of an analogy is an assertion that the target of the analogy belongs to the category represented by the base, as opposed to simply a match between the target and the base. Under this ontology, it becomes possible to sketch a definition of analogy that differs quite fundamentally from similarity – a definition lacking from other models of analogy. Analogy in this definition becomes a deliberate cognitive move that acknowledges the presence and possibility of two distinct cognitive models and privileges one over the other.

In considering the directions for future research, I would like to begin by considering this final point above: analogy as a *negative* assertion and a move *from* something – the cup of water is *not* like other cups of water, a beanbag dropping is *not* like throwing a rock from a bus, motion of electrons in a dense media is *not* difficult like the motion of a person through a dense crowd, and solving angular momentum problems in physics is *not* something to be done from first principles. This idea of defining and understanding concepts by what they are not echoes claims from literary analysis, which in turn raises questions for future research.

Negative analogies

<u>*Literary analysis and differénce*</u>

At the beginning of the 20th century literary analysts were dedicated to identifying similarities between texts – this script that defined a story. Their work focused on determining the story on which all stories were based – thereby reducing all particular stories to the general. Jung (1969) explored the relationships between all myths and rituals. Psychologists (among them Fromm, 1957) developed a theory of fairytale in which all fairytales are variations on a single fairytale theme. But in the 1950's Roland Barthes began to stress the importance of recognizing how things are different – that the theme is not the meaning, but the variation on that theme. Barthes summarizes the task of analysts of narrative in reducing all stories to one model as a:

> task as exhausting as it is ultimately undesirable, for the text thereby loses its difference. This difference is not, obviously, some complete irreducible quality (according to a mythic view of literary creation), it is not what designates the individuality of each text, what names, signs, finishes off each work with a flourish; on the contrary, it is a difference which does not stop and which is articulated upon the infinity of texts, of languages, of systems: a difference of which each text is the return. A choice must then be made: either to place all texts in a demonstrative oscillation, equalizing them under the scrutiny of an in-different science, forcing them to rejoin, inductively, the Copy from which we will then make them derive; or else to restore each text, not to its individuality, but to its function, making it cohere, even before we talk about it, by the infinite

> paradigm of difference, subjecting it from the outset to a basic typology, to an evaluation…. (Barthes/Miller, 1991)

Barthes theory stems from a tradition in semantic theory developed some 40 years earlier. In the 1910's Ferdinand de Saussure developed a theory of "differénce" whereby words (or rather "signs" – the sum total of information from gesture, word, tone, etc.) get their meaning not from a simple one-to-one relationship with the external world, but "one unit has value within the system because it is *not* some other unit within the system" (Tyson, 1999). Concepts are defined in opposition to other concepts.

Laura Otis, whose work was reviewed when discussing the history of science, comments on noticing the following parallels between Saussure and science, retelling her experience in a lab that studied visual perception:

> I was a biochemist, a mere visitor to the lab, but I learned an important lesson that night. The eye, and the regions of the brain that interpret visual information, respond only to changes, to borders between light and dark. There are cells that fire only when a bar of light moves horizontally, and cells that fire only when it moves vertically… there are no cells that respond to a uniformly illuminated screen, with no movement, no edges, and no borders…
>
> Fresh from the lab, I learned the same lesson in Jonathan Culler's introductory course on literary theory. Explaining Saussure's idea of how words were paired with objects, Culler proposed that we define concepts not based on what they are, but on what they are *not.* When defining something, we typically compare it to something similar and then, like the eye, focus on the way it differs from the concepts most closely related to it. A cow, for instance, has four legs like a horse, but it is fatter. There is no natural match between a word and the thing it represents; no positive assertion of a thing's identity, just as there will be no firing in response to a blank screen, even when it is brightly lit. Like our visual system, we create meaning only through the differences we perceive and the boundaries we believe are present. (Otis, 1999 p. 1–2)

Otis, a professor of comparative literature, presents this story at the beginning of her work on membranes to note two things: one, she is interested in boundaries – this book explores the concept of membranes in political and scientific climates, and, two, that the boundary "between the humanities and the natural sciences as a another boundary arbitrarily drawn." (Otis, p. 3.) I present it here to revisit the idea of the negative assertions that are implicit to analogy.

<u>*Negative analogies*</u>

I have argued that analogies involve more than just similarity, but also dissimilarity – they dislodge the target from its expected categorization and schema and place it in another one. The claims of Barthes and Saussure, and reiterated by Otis, suggest that perhaps the most significant function of the analogy is the "dislodging," negative part of analogies and the contrast the analogy highlights: what is crucial is not the claim that *a* is like *b* but instead, implicit in this claim, that *a* is not like *c*. However, the idea of differénce also suggests that there is something negative inherent in the "*a* is like *b*" claim – for Barthes claims that "[reducing all stories to one model is a] task as exhausting as it is ultimately undesirable, for the text thereby loses its difference." It is this idea that I suggest as a significant area for future research.

When drawing analogies between two cases, the significance comes not only from the similarities between the two compared cases and the difference between the target case's expected and asserted schemas, but also the differences between the two compared cases. The value assigned by the analogy also comes from the difference between the items that are asserted to be members of the *same* category. It illustrates what is essential to the category as well as identifying what is unique about the phenomena. Furthermore, as Barthes (1991) notes, this difference is

> not what designates the individuality of each text, what names, signs, finishes off each work with a flourish; on the contrary, it is a difference which does not stop and which is articulated upon the infinity of texts, of languages, of systems: a difference of which each text is the return.

By paying attention to how our target differs from the base, and doing so in a dynamic way, we set up a dynamic science – one that evolves, "making it cohere, even before we talk about it, by the infinite paradigm of difference, subjecting it from the outset to a basic typology, to an evaluation…" (Barthes/Miller, 1991).

Without negative analogies we're just doing the *same thing* over and over – we have a set of solved problems and the business of science is to recognize how new phenomena fit within these solved problems, but taking into account the negative analogies, we're changing – adapting our categories, extending and limiting them. Below I present a brief sketch of research and questions concerning negative analogies – that is, the places where analogies are not correct but the analogy overall is still accepted and the base is understood within this new cognitive model. These analogies shift our understanding not only of the target – because it is placed into a new, unexpected schema – but also the base of the analogy, because elements that seemed inherent to that base and fundamental to the schema become tangential.

At the time that I first came across these readings by Barthes and Saussure, I had just left a condensed matter laboratory, where I spent most of my time writing computer programs to interpret data on the structures of sandpiles (Atkins, et al. 2001). Much of programming – at least in the sciences – involves taking a piece of code that is in some fundamental way the code that you need (usually from *Numerical Recipes in C*), but not quite, and modifying it. The original programs often bear very little resemblance to the final program – but the core of the idea remains. How do programmers choose a particular structure for their programs? How do they analyze the strengths of these particular lines of code, know what to modify and what to keep?

Rachel Scherr, as part of her doctoral work on relativity, created a set of tutorials that leads students to arrive at the relativity of simultaneity. The context of the tutorial is two relativisitcally related reference frames, each of which is observing a single tape player in a scenario that is contrived to give students the following options: either the tape player is seen by one observer to play and another observer to remain off, or simultaneity is relative. As Scherr (conversation) claims: "If you have to choose, I'd much rather give up simultaneity than allow the tape player to both play *and* not play." It is this determining of what is essential that lies at the heart of much of scientific discovery – do we "give up" simultaneity in order to preserve causality? Which is more fundamental to our science if we can't have both? Do we allow popes to be bachelors or do we refine our definition of bachelor? Which is the more primary? Are quasi-crystals crystals? Are viruses organisms?

Negative analogies in physics

In "Analogy as the Central Motor of Discovery in Physics," a talk given by Hofstadter at the Ohio State University (2003), Hofstadter argues that analogies are a driving mechanism for discovery in science. He details the progression of ideas from a literal field with hills and valleys, to assigning the gravitational potential to every point in space – a scalar field. And from there scientists tried to draw the analogy from the gravitational field to the electric field, and eventually ran into a problem with magnetism: what could they "give up" or "tweak" about the scalar potential and still maintain its more important underlying structure (as a thing you differentiate to find the force)? – the answer was to recast the scalar field as a vector field. Much of science consists of trying to extend a known law into a new area where it was not meant to be applied – drawing analogies between pieces and "tweaking" a few things. These tweaks – that the electric field is like the gravitational field but different, or that in relativistic scenarios we must abandon simultaneity – are the differénce introduced by Saussure and expanded upon by Barthes. They argue that in drawing an analogy between the two fields, the relevance is not in the ways in which the two are similar – that overarching schema in which both are understood – but the places where they are different. This idea has been termed the "negative analogy" in the philosophy of science.

Negative analogies as a caveat

The negative analogy – the pieces of the base that do not transfer to the target – was first introduced by Hesse in 1966, but has not been widely recognized since. One reference can be found in "The Metaphorical Transfer of Models" by P.B. Sloep (1997). In this article, Darwin's natural selection is seen as an analogy to the selective breeding of gardeners, and the negative analogies are as crucial as the positive analogies:

> …natural selection and artificial selection differ too. It is not for nothing that we said in the above 'it looks *as if* someone selected them.' While the proto-fantails were hand-picked by their breeders, in natural populations selection results from natural processes such as the struggle for existence. Here we have a difference or a *negative analogy*, as Hesse would call it: a human selecting agent versus natural processes. Negative analogies are as essential an ingredient of metaphorical transfer as positive analogies. A metaphor without them would cease to be a metaphor – i.e. an explicitly non-literal referring term – it would be the 'real thing' – i.e. a literal referring term – and we would end up with an identity

> relation rather than one of analogy. At the same time, negative analogies embody the limitations of a metaphor… if negative analogies are not recognized for what they are, mistaken inferences loom large.

It is true that negative analogies are a crucial element of science – but not solely because "if not recognized for what they are, mistaken inferences loom large." I don't want to place a caveat *against* negative analogies – there is the danger in reading this passage and believing negative analogies to be no more than pitfalls, limitations and places for error. This interpretation of negative analogies is widespread (i.e., Gentner and Gentner, 1983; Clement, 1987; and Lulis, Evens and Michael, 2004). David Brookes (2003, 2004) has argued that scientists are inconsistent with their approaches to problems: speaking of quantum mechanics in the Bohmian sense one moment and then the Schrodinger model the next. We talk about heat as though it is a fluid, but treat it mathematically as a process. This is cited as a concern, but I believe that many and conflicting representations of phenomena may be a strength if appreciated and understood for what they are.

Meaning arises in these negative analogies – the places where the representations are not accurate (can lead to incorrect predictions) and where they conflict – and this may be a strength of analogies. Meaning comes not only from the patterns and similarities between things but also the differences. It is in the tweaks – the fact that the magnetic field is a vector, that heat seems like a fluid and isn't, that we think of quantum mechanics in a Bohmian sense but also don't – that we find the science.

Directions for future research regarding analogies and mind

The changing schema

A direction for future research is to investigate what happens to the *schemas* through the use of analogy? How does the analogy change the understanding not only of the target, but also of the schema for which the base is a representation? For instances in which the schema is "tweaked" in constructing analogies, how do we determine when it is a "variation on a theme" and when it is a new theme altogether? Is this a continuum or is there a clean delineation between including the target in an established and stable schema and changing that schema slightly to accommodate the target?

Conceptual blending

A possible extension of these questions – concerning how the negative analogies between the target and the base affect our understanding of the schema that applies – relates to work on conceptual blending. Fauconnier and Turner (1994) note the following regarding conceptual blending (also known as conceptual integration):

- Mental spaces are small conceptual packets constructed as we think and talk, for purposes of local understanding and action. They are interconnected, and can be modified as thought and discourse unfold.

- In blending, structure from two input spaces is projected to a third space (the "blend").
- The blend inherits partial structure from the input spaces, and has emergent structure of its own.

These ideas are related to and could possibly provide a partial answer to the questions raised above regarding how our schemas change to accommodate new phenomena. Constructed bases (as opposed to recalled ones) may arise from the piecing together of schemas that are not typically associated with one another.

The implications of technology on science

Another interesting question is to explore the connection between technology and theory. One interesting implication from Otis' research is that not only does our science create new technology, but technology creates new science: not only because of the technological affordances, but the introduction of new schemas and new language. Scientists had no accurate way of envisioning the nervous system prior to the invention of the telegraph – they borrowed language from hydraulics but it was of limited use. There was no way of understanding the olfactory system prior to the scanning tunneling microscope – scientists spoke in terms of enzymes because that was the paradigm in other biological processes. Is this a rare phenomenon, or can most of our scientific theories and conceptual revolutions be, at least in part, attributed to changes in schemas that were brought about by new technologies?

Science in the absence of analogy

Related to this question are questions concerning systems for which there are no "good" analogies. In particular, I am interested in the way that quantum mechanics is taught and the way in which it is conceptualized. There are few, if any, systems that are analogous to quantum mechanics: most seemingly analogous systems incorporate a "hidden variables" component. What are the analogies that people use to understand quantum mechanics? What schemas do people tap into to understand and come to grips with this strange phenomenon? Above I suggested that quantum mechanics is perhaps not an analogy to physical phenomena but to mathematical ones. Although I later began to conceptualize probability amplitudes by comparing them to electromagnetic waves, it was initially an understanding of linear algebra that first informed and explained quantum mechanics. (My undergraduate professor for mathematical methods for physicists claimed that all of physics is linear algebra.) Of course, analogies from physical to mathematical systems beg the question as to whether or not mathematics is understood via analogies to the physical world. Lakoff and Nunez, in the book *Where Mathematics Comes From*, argue that math, far from being an abstract and objective field, is intimately tied to analogies to the physical world:

> When you think about it, it seems obvious: The only mathematical ideas that human beings can have are ideas that the human brain allows. We know a lot about what

human ideas are like from research in Cognitive Science. Most ideas are unconscious, and that is no less true of mathematical ideas. Abstract ideas, for the most part, arise via conceptual metaphor-a mechanism for projecting embodied (that is, sensory-motor) reasoning to abstract reasoning.

This book argues that conceptual metaphor plays a central, defining role in mathematical ideas within the cognitive unconscious – from arithmetic and algebra to sets and logic to infinity in all of its forms. (Lakoff and Nunez, 2001 preface)

Embodied cognition and analogies in science

In the above passage is a final question for generated analogies in science – that of embodied cognition. The idea of embodied cognition is that "human ideas are, to a large extent, grounded in sensory-motor experience. Abstract human ideas make use of precisely formulatable cognitive mechanisms such as conceptual metaphors that import modes of reasoning from sensory-motor experience." (Lakoff and Nunez, 2001, xxi). That is, when you ask someone what a triangle is, the definition they immediately turn to is not mathematical formalism, but a process by which you draw that triangle – often involving gestures.

For abstract concepts like "what is truth?" Barsalou and Wiemer-Hastings (2004) have shown that definitions often involve scenarios: "It's when you…". The relationship between analogies, categories, gesture and embodied cognition is interesting. The schemas that I have argued as fundamental are abstractions from concrete, embodied experience and analogies between concrete experiences, I have argued, are mediated by this abstract schema. Perhaps at some deeper level, these schemas are represented as sensory-motor patterns, which are in turn associated with objects existing in the world, and the choice of base for our analogies may be related to this sensory-motor experience. This relationship has not been explored in this thesis but is a logical extension of this work.

Analogies as a tool for exploring categorization

Having established that analogies are assertions of categorization, this research can inform many of the open questions in categorization. Current questions involve the structure of categories and distinctions between taxonomic categories and other forms of categories. The vast majority of investigations of the mind's organization start with a prompt for the participants of the study, such as asking for a list of trees, "things to take from a house during a fire," or even to guess at a professor's judgment of the typicality of a certain type of bird. Such studies miss the everyday acts of categorization that happen without awareness or effort. Students in a class discussing why this sky is blue came up with many different analogies: the sky is like a bubble, a prism, or a neon sign. But when these students were informed by the instructor that their analogies all were ways of getting color from a colorless thing, they expressed surprise. And had they been given the prompt, "what are ways to get color from colorless things," it is not clear that the analogies – or members of this category – would have been identical to the analogies they constructed without such a prompt. This suggests an alternative and less "invasive" or contrived manner of arriving at the organization of concepts by studying spontaneously-generated analogies.

Network theory and analogy

A final direction for this research is to use analogies as a means of understanding the cognitive map as a conceptual network. Lexical maps have been constructed (Fellbaum, 2003 and others), that relate our semantic terms in a network – thesaurus-like or internet-like in its construction. In these, words are nodes and linked to one another, and the activation of a node activates those that are linked to it. A similar construction has been considered for the linking and activtion of concepts (Collins and Loftus, 1975) – but this would beg the question of what is *a* node? As Hofstadter notes (2001) a concept can be quite large and particular, as in "a strange shape that the electrical charge may take that cannot be then be solved from first principles." And yet our large concepts seem to be pieced together from smaller schemas. How are these concepts and schemas organized in the mind? What size pieces are fundamental – or is that question even meaningful?

Below I turn to questions for the implications of this research on instruction.

Directions for future research on the implications for instruction

While I make claims about *what* analogies assert and the cognitive mechanisms involved, I have not come to any conclusions about *how* this happens. How does Miranda make this incredible leap from seeing a cup of water to thinking of a cat in a basket – why were these schemas activated for her? Of course the experience with the schemas involved was necessary, just as Luca Turin had to know about scanning electron microscopes before he could draw an analogy between this and scent, but what habits of mind and what structure of education can encourage this kind of creative re-categorization of concepts?

Questions regarding student epistemology

As a first pass at a partial answer to this question, I would like to suggest that students must know that they *should* generate analogies as part of what it means to do science. That is, it requires a change of students' epistemological stance towards science. This is an argument that was discussed in the chapter regarding implications for instruction. But it leaves open the question as to how to change student epistemologies. I have found – anecdotally – that telling students to use analogies often results in superficial analogies: temperature equilibrating is analogized to a chameleon changing color, or an electrical circuit is imagined to be like a cow's digestive tract (both analogies have occurred in Maryland physics classrooms). These students, when *told* to draw an analogy, are not choosing a story that makes sense to them could apply here. I don't quite know what they're doing with the analogies they construct – and they don't quite know why I am asking them to construct. In trying to understand these moments, I've wondered if these strange analogies can be understood in the context of a teaching philosophy from *The Inner Game of Tennis* (Gallwey, 1997). This sports psychology book argues that too explicit of instruction can (in the context of tennis) lead to unnatural and unfavorable results; telling someone where the ball should hit the racket, say, decontextualizes what should be one piece of an integrated whole. So perhaps an explicit focus on analogies prevents the natural evolution of an analogy – as response to an unexpected result and stemming from activated schemas. This is just speculation at this point. But it suggests a possible starting point for how we can design curriculum and learning spaces in a way that encourages analogy generation.

The design of learning environments

An additional, related question is whether the use of analogy (or lack thereof) a question of expectations, epistemology, or is it a domain-general ability? That is, in designing our learning environments to encourage analogy, should we be addressing students' ideas about what kind of knowledge they should bring to bear? Should we try to encourage the activation of multiple, contradictory schemas? Or is it a general facility with or predisposition towards analogies – does a facility with analogies in, say, literature, translate to an increased use of analogy in science?

Concluding thoughts

Before my work on analogies, I was involved in curriculum development surrounding wave phenomena. In watching students interact with this and similar curricula I was dismayed that, though they eventually understood the concepts that the curriculum was addressing, the students never approached *new* topics in a creative, scientific, sophisticated way. They were better *engineers* in the end – they could apply algorithms that the curriculum had carefully developed, but they weren't better *scientists*. It seemed they were at a loss when learning new topics and constructing novel ideas. A student came to class one day wearing a t-shirt from a punk rock band. It read: *You can lead a man to reason, but you can't make him think*. I wanted my work to address this. To begin to think of the classroom as more than a place to lead our students to reason, but as a place where deep scientific thinking occurs. I think this thesis is a start. It highlights one significant component of scientific thinking – analogy. I claim that analogy is the ability to consider alternative models, deliberately overriding cognitive knee-jerk reactions to phenomena by tapping into alternative models and representing the categories that these models construct.

In *Drawing on the Right Side of the Brain* (Edwards, 1989), readers are instructed to turn a Picasso sketch upside down and then try to reproduce the upside-down drawing. Results are phenomenal – even people who have trouble drawing stick figures are often create remarkably accurate reproductions. We cannot help but see a nose when a right-side-up nose is drawn before us, but by turning it over we can begin to see the lines and curves as lines and curves and override our assumptions about how noses are shaped or where eyes go. Analogies allow us to do a similar thing – they demand that we turn the pictures upside down and dislodge the cognitive models that we were applying.

Analogies allow us to stop seeing the nose as a nose – we stop seeing the cup as a cup and instead pay attention to the way in which it as a basket, how metal is a set of stepping-stones and quantum mechanics problems are like Bugs Bunny's ears.