

EMBODIED EXPERIENCES FOR SCIENCE LEARNING 1

EMBODIED EXPERIENCES FOR SCIENCE LEARNING: A COGNITIVE  
LINGUISTICS EXPLORATION OF MIDDLE SCHOOL STUDENTS' LANGUAGE IN  
LEARNING ABOUT WATER

by

Ivan Eduardo Salinas Barrios

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A Dissertation Submitted to the Faculty of the

DEPARTMENT OF TEACHING, LEARNING AND SOCIOCULTURAL STUDIES

In Partial Fulfillment of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

WITH A MAJOR IN TEACHING AND TEACHER EDUCATION

In the Graduate College

THE UNIVERSITY OF ARIZONA

2014

EMBODIED EXPERIENCES FOR SCIENCE LEARNING 2

THE UNIVERSITY OF ARIZONA  
GRADUATE COLLEGE

As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Ivan Salinas, titled “Embodied Experiences for Science Learning: a Cognitive Linguistics Exploration of Middle School Students’ Language in Learning about Water” and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

\_\_\_\_\_  
Kristin L. Gunckel

Date: (April 15, 2014)

\_\_\_\_\_  
Bruce Johnson

Date: (April 15, 2014)

\_\_\_\_\_  
Ronald W. Marx

Date: (April 15, 2014)

\_\_\_\_\_  
Sandiway Fong

Date: (April 15, 2014)

Final approval and acceptance of this dissertation is contingent upon the candidate’s submission of the final copies of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

\_\_\_\_\_  
Dissertation Director: Kristin L. Gunckel

Date: (April 15, 2014)

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SIGNED: Ivan Eduardo Salinas Barrios

ACKNOWLEDGEMENTS

As any accomplishment, mine is the result of many efforts and personal liberties that exceed my own volition, but have crossed my life. I first want to thank my parents and family. Son mis padres los que me han dado la libertad de hacer con mi vida lo que quiera, y gran parte de mis logros los debo a su apoyo en ello. A Poli y nuestra pequeña Amaya, por acompañarme, apoyarme, y por ser un cable a tierra en todo el introspectivo camino de sacar un doctorado y su tesis. Les amo, y me siento muy afortunado de tenerlas en mi vida.

Second, I thank the friends I have made in coming to Tucson. Dennis and Alyssa Rosemartin, Jenaro García-Huidobro, Camila Bauer, Marco Menchaca, Carolina Lillo, Patricio Valdivia, María Paz Gómez, Amanda Jaksha, and many others who have made these years more adventurous than an academic degree. I also thank my friends Yoyi and Assaf, whose similar paths in other geographies have not loosened our friendship.

Third, I want to thank the staff and faculty of the College of Education and the University of Arizona. Their inspiring and provoking work strengthens important values for educators: equity, social justice, inclusion and respect for diversity. I felt welcomed by many people at the U of A, and challenged to learn as well, and I appreciated that. I am particularly grateful of the generosity of my committee members, Ron Marx, Bruce Johnson, Sandiway Fong, and to Kristin Gunckel, for her continuous encouragement, challenging questions, and for providing opportunities for my development as scholar.

I also want to thank the financial sustenance of Chilean and American taxpayers. The support of CONICYT-Chile and Fulbright-Chile, and U.S. research funding agencies made my work and course of studies possible. I am indebted to their generosity. To all of you, thank you.

DEDICATION

“I assume that amid all uncertainties there is one permanent frame of reference: namely, the organic connection between education and personal experience; or, that the new philosophy of education is committed to some kind of empirical and experimental philosophy. But experience and experiment are not self-explanatory ideas. Rather, their meaning is part of the problem to be explored. To know the meaning of empiricism we need to understand what experience is.”

-John Dewey, 1938

DISCLAIMER

The data used in this research has been obtained in the context of grants from the National Science Foundation: Targeted Partnership: Culturally relevant ecology, learning progressions and environmental literacy (NSF-0832173), and Tools for Reasoning about Water in Socio-ecological Systems (DRL-1020176). Any opinions, findings, and conclusions or recommendations expressed in this dissertation are those of the author and do not necessarily reflect the views of the National Science Foundation.

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**Abstract**

I investigated linguistic patterns in middle school students' writing to understand their relevant embodied experiences for learning science. Embodied experiences are those limited by the perceptual and motor constraints of the human body. Recent research indicates student understanding of science needs embodied experiences. Recent emphases of science education researchers in the practices of science suggest that students' understanding of systems and their structure, scale, size, representations, and causality are crosscutting concepts that unify all scientific disciplinary areas. To discern the relationship between linguistic patterns and embodied experiences, I relied on Cognitive Linguistics, a field within cognitive sciences that pays attention to language organization and use assuming that language reflects the human cognitive system. Particularly, I investigated the embodied experiences that 268 middle school students learning about water brought to understanding: i) systems and system structure; ii) scale, size and representations; and iii) causality. Using content analysis, I explored students' language in search of patterns regarding linguistic phenomena described within cognitive linguistics: image schemas, conceptual metaphors, event schemas, semantical roles, and force-dynamics. I found several common embodied experiences organizing students' understanding of crosscutting concepts. Perception of boundaries and change in location and perception of spatial organization in the vertical axis are relevant embodied experiences for students' understanding of systems and system structure. Direct object manipulation and perception of size with and without locomotion are relevant for understanding scale, size and representations. Direct applications of force and consequential perception of movement or change in form are relevant for understanding of causality. I discuss implications of these findings for research and science teaching.

## **Chapter 1: The Problem: Understanding Embodied Experiences for Science Learning through Students' Language**

This study is about students' understanding of science in relationship to their embodied experiences. Embodied experiences refer to those deriving from the interactions between the human body and the physical world. Because the human body has defined biological and developmental properties, the embodied experiences available to humans are limited by the natural capacity of the body to interact with the physical environment. These body-environment interactions are pre-linguistic; that is, they occur before the human body is able to communicate through a language, but they are linked to the development of cognition (Lakoff & Johnson, 1999). Examples of these experiences include sensory experiences (e.g., vision, balance, gravity) and feelings or emotional experiences (anger, happiness).

To better understand the relevance of embodied experiences in learning about scientific concepts, consider the use of the word “folding” in the following two text segments taken from the Corpus of Contemporary American English (Davies, 2008):

- “... she said, folding over the corner of a page”
- “A folding synuclein molecule first collapses on itself, then doubles over into a hairpin shape.”

As shown, at least two ways of talking about “folding” are possible and acceptable in English. The difference between the two presented above is that one is a direct embodied experience and the second is an abstraction that derives from the meaning of an embodied experience. In this case, the direct embodied experience is the actual use of the body (hands and fingers) to perform an action over a physical entity (a page—a paper surface) that modifies the physical display of the entity (the “folded corner”). The “folding molecule” in the second

example refers to the condition of an entity (a molecule) that has been constructed as following the physical action of folding (e.g., changing its display to a “hairpin shape”). The conceptual correspondence between the embodied and abstract experience is unidirectional; that is, one meaning of “folding” can be understood in terms of the other, but not otherwise. In the case above, the “folding molecule” represents a conceptual domain derived from the embodied experience of “folding page.” The opposite case, the meaning of a “folding page” deriving from the experience of a “folding molecule,” does not represent a correspondence that provides understanding of the use of “folding.” The embodied experience of “folding” allows conceptualizations that might be used in other domains that are not embodied, such as the case above.

Embodiment and embodied experiences and their relationship to understanding are summarized in a perspective called experientialism. The theory of experientialism claims that our knowledge of abstract concepts stem from our experience with other domains of knowledge, particularly the experiences of the human body in the environment (Lakoff, 1987). The embodied cognition thesis holds that humans’ conceptual systems depend upon the ways in which the human body interacts with the environment (Evans & Green, 2006). An immediate consequence of this thesis is that the nature of the human body and its perceptual system limits human conceptualizations (Lakoff & Johnson, 1999). In such a way, humans have only access to thinking what the body allows perceiving and conceiving.

The inquiry into language, cognition and embodiment is important for scientific thinking. For example, Pinker (2010) argues that, in evolutionary history, science is the result of the human ability to make *conceptual metaphors*. Conceptual metaphor can be understood as a correspondence between aspects or domains of experience that are mostly sensorimotor and

aspects or domains of experience that can be *reasoned* in terms of the sensorimotor experiences, but do not represent an objective similarity (Alarcón, 2010; Lakoff & Johnson, 1999). In the second example above, the idea of a molecule doubling itself “into a hairpin shape” uses one perceptual domain of experience (e.g., observing a hairpin) to make sense of an abstract domain of experience (molecule folding) that is relevant for understanding molecular phenomena of proteins. These types of examples are ubiquitous in language (Lakoff & Johnson, 1980, 1999), including scientific language (e.g., Brown, 2003), which indicates the importance of studying the link between embodiment and language to understand student learning in science.

Educational researchers have increasingly paid attention to the notion of embodiment both to understand learning and to promote learning experiences, which stems from advances of research in several disciplines, including linguistics. Recent perspectives state that cognitive processes involved in learning build on physical embodiment (Lindgren & Johnson-Glenberg, 2013); also that understanding science needs embodiment (Niebert, Marsch, & Treagust, 2012). Other work calls for a consideration of embodied experiences in teaching science (Fuchs, 2007, 2009, 2010; Gee, 2005a). There is an emergent argument for understanding embodied experiences of students and their meaning for developing and designing science teaching.

In this study, I explored students’ embodied and perceptual experiences by examining their school’s science language in the context of learning about water in the environment. I focused my analyses on specific scientific reasoning features emphasized by current science education documents. I used an integrated cognitive and linguistic perspective, cognitive linguistics, which is principled upon and analytically related to the embodied cognition thesis.

In the next lines I provide the thread of reasoning to explain the problem of study. I introduce the notion of embodiment and perception in relation to language and cognition, and its

relation to learning science in general and student learning about water in particular. I also introduce the research questions and significance of the study and provide an outline of the next chapters.

### **Embodiment Provides Sources of Experiences for Science Learning**

Embodiment in relation to cognition can generally be understood as the deep link existent in what is possible to conceptualize and the limited perceptual and sensorimotor properties of the human body (Lakoff & Johnson, 1980, 1999). Science education researchers have recently started noting the importance of embodiment for understanding science learning. For example, in several theoretical essays, Fuchs (2007, 2009, 2010) elaborated on the need for searching the “sources” of key conceptualizations in physics and fluid dynamics. The sources Fuchs refers to are the embodied and perceptual origins of figurative thought, so common in science. In the same line of argument, Niebert, Marsch and Treagust (2012), in an analysis of conceptual metaphors in science learning, claim that fruitful communication of science requires more than mere connections to daily life, and assert that good instruction needs embodiment as sources of metaphors and analogies. The design of science teaching and learning experiences with basis on embodiment and perceptual experiences is a challenge that requires more understanding about the sources of embodiment for school science.

### **Cognitive Linguistics as a Perspective to Study Language, Cognition and Embodiment**

Cognitive linguistics offers the possibility to study cognition through examination of language. A basic tenet of cognitive linguistics is that language is not a separated faculty from cognition (Evans & Green, 2006; D Geeraerts & Cuyckens, 2007; Lee, 2001; Ungerer & Schmid, 1996). That is, phenomena of language (linguistic phenomena) are not arbitrary, but *motivated* by humans’ cognitive or conceptual structure. Conceptual structure cannot be separated from the

body, and thus, is a result of embodied experiences and perception. Therefore, analysis of linguistic evidence can provide elements to understand how embodied and perceptual experiences motivate language in science classrooms.

Using linguistic evidence, cognitive linguistics offers analytical categories and perspectives that provide an understanding of language in relation to cognition, embodiment and perception (Evans & Green, 2006; Gonzalez-Marquez, Mittelberg, Coulson, & Spivey, 2005). In this study, I assumed this perspective to explore students' understanding about key aspects of scientific reasoning.

### **Students' Understanding about Water**

There is no doubt that water has been and is a topic of interest for science educators, for several reasons. The United Nations Educational, Scientific and Cultural Organization (UNESCO, 2009) substantially describes water issues at several levels, including a global water crisis and effects of demographic changes impacting the crisis. Education is seen as one of the social drivers to address the crisis, equipping people with a better understanding of sustainable use of water resources, greater efficient use of water, and greater knowledge of water systems for extending water services. The partial role of education in facing a global water crisis justifies the political attention to water as a topic of understanding in science education. Also, water is a topic that crosscuts scientific understanding across disciplines, at different levels and dimensions, from Earth sciences to biology, chemistry and physical sciences. Water can be related to the core ideas of any of the four disciplinary areas defined by the *Framework of K-12 Science Education* (NRC, 2012), which means a general agreement among science educators that studying water is an important part of school science curricula. Experiences with water are biologically bounded to the human body. Given the importance of embodied and perceptual experiences for

understanding in science (Niebert et al., 2012), understanding how students learn about water offers a common ground to link to embodied experiences for inclusion of diverse students.

For several decades, science education researchers have focused on students' understanding of many water-related topics, such as ocean and climate change in relation to the water cycle (Bar, 1989; Shepardson, Wee, Priddy, Schellenberger, & Harbor, 2009; Taiwo, Ray, Motswiri, & Masene, 1999; Tran, 2009), water phase changes (Bar & Travis, 1991; Osborne & Cosgrove, 1983), the molecular structure of water (Laing, 1987); and watersheds (Endreny, 2009; Shepardson, Wee, Priddy, Schellenberger, & Harbor, 2007). They have reported, among other findings, that students do not think about water in cyclical and dynamic systems; that students in early grades have difficulty describing water in places where it is not visible, including the atmosphere; have conceptions of watersheds as human structures (e.g., water towers or sheds); and have difficulty conceptualizing substances and water transport of substances (Covitt, Gunckel, & Anderson, 2009; Gunckel, Covitt, Salinas, & Anderson, 2012).

Recent work on student understanding about water has focused on change in students' ideas about water in the environment, comprising natural and human-engineered elements and a variety of phenomena (Gunckel, Covitt, & Anderson, 2009; Gunckel, Covitt, Salinas, & Anderson, n.d.; Gunckel, Covitt, et al., 2012; Gunckel, Mohan, Covitt, & Anderson, 2012). In this line of research, the progression of students' understanding about water has been defined within *progress variables* that are linked to the crosscutting concepts proposed in the *Framework for K-12 Science Education* (NRC, 2012). I built on this connection to propose three areas of scientific thinking that I explored in this study.

**Problem of Study: Research Questions**

Embodied cognition, perceptual experiences, and the analysis of linguistic evidence are the frames under which I situated the problem of study. I focused on specific areas of scientific reasoning based on the crosscutting concepts defined in the *Framework for K-12 Science Education* (NRC, 2012), and on understanding embodied experiences as motivation for students' scientific explanations. Particularly, I examined patterns within students' understanding about structures and systems, scale, size and representations, and scientific principles and causality in the context of their learning about water in the environment.

I used cognitive linguistics to analyze middle school students' language after they completed academic assessments in regard to learning about water in science classes.

Specifically, my research questions are:

1. What embodied experiences do middle school students bring to understanding of systems and systems' structures in water phenomena?
2. What embodied experiences do middle school students bring to understanding scale, size and representations in water phenomena?
3. What embodied experiences do middle school students bring to understanding causality in water phenomena?

**Significance and Contribution of the Study**

The literature I have reviewed indicates that the field of science education has a germane and growing interest in embodiment for understanding student learning. At the same time, authors in other fields of study assert that even the origins of science, in evolutionary terms, are closely related to embodied and perceptual experiences (e.g., Liebenberg, 2013; Pinker, 2010). This study adds an understanding of embodiment that stems from purely linguistic evidence in

the context of science education, which is a common source of evidence for judging academic school work. The results of this study can provide insights into instrumental similarities of embodied experiences and their relation to key concepts of scientific reasoning, which can be leveraged to provide principles for designing inclusive science learning experiences.

### **Dissertation Outline**

I have organized the text in this dissertation as follows. In Chapter 2: *Theoretical Framework and Background* I provide a frame for the problem of study. I expand on cognitive linguistics and its relationship to embodiment, perception, and scientific reasoning. I also review some of the research regarding students' understanding about water, and detail the links between current frontier discussion about science education and the three areas of scientific reasoning I focused my study upon: structures and systems; scale, size and representations; and causality. In Chapter 3: *Methodological Generalities and Research Design*, I describe the primary analytical perspectives, the participants of the study, and data collection procedures. I also provide the analytical definitions I used to present the findings, the study design and rationale, and the primary analytical procedures and outputs. I include a brief discussion about limitations and validity of the results. In Chapters 4, 5, and 6 I answer each of the research questions, describing secondary methods, interpretive procedures and the findings of the study regarding each question. In Chapter 7: *Discussion and Conclusion*, I summarize the findings and discuss potential implications for research and teaching resulting from the commitment of this study.

## Chapter 2: Theoretical and Methodological Frameworks

In Chapter 1 I have outlined embodied experiences in relation to science learning, and cognitive linguistics as a framework for understanding embodiment and perception. In this chapter I provide more information on cognitive linguistics, linking embodiment and perception to understanding of science. I expand the rationale for connecting scientific reasoning to linguistic phenomena. I continue with a summary of current research-based recommendations for emphases in science education in the U.S., synthesized in the *Framework for K-12 Science Education* (NRC, 2012).

### Cognitive Linguistics to Explore Language and Cognition

Cognitive linguistics defined several emphases of this study. According to the *Longman Dictionary of Language Teaching and Applied Linguistics* (Richards & Smith, 2002), cognitive linguistics is an approach to linguistics

which stresses the interaction between language and cognition ... Issues addressed within cognitive linguistics include structural characteristics of language such as ... metaphor, and imagery; functional principles of language organization ...; the interface between syntax and semantics; and the relationship between language and thought (Richards & Smith, 2002, pp. 83-84).

Researchers in cognitive linguistics assume that language reflects “certain fundamental properties and design features of the human mind” (Evans & Green, 2006, p. 5). The major assumptions, principles or hypotheses of cognitive linguistics are:

- Language is not an autonomous cognitive faculty
- Grammar is conceptualization
- Knowledge of language emerges from language use (Croft & Cruse, 2004, p. 1)

Two conclusions derive from the first assumption. One, language is a reflection of cognition, or knowledge about language equals knowledge about meaning, form, and thinking processes. The other, knowledge about language use is not different from knowledge about cognition in domains other than language. The second assumption implies that human cognitive ability is characterized by a capacity to conceptualize the experience to be communicated. The third assumption implies that meaning structures and categories, syntax, morphology and phonology are built from knowledge of linguistic expressions in their context of use (Croft & Cruse, 2004).

The principles above mean that cognitive linguistics informs the relationship of language to cognition in a systematic approach. Cognitive linguistics links the ‘production’ of language to the ways in which humans conceptualize events being talked about or referenced using language. Language reflects conceptualizations that are constrained by embodied experiences, common to all human beings (Evans & Green, 2006). This perspective has particular consequences for understanding science, and its language. Specifically, science can be seen as the result of conceptualizations that stem from embodied and perceptual experiences. For this reason, I address the foundational theory for embodiment in relation to language, and the relation of this to science and science education. Also, I provide some background on linguistic phenomena explored within cognitive linguistics.

### **Limits of the Body: the Embodied Cognition Thesis and Experientialism**

The embodied cognition thesis holds that humans’ conceptual system depends upon the ways in which the human body interacts with the environment, which limits human conceptualizations (Evans & Green, 2006; Lakoff & Johnson, 1999). This way, humans have access to thinking only about what the body allows itself to perceive and conceive. The idea that

a reality ‘out there’ is represented and processed, or mediated, by perceptual and cognitive mechanisms of the human body is called experientialism or experiential realism (Lakoff & Johnson, 1980, 1999; Lakoff, 1987).

The ways in which the human body limits language and conceptualizations are varied. An example of an embodied constraint is vision. The human body perceives only a small amount of the electromagnetic spectrum, e.g. colors. Consequently, only conceptualizations derived from the capacity to see colors are available to humans, but not other ranges of invisible waves. Also, despite the differences in geographical location, there are features of the environment available to the whole human species, such as gravity. The ways in which human body morphology interacts with gravity, different from birds for example, limit what is available to experience at the cognitive level. Sensory experiences (e.g. space, motion, temperature) and introspective or subjective experiences (e.g. emotions, consciousness) are also dependent on the capacities of the human body. Additionally, perceptual mechanisms, such as the ones studied under Gestalt psychology, add to the constraints of embodiment to conceptualization and language (Evans & Green, 2006, pp.65-68). In sum, perceptual and embodied experiences limit humans’ thinking possibilities to the cognitive phenomena that depend on the interactions of the human body with the environment.

### **Science and its Language as the Result of Embodied Experiences**

While scientific language has been described as a second language or discourse in several arguments within science education (Bruna & Gomez, 2009; Gee, 2005a; Lemke, 1990; Reeves, 2005; Roth, 2005), the perspective offered by cognitive linguistics poses scientific language as the result of embodied experiences. Linguist Steven Pinker (Pinker, 2010) refers to the ‘language products’ of science as the result of a capacity of humans called *metaphorical abstraction*

(Lakoff & Johnson, 1980; Lakoff, 1993). Metaphorical abstraction in relation to science has gathered attention for documenting what conceptual metaphors scientists and science educators use and their role in scientific knowledge (Bradie, 1999; Brown, 2003; Niebert et al., 2012).

Pinker (2010) uses the following examples to illustrate metaphorical abstraction:

1. The messenger went from Paris to Istanbul.
2. The inheritance went to Fred.
3. The light went from green to red.
4. The meeting went from 3:00 to 4:00. (p. 8997)

The examples show there are different forms of usage of the verb *to go* that convey different meanings. Whereas in 1 there is a spatial (concrete) form of interpreting the sentence, the meanings in 2, 3, and 4 represent motion where *going* is not conceptualized in spatial concrete meaning, but as an *abstract* motion, a *state* motion, and a *time* motion. These types of metaphorical projections in language are so ubiquitous that their meaning is taken for granted.

The productive use of abstract language as a distinctive feature of humans includes a shift toward using faculties deriving from solving problems in the physical world. The examples above suggest that abstractions, including science and its language, are an evolutionary result of human cognition, which adds to arguments locating the emergence of science as a result of humans' natural evolution (Liebenberg, 2013). This is ecologically related to humans occupying a 'cognitive niche' (Pinker, 2010). Whichever the language, concrete experiences with 'space' receive words to describe them (e.g., the verb *to go*, and the prepositions *from* and *to*). The variation of words attached to a concrete experience corresponds to form-meaning pairs that are part of the linguistic repertoire of a language. When the formalities of spatial form-meaning pairs are attached to experiences that are not concretely spatial, there is a shift to a metaphorical

abstraction: understanding *abstract* experiences in terms of *concrete*, *perceived*, and *felt* ones.

That is how the link between science and embodiment can be observed. For cognitive linguists, for example, humans do not compare time and space, but time *is understood* as space (Lakoff & Johnson, 1980; Lakoff, 1993).

Metaphorical abstraction allows not only the sense-making emerging from concrete (and embodied) experiences with the world, but also the linguistic attribution of cause and entity-naming. Pinker (2010) also offers examples for this:

5. Rose forced the door to open.
6. Rose forced Sadie to go.
7. Rose forced herself to go.

In these three sentences, the syntax is similar, but the meaning is concrete in 5 (a physical exertion of force), not as concrete in 6 (a physical or psychological process in interpersonal relationships), and definitively metaphorical in 7 (an intrapersonal *forcing*). The attribution of force in language is directly related to the development of causal mechanisms that explain scientific phenomena (Hilton, 2002). Take example 8:

8. The *government's decision* to print money *caused inflation* to go *up*.

The meaning of the sentence in example 8 implies several cognitive processes of abstraction: *nominalization*—or naming—of entities (*government's decision*, *inflation*), causal mechanism (verb *cause*), and a metaphorical projection of space (going *up*). Concrete and embodied experiences, before becoming metaphorical in language, benefit from the cognitive process in which a person names spatial relationships. Orientations to space such as *front/back*, *in/out*, *up/down* are the result of embodied and perceptual experience with the material world and

play a central role for both meaning-making and for the emergence of cultural experiences, such as science and its language.

### **Exploring Language through Cognitive Linguistics for Science Education**

Through cognitive linguistics I assumed linguistic phenomena explain connections of scientific reasoning and language to embodied experiences, which implies a logical link to science education. However, the literature on these connections is emergent, and rather recent or located in traditions that are outside the U.S. science education researchers' community. For example, Fuchs (2007, 2009, 2010) has developed an analytical justification for the consideration of embodied experiences, based on phenomena described using cognitive linguistics. Fuchs' work in physics education articulated the importance of considering cognitive linguistics for understanding students' conceptions of scientific concepts. He brought attention to linguistic phenomena such as *conceptual metaphors*, *force-dynamics*, and *image schemas*. I refer to these phenomena later in this section.

There are limited examples of research studies that link science education with cognitive linguistic analyses of student work. Brookes and Etnika (2007) studied the language of scientists talking and teaching and students learning about quantum mechanics. They concluded that physicists use conceptual metaphors in their naturalistic talk about quantum mechanics phenomena, but students have difficulty interpreting the metaphors because of the literal interpretations they make of them. Nehm and colleagues (2010) analyzed, through a computerized system of assessment, the frequency with which biology majors used words associated with force-dynamic terms as a way to explore the scientific accuracy or inaccuracy of students' explanations in evolutionary biology. They concluded their research cautioning science educators about using "force-talk" in order to explain evolutionary models because of its leading

to ‘faulty’ explanations. In the context of developing learning progressions for carbon cycling and water in environmental systems, researchers have introduced force-dynamics as a primary-discourse of students learning science, and as a criteria for locating students’ performance in science along a line of progression toward more sophisticated model-based scientific reasoning (Gunckel, Covitt, et al., 2012; Gunckel, Mohan, et al., 2012; Mohan, Chen, & Anderson, 2009). Niebert and colleagues (2012) performed a reanalysis of published work concerning metaphors and analogies in science instruction and learning. In their analyses, they found 199 conceptual metaphors used in the context of reporting academic work in science teaching and learning, including metaphors used by teachers as well as students and researchers. Their reanalysis focused on the need for extending the view of previous knowledge toward a view that manifestly recognizes the need for embodied experiences to facilitate students’ understanding of scientific concepts. It also suggested that “analysis of the experiential background of everyday and scientific conceptions can provide a fruitful basis for the development of learning environments” (p. 23).

The study I conducted in this dissertation contributes to the evidence about fruitful ‘experiential background’ of students in learning scientific concepts, particularly those emphasized in current debates about science education (NRC, 2012). By using cognitive linguistics as a framework, I operated with linguistic evidence to understand what fruitful experiences students bring to the classroom when they learn science. Because of cognitive linguistics’ base on embodiment and perception, the analyses I performed aimed at common embodied and perceptual experiences that can be leveraged for fostering students’ understanding of science in diverse classrooms.

### **What to Observe in Language through Cognitive Linguistics**

To explore language in search of linguistic evidence about embodiment and perception, I relied on some of the patterns of cognition, analytical categories or linguistic phenomena that are part of cognitive linguistics attention. These phenomena have already been mentioned in the previous sections, and here I describe them in general terms. In *Chapter 3: Methodological Generalities and Research Design*, I will link these linguistic phenomena to the scientific concepts I explored. The linguistic phenomena are: image schemas, conceptual metaphors, event schemas and force-dynamics.

#### ***Image Schemas***

*Image schemas* can be generally defined as “dynamic analog representations of spatial relations and movements in space” (Gibbs Jr. & Colston, 2006, p. 240). They are one of the pre-conceptual or pre-linguistic patterns of experience that provide knowledge structures for other concepts. Image schemas are not sensorimotor processes, but cognitive processes that stem from perception and motor processes. Meaningful experiences with the body derive into meaningful image schemas, such as those of containment or vertical orientation. For example:

9. Water vapor going *up into* the air, day after day after day.

10. You need to stay *on top* of the situation by going for regular exams.

Example 9 shows both a vertical orientation image schema (*up*) and a containment schema (*into*), and example 10 shows a vertical orientation schema (*on top*). Due to image schemas being meaningful, air can be considered a container where an entity (*water vapor*) can get *into*, while being *on top* of has the meaning of exerting control on an entity, in this case, a situation. Image schemas can be said to be cognitive topologies (knowledge about spatial properties) deriving from embodied experience, and represent a linguistic phenomenon to be studied for

understanding embodied cognition. Cognitive linguists hold that the meaning of expressions like the above mentioned (examples 9 and 10) results from the capacity to make a metaphorical projection of image schemas into domains that are more abstract (Lakoff & Johnson, 1980); that is, the capacity for conceptual metaphors.

### *Conceptual Metaphors*

Metaphor in cognitive linguistics, or *conceptual metaphor*, describes conceptualization as a general mapping from an abstract conceptual domain (*target domain*) to a concrete physical or embodied experience (*source domain*). The target domain is the domain of the concept being described, whereas the source domain is the domain that serves as a source to describe the target domain. These sources are concrete, perceptual and embodied, and sometimes cultural, experiences. Metaphorical thought cannot be avoided and is mostly unconscious. Conceptual metaphors, as mappings, are unidirectional across the conceptual domains being mapped. That is, a target domain can be understood as a source domain, but a source domain cannot be understood as a target domain. Take the examples 11-13<sup>1</sup> below:

11. Do not let the water *boil*.

12. It just makes my blood *boil*.

13. Anger on both sides *builds*, threatening to *boil over* at any moment.

The examples 11 to 13 illustrate the projections of a physical and perceivable phenomenon (*boil* in 11) for extending the meaning of an embodied experience (arguably *anger* in 12 and 13). The creation of similarity can be understood by the unidirectional nature of the mapping: boiling as a physical phenomenon is not understood as anger. Also, in example 13 another metaphor combines the source domain ‘construction’ (*builds*) and a physical change

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<sup>1</sup> Most of the examples used in the rest of the chapter are taken from the Corpus of Contemporary American English (<http://corpus.byu.edu/coca/>).

(*boil*) to make sense of a situation where a conflict might occur. Formally, conceptual metaphors are written using low-sized capital letters, as: TARGET DOMAIN IS SOURCE DOMAIN. In example 13 these formalities could write as: ANGER IS A BUILDING and ANGER IS A (BOILING) FLUID.

Metaphors can be structural, ontological and orientational (Lakoff & Johnson, 1980). These categories relate to the use of the metaphor for understanding a concept (e.g., time *is* money), creating a concept (e.g., combating *inflation*), or organizing a whole set of concepts (e.g. the *upper* class, prices *rise*), respectively. Conceptual metaphors are also generative, as they offer a framework to build more expressions that show mappings between conceptual domains. See examples 14-17 below:

14. Water *goes* from liquid to gas, evaporating.
15. The fear is that this committee's recommendations will *evaporate*.
16. This moist substance *gave rise* to clouds.
17. This rising hysteria *clouds* the real *issues*.

Example 14 is illustrative of how a physical phenomenon (evaporation, *evaporating*) is named and conceptualized in terms that change in location or state (*going from state x to y*). 'Evaporation' is then used to conceptualize an abstract entity (*recommendations* in 15), and its perceptual properties in context (e.g., when something evaporates is no longer visible). Further, conceptualizing cloud formation as a process of directional transfer (*gave rise* in 16), and the perception of physical clouds as an entity that occludes the vision of an abstraction (*issue*, in 17) illustrates the use of conceptual metaphors. The directionality of some of the linguistic units (*rising hysteria* in 17) shows the organizational nature of orientational metaphors (such as MORE IS UP). In each of the examples presented so far there is a sense of perspective, a construction of

an event about something in the world. These events are also schematic and informative about embodied experience, as I show in the next lines.

### ***Event Schemas***

Event schemas are *construals* of the world ‘out there,’ which can be thought of in a wide sense, as both actions and states (Dirven & Verspoor, 2004; Radden & Dirven, 2007). *Construals* are ways in which a person can describe a situation in the world, or can create an encoding of that situation.<sup>2</sup> Construals show a relationship between perception and the ways in which situations are ‘construed.’ The ability to attend to different aspects of a scene gives rise to structuring different roles in exposing a situation through language. When construing a situation, foregrounding one entity leaves other elements out of the focus of attention, backgrounding them and reducing their prominence from the perspective of the utterer of the construal. In studying students’ explanations of water phenomena, such as puddles disappearing from a soccer field, researchers have observed sentences (construals) such as *The water evaporated*, and *The Sun evaporated the water*, revealing different attention patterns evident in grammar (Gunckel et al., n.d.; Gunckel, Covitt, et al., 2012). Rather than focusing on grammar only, event schemas provide conceptual analysis of construed situations, where semantical roles are attributed to understand meaning. For example, in the sentence *The water evaporated*, a grammatical or syntactic analysis would help discerning the subject “The water” from the verb phrase (verb) “evaporate.” Differently, a conceptual analysis would discern participant roles, such as “The water” from the participant relation “evaporate.” These types of analyses are highlighted by patterns of event schemas, which I used in the analyses of students’ language.

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<sup>2</sup> Some linguists use also the term construction, which is different from construal. Construal refers to the general ways of encoding a situation and emphasizes that situations are conceptualized differently by different people. Construction refers to the idea that certain word arrangements (syntax) represent meaning as a whole and not because of their individual components. Constructions, in a sense, are a form of construal.

### ***Force-Dynamics***

*Force-dynamics* is an area of the study of language that observes grammatical and semantical patterns defining the role of entities in relation to force (Pinker, 2007; Talmy, 1988). Sometimes, grammatical patterns in sentences and utterances drive attention to entities exerting force *for* (agonists) and *against* (antagonist) each other or other entities, from which interaction an event results. This resultant event can mark a tendency toward movement or rest of entities, either material or abstract. An example is the situation in which *water flows down a hill*. The force-dynamic analysis focuses on how the lexico-grammatical elements can be arranged to evidence attribution of causal role on the water flowing down (e.g., gravity pulls the water down), or how the event can be presented with no causal agent (e.g., water flows down), or with antagonists (e.g., a dam attempted to stop water flowing down). In the resulting events there lies an attribution of causality toward any of the entities that explicitly or implicitly participate in the event. Researchers agree that attribution of causality is a key feature of scientific thinking and practices (Hilton, 2002; NRC, 2012).

Cognitive linguistics' main claim is that language is not a separate faculty from cognition, which means that linguistic phenomena are not arbitrary, but are motivated by elements described as part of cognitive or conceptual structure. Because of the relevant link between cognition and embodiment, cognitive linguistics provides elements to represent, through linguistic analyses, a window into relevant embodied and perceptual experiences that the 'producers' of language have and bring to use. The linguistic phenomena presented above provide analytical perspectives to understand what students bring to the classroom as fruitful embodied experiences to learn science. For this dissertation study, I analyzed patterns of

students' written language to infer students' embodied and perceptual experiences using cognitive linguistic elements.

### **Science Educators and Researchers Proposed a New Framework for School Science**

In this study, I relied on some of the crosscutting concepts from the proposal of the *Framework for K-12 Science Education* (NRC, 2012) as guiding topics for outlining the focus of my examinations of students' language. The *Framework for K-12 Science Education* (NRC, 2012) is one of the latest documents by the National Research Council of the National Academy of Sciences to influence science education policy in the United States. The Framework was created to guide the elaboration of the *Next Generation Science Standards* (NGSS Lead States, 2013), a document that organizes performance expectations and content for the design and development of K-12 science curricula in several states in the U.S. The Framework articulates the latest scientific research in education and cognition to provide a rationale for organizing science and engineering education around three essential dimensions: science and engineering practices, crosscutting concepts, and core ideas in science disciplines. The term "scientific practices" is used to stress the importance of engaging students in scientific inquiry and engineering practices. The Framework proposes eight scientific practices for science and engineering, and four core disciplinary areas, under which *core ideas* of science and groups of component ideas are included. Core ideas are concepts considered to be the most important for teaching, learning and assessing.

Finally, the *Framework* also proposes seven *crosscutting concepts*, or concepts, ideas, and practices that unify and can be applied across all scientific disciplinary areas. The crosscutting concepts are themes that provide a link across the disciplines, and tend to appear consistently in the study of science. These are:

1. Patterns. Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

2. Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.

3. Scale, proportion, and quantity. In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

4. Systems and system models. Defining the system under study—specifying its boundaries and making explicit a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.

5. Energy and matter: Flows, cycles, and conservation. Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.

6. Structure and function. The way in which an object or living thing is shaped and its substructure determine many of its properties and functions.

7. Stability and change. For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study (NRC, 2012, p. 84).

The *Framework* presents some groupings of these crosscutting concepts. Concepts 1 and 2 are fundamental to the nature of science. The last four concepts are also grouped because concept 4, systems and systems models, is expanded by the last three. In the NGSS (Lead States, 2013), concepts 5 and 7 are renamed as “Energy and Matter in Systems” and “Stability and Change in Systems” respectively.

The crosscutting concepts are detailed in terms of progression of students’ understanding and learning, which allows linking the concepts to models of students’ cognition. The study of learning progressions had fruitfully produced several perspectives on student learning and progression in science education (e.g., Corcoran, Mosher, & Rogat, 2009; Duschl, Maeng, & Sezen, 2011; Gunckel, Mohan, Covitt, & Anderson, 2012). Learning progressions about students’ understanding of water in socio-ecological systems established a relationship between “elements of model based accounts” and the crosscutting concepts present in the *Framework* (Gunckel, Covitt, et al., 2012). These model-based accounts are organizers of the progression and included students’ understanding about: structures and systems; scales; scientific principles; representations; and human dependency.

In this dissertation study I focused on students’ understanding about water systems in the frame of three areas of scientific reasoning development, all of which touch on the Framework’s (NRC, 2012) crosscutting concepts and the five progress variables for a learning progression in water (Gunckel, Covitt, et al., 2012). These areas of scientific reasoning are: structures and systems; scale, size and representations; and causality. I provide details on connections of each of these to student learning in following chapters of this dissertation (Chapters 4, 5 and 6).

### Chapter 3: Methodological Generalities and Research Design

In the previous chapters I have discussed the nature of the problem of study in this dissertation, the research questions, and the frameworks where I locate my exploration. In this chapter I describe the use of *content analysis* methodology to address the research questions. Content analysis is a research approach that allows making valid and replicable inferences about the meaning of texts within the contexts of their use (Krippendorff, 2004). In this study, I analyzed the content of a corpus of linguistic units of students' language in the context of their learning about water in formal schooling. Formally, linguistic units are defined as conventional *symbolic assemblies* ('pieces' of language) for which speakers share a tacit or explicit agreement on their uses and meaning. Units can be a meaningful part of a word or *morpheme*, a whole word, a set of words that 'belong together' (a *phrase*) or a sentence, and they express certain grammatical and semantical regularities (Evans & Green, 2006). Operationally, for this study, I consider linguistic units to be students' written responses to assessment questions in the context of learning about water. The nature of this research is exploratory, which is consistent with the logic of content analysis design (Krippendorff, 2004) and the cognitive linguistics' principle that knowledge about language emerges from language use.

In this chapter, I address generalities about content analysis and the construction of corpora, a collection of language expressions in the form of text. Then I describe the study design, including the context, sources of data, analytical definitions and descriptions, and the general procedures I performed to analyze the data for answering the research questions. I also provide limitations of the method and the study.

## Content Analysis

As a research method, content analysis shows relationships of content to text (Krippendorff, 2004). In a sense, content analysis is about inferring the meaning of texts according to particular analytical stances applied to texts, which aim for understanding the particular contexts of the producer of the text and the intended reader of the text. However, a content analyst is an observer timely and spatially independent of the situation in which the text is produced, requiring understanding of the context of the text production.

Krippendorff (2004) lists seven conceptual components of a content analysis. These are:

- A body (or bodies) of text
- A research question (or questions)
- A context in which to make sense of the body of text
- An analytical construct
- An inferential process to answer each of the research questions, and
- Validating evidence

Bodies of text are the data to start the research, which, for this dissertation, correspond to formatted collections of the text students used to answer science assessment questions.

Answerable research questions using content analysis should concern phenomena unobserved within the context of the texts; should demand several possible answers; and should provide at least two ways of selecting answers. Assumptions about the context are of key relevance, as well as the analytical elements that provide rules to make inferences about the content text. As such, content analysis should be *validatable in principle*, which means that conclusions of a study can be valid as a result of what they express in relation to other potential forms of evidence. For example, if the results of this research show that a particular emphasis on certain experiences of

students is beneficial for developing certain scientific concepts, then other evidence observing the same sort of phenomena in similar contexts should show similar conclusions. This validation ‘in principle’ is also important when the validation in practice (related to the methodic collection of evidence about the studied phenomena) cannot be achieved with the current state of the analyses.

Content analysis provides inferences of an abducting kind; that is, it starts with rules and accepted assumptions (logical facts) about the data and provides an argument for cases that emerge from the exploration of the data given these rules and assumptions. An example of a case is ‘the bus is red,’ uttered by an observer in the corner of a street in a big city. A rule is something that would explain the situation, resulting from collection of data or assumption. For example, ‘buses running north-to-south are red’ (that is, given A—north-south buses = red—then B—‘the bus is red’—is possible). This abduction allows making a logical inference of an occurrence as explanation of another occurrence given the assumption of the ‘logical fact.’ In this case, it would be that ‘the bus runs north-to-south.’ Even if the bus is not running north-to-south, the consequence is the most plausible given the context. Because the logical facts and rules are given through analytical constructs, and can be stated in logical “if-then” relations of condition and consequence, abductive reasoning is applicable to texts by an external observer.

### **Corpus Analysis and Corpora**

Corpus analysis is the qualitative and quantitative inquiry about instances of language in large collections of texts (Gonzalez-Marquez et al., 2005). A corpus is defined as a:

[C]ollection of pieces of language text in electronic form, selected according to external criteria to represent, as far as possible, a language or language variety as a source of data for linguistic research (Wynne, 2005, p. 16).

There are some requirements for the electronic systems that allow creating and managing corpora. For example, corpus systems require functions such as capabilities to query a database of texts linked to metadata, as well as capacity to perform frequency analyses of keywords, adjacency of other linguistic units, registry of observations or comments and coding, and capacity for storing and informing data for statistical analyses.

As technical artifacts, corpora are not different from a retrieval system of text. However, there are some conceptual elements to consider when building a corpus. The design of corpora is fundamental for clarifying the assumptions about the function of language to be analyzed, and also allows for hermeneutical and observable data to have a valid linkage. That is, interpretation of content should be evidently related to actual and available text. Wynne (2005) proposed ten principles for building corpora, which include conceptual elements such as considering texts because of their communicative function, representative of the language chosen, and external establishment of the subject matter of the texts. I built corpora to explore students' language.

### **Study Design**

This study was an exploration of understanding students' embodied experiences by analyzing their written explanations about water phenomena in school-based science, in English. To describe the design of the study, I start with the context of the study, continue with a general description of the design, and detail components of content analysis described by Krippendorff (2004) in relation to the study. As I describe the design, I provide definitions of key terms used within the study, as well as procedures performed for analysis.

### **Context**

This study was conducted in a Southwestern U.S. urban location, using data from students attending sixth grade in four middle schools where their teachers were teaching units

about water. Three of the schools were from a public district and one was a charter school. I collected all the data during the academic school year 2012-2013. Statistical information about the public school district for school years 2010-2012 indicated that almost 21% of the students in the district were English Language Learners or had Individualized Education Programs (U.S. Department of Education, 2014). The three public district schools had a high percentage of students classified as English Language Learners and Fluent English Proficient<sup>3</sup> for the 2010-2011 school year (Table 1).

Table 1. Reported 2010-2011 School Year Statistics for English Language Learners (ELL) and Fluent English Proficient (FEP)** students in the schools where data was collected.				
School	ELL reported percentage	FEP reported percentage	ELL + FEP reported	Hispanic reported
School 1	1.6%	22.1%	23.7%	85.0%
School 2*	0.0%	0.0%	0.0%	18.0%
School 3	4.5%	10.5%	15.0%	53.0%
School 4.	17.8%	18.4%	36.2%	65.4%
* <i>charter school</i>				
**FEP students are those whose primary home language is different from English and have taken a mandated English proficiency test, scoring at “proficiency” level.				

### Data Sources and Sampling

I administered students a pre-instruction and a post-instruction assessment instrument, which prompted them to explain water phenomena. Students could answer questions online or on paper when computers were unavailable. To avoid the semi-controlled effects of instruction, I only considered pre-assessments for this study. I obtained all the data following Institutional Review Board protocols for research with human subjects.

The assessment instrument included 13 items as open-ended questions, clustered in five thematic groups and displayed in two forms. Clusters of questions in each theme related to topics

<sup>3</sup> Fluent English Proficient refers to students whose primary home language is not English and have taken a mandated test and obtained a “proficiency” score. Statistical reports for each school’s English Language Learners and Fluent English Proficient students from previous years are not available on the NCES web anymore (U.S. Department of Education, 2014), but were obtained before they changed their system (NCES, 2012).

such as groundwater, engineered systems, and water pollution and flow. The only difference between forms was the order in which the clusters appeared. Appendix A shows a sample of the assessment instrument. Metadata in the assessment included questions about student ethnicity and linguistic background. A total of 290 students took the pre-instruction assessment either online or in a paper-and-pencil format.

Given the exploratory nature of this study, I decided to select two questions providing different aspects of students' reasoning. I anticipated that students providing different lexical choices to answer the questions would suffice the criteria. To select these questions I performed word-cloud analyses on a sample of the data, searching for patterns on the frequency of words that indicated different foci in students' explanations. Using the online tool *TagCrowd* (Steinbock, 2014), I visualized the patterns that each question prompted, and selected two questions that showed distinct word clouds for inclusion in the sample. These two questions address two topics. The Puddles question addresses natural processes of water moving in the atmosphere and toward the ground. The Engin-systems question addresses the tracing of water through connected natural and human-made artifacts and systems. Figure 1 shows the two questions, including the word cloud visualizations I used as criteria for selecting them.

I sampled students using two criteria: one, I sorted students whose metadata information was incomplete out of the sample; and two, I sorted students who did not answer the two selected questions out of the sample as well. As a result, I included 268 students in the sample, each of whom had two answers. The final sample of students gave a total of 536 answers. In the remainder of this dissertation, I refer to individual answers to an assessment question interchangeably as *answer*, *explanation*, or *linguistic unit*, and to the two questions as Puddles and Engin-systems. I used these data to constitute the *bodies of text* described as one of the

conceptual components of content analysis, and to create a corpus, or formatted collection of texts.

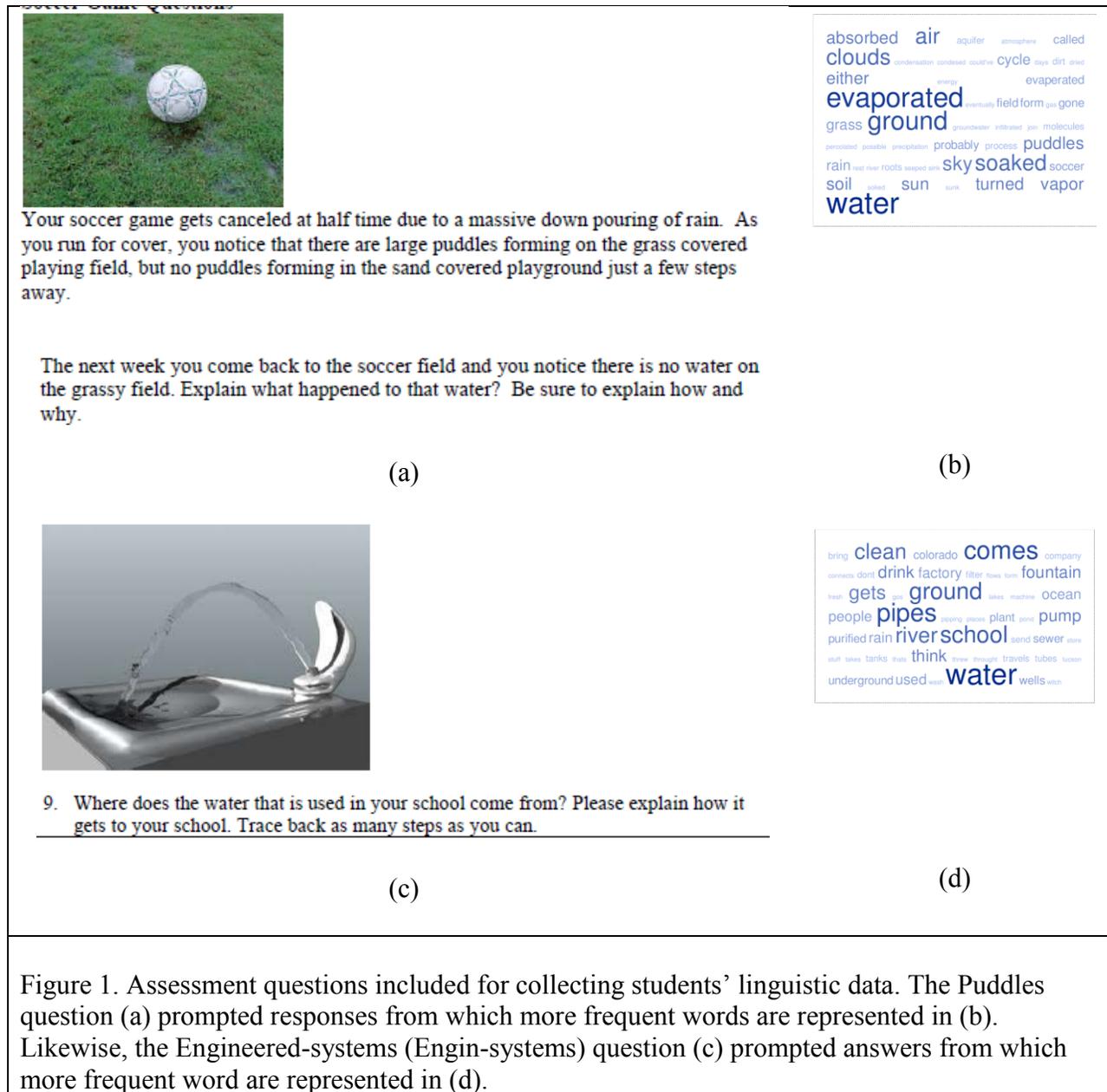


Figure 1. Assessment questions included for collecting students’ linguistic data. The Puddles question (a) prompted responses from which more frequent words are represented in (b). Likewise, the Engineered-systems (Engin-systems) question (c) prompted answers from which more frequent word are represented in (d).

### General Analytical Definitions and Descriptions

To explore the data, I examined each text using specific analytical criteria. These criteria are linked to the cognitive linguistic phenomena described in Chapter 2. I operated with these linguistic phenomena by creating initial coding schemes. Each coding scheme offered criteria for

assigning particular codes to segments of text in each linguistic unit. Therefore, *coding* is defined as the procedure for assigning a code to a segment of text within a linguistic unit. A *code* is a descriptor of some aspect of a cognitive linguistic phenomenon of interest. Because I explored several cognitive linguistic phenomena, including some that are not reported in this study, I performed several rounds of coding on the same linguistic unit using different criteria. From now on, I refer to each of the coding schemes associated to rounds of coding linguistic unit as a *coding layer*. I piloted these coding layers with a small sample of texts from previous databases until reaching coding layers that would reflect the most relevant categories in the data. In the next lines I refer to the connection between coding layers, coding procedures, and cognitive linguistic phenomena.

### **Coding Layers and Analytical Constructs**

I used four coding layers that relate to particular cognitive linguistic phenomena. Each coding layer is associated with a coding scheme that provides criteria for the inferences linked to the linguistic phenomena mentioned in Chapter 2. I performed the coding procedures using the software for corpus analysis and annotation of texts UAMCorpusTool<sup>4</sup> (O'Donnell, 2008). Below, I make some preliminary remarks about linguistic labels and describe the four coding layers: Role Configurations, Events Relationship, Spatial Orientation and Landmark Dimension.

### ***Preliminary Remarks***

Coding in search of cognitive linguistic phenomena requires a focus on semantical or conceptual analysis rather than grammatical structure. For example, consider the sentence *The water evaporated into the sky*. A grammatical analysis yields two structural elements, the subject: *The water*, and the verb phrase: *evaporated into the sky*. Differently, a conceptual analysis yields two *participant roles* connected by a relation that defines a *conceptual core*: *The*

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<sup>4</sup> The software can be downloaded from <http://www.wagsoft.com/CorpusTool/>

*water* is a theme (or <theme>), *the sky* is a goal (or <goal>), and the relation between these two roles is *evaporate*, which defines the conceptual core. I considered a <theme> as a participant role that defines the patient entity being talked about, while verbs represent a –relation– between the theme and other entities. Places, such as the sky in the above example, represent a <goal> participant role when interacting with a dynamic entity, or <location> when interacting with a static entity. I considered entities that perform an action, either sentient or not, as <agents>. I describe other examples of participant roles in the following subsections.

### ***Role Configurations and coding procedures***

This coding layer has two major sets of categories for coding. First, there is the coding of event schemas, adapting previous classifications of event schemas (Dirven & Verspoor, 2004; Radden & Dirven, 2007) and adding some of the elements that emerged from the pilot coding. Second, each schema organizes or structures a set of *participant roles*, or entities that participate in the students' explanations by means of semantical relations. Thus, I used this coding layer to analyze both event schemas and participant roles. The most important types of event schemas, and their associated participant roles, are:

1. Theme Relation Schema: This schema shows states or processes of entities whose roles are that of <theme><sup>5</sup>, establishing relations such as things *being true*, *resembling something*, or others *going wrong*. The important role to establish is the <theme> and a relation that gives meaning to what is being said about the <theme>. For example, in the sentence *The water evaporated* the event schema would be a Theme-Relation (T-(T)), and the <theme> is “The water,” with “evaporated” being the relation.

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<sup>5</sup> The notation for indicating semantical roles is to enclose them in <>brackets.

2. Location Schema (T-L): This schema describes the location of an entity, the <theme>. Therefore, two participant roles and one relation make the prototypical location schema. The roles in this schema are organized as <theme> – relation – <location>, as in *The box is in the car*, where the two roles are “The box” (<theme>) and “the car” (<location>).
3. Motion Schemas: Three categories of event schemas organize participant roles in terms of motion; that is, describing a change in an entity’s position or location. The goal schema (T-G), the self-motion schema (A-G), and the caused-motion schema (A-T-G). Within these schemas, the <goal> role represents an entity, abstract or physical, to which the <theme> or <agent> changes its location. Different from a <theme>, an <agent> is a role that actively participates in the change of motion, either for itself or causing the motion of a <theme>. For example, the sentence *It went from cold to warm* implies a moving schema where the <goal> is metaphorical (state) “warm,” and the <theme> is the indeterminate “It.” Additionally, this sentence has another participant role, the <source>, which in this case is also metaphorical (state) “cold.” In sentences like *The levers pumped the water to the roof*, the additional <agent> role of “The levers” relate to the <theme> “the water” and the <goal> “the roof.”
4. Possession Schema (P-T): This schema shows two roles related through a possession mechanism, the <possessor> and the <theme>, which is the entity possessed. This possession can also be in metaphorical terms and not just physical (e.g., as in *She had an idea*).
5. Perception or Cognition Schema (E-T): This schema highlights processes of thought and perception, or mental processes of someone in connection to the world. The role

- of <experiencer> is related to a perceived or thought of entity, the <theme>. For example, the sentence *I think the car was blue* shows the role of <experiencer> to “I”, while the <theme> is the sentence “the car was blue.”
6. Action Schema (A-T): This schema organizes two roles, an <agent> that acts upon a <theme>, as in *The ball broke the window glass*. In the example, “The ball” is construed as the causing entity of the breaking action upon the <theme> “the window glass.”
  7. Schemas of Circumstance, Cause, Reason and Purpose: These schemas organize situations where external conditions (Ev-Cir), causal entities or events (Ev-Ca), adduced explanations (Ev-Re), and attributed goals (Ev-Pu) are mentioned in relation to the occurrence of an event. For example, the sentence *The mother took the car to a mechanic to check the brakes*, organizes an event “The mother took the car to a mechanic” (caused-motion schema event) in relation to a <purpose> “check the brakes.”
  8. Existential Schema: When the construer of a situation signals the existence of an entity, such as in the sentence *There is a cycle where water runs through*, the existential scheme is present. In this case, the role <theme> is assigned to “There” and the relation is established with the role <other>, representing the existent entity, in this case, “a cycle where water runs through.”

The analysis of linguistic units using the *role configuration* coding layer permits visualizing several linguistic phenomena, including events schemas, force-dynamics, and conceptual metaphors. As exemplified above, events schemas can be explicitly coded as arrangement of participant roles within a student’s explanation of water phenomena. Force-

dynamics can be explored by attention to the agency attributed to certain entities explicitly coded as <agent>. Likewise, conceptual metaphors can be explored by analysis of participant roles for which an abstract nature is inferred, which I coded as <###/state>, where ### correspond to any of the abovementioned roles (e.g. goal, location).

### ***Events relationships and coding procedures***

This coding layer focuses attention on patterns of relation existing between events when presented in single or multiple forms within the linguistic unit. The coding scheme has four main categories: single event, events sequences, events likelihood, and other relationships. The single event category has two subcategories: ‘certain event’ or ‘likely event.’ A sentence like *The Sun dries up the clothes* fits the ‘certain event’ description of a single event category. A sentence like *The Sun might dry up the clothes* fits the ‘likely event’ description of a single event category. When a linkage of events is developed without any indication of possibility, I coded the answer as event sequences. For example, a sentence like *The car broke and I took it to the mechanic who charged me one hundred dollars*, consists of three events, coded sequentially. That is, event 1: “The car broke,” event 2: “I took it to the mechanic” and event 3: “[he] charged me one hundred dollars.” When there is an indication of possibility, the answer can be coded as events likelihood. For example, a sentence like *We could swim or lay on the beach sand* can be coded as two likely events, the first being “We could swim” and the second “[we] could lay on the beach sand.” Because some student answers can have more than one sentence, these codes are not mutually exclusive.

The coding I performed with this coding layer provided information about students’ conceptualizations of multiple events in an explanation. From the arrangement of these events I inferred patterns about students’ causal chains or causal attribution of phenomena.

***Spatial orientation and coding procedures***

This coding layer provides information about students' orientation of entities with regard to space. To do this, I used the categories *up*, *down*, *state/metaphorical*, *other* and *unknown* to texts which inferred meaning indicated either a location or a movement toward one of these directions. For example, in a text like *They were buried six feet under*, using this coding perspective I would assign the full text as a down orientation, given that the entity "They" is located in a down orientation in relation to a prototypical body posture, but also because of the preposition "under." Both lexicon and prepositions are indicators of orientation. In the above example, both the verb "bury" and the word "under" reaffirm the down orientation of the text. However, sometimes an orientation cannot be discerned. For example, the sentence *He went into a cycle of feelings* provides elements to think about physical movement, but the orientation of this movement cannot be ascertained by spatial means, even when a spatial preposition is present. Because the use of "cycle of feelings" is spatial, I consider segments of text like this as having a metaphorical orientation.

Coding for up and down spatial orientation provides information about students' use of the vertical image schemas in their explanations of water phenomena. Also, the realization of metaphorical elements in these spatial orientation permits describing conceptual metaphors present in the answers, making possible to connect the embodied experiences with vertical orientations to abstractions used by students in their answers.

***Landmark Dimensions and coding procedures***

This coding layer allows focusing on both the recognition of spaces where events and entities are to be found (landmarks) and the geometric form attributed to these landmarks by means of linguistic markers, such as spatial prepositions. Construed situations such as *The bus*

*stopped at the shopping mall* and *I was in the shopping mall buying clothes* express different geometrical properties of the same entity. In the first case, “the shopping mall” is referred to as a zero-dimensional entity, marked by the preposition “at,” while in the second case, the preposition “in” suggests “the shopping mall” as a tri-dimensional entity. With this coding layer, I explored how students conceptualize landmarks in terms of their dimensions. Given that geometrical properties of entities imply different schematic representations of the space they occupy, the Landmark Dimensions coding layer provides information about image schemas.

The relationship between the cognitive linguistic phenomena and the coding layers is presented as overall in Table 2. The table shows that each cognitive linguistic phenomenon can be explored in at least two coding layers.

Table 2. Relationship of coding layer to cognitive linguistic phenomena in explorations of student explanations.

Coding Layer	Analytical Category or Linguistic Phenomenon			
	Event Schemas	Force Dynamics	Image Schemas	Conceptual Metaphors
Role Configurations	X	X		X
Events Relationships	X	X		
Spatial Orientation			X	X
Landmark Dimension			X	X

**Coding Inputs and Outputs**

For each coding layer I applied to students’ answers there is a relationship to at least two linguistic phenomena of interest (see Table 2). The conceptual link to the crosscutting concepts or areas of scientific reasoning will be detailed in Chapters 4, 5 and 6. Because each of the research questions of this study deals with data that stem from the coding procedures described

above, I here provide a brief account of how the data is inputted in UAM CorpusTool and what are the most used outputs for secondary analyses.

First, I formatted each student answer as an individual text file, the name of which corresponds to the student id number. Then, I built one independent corpus for each of the assessment questions. Consequently, one corpus included the Engin-Systems questions text files and the other one the Puddles question text files. I performed four rounds of coding, one per coding layer, in each file for each of the assessment questions. In total, for this study I performed 2,144 rounds of coding (four coding layers, 268 students, two files per student).

Using the capabilities of the UAM CorpusTool software, I relied in two main forms of outputs. First, an output is the frequency of instances where each category in each coding layer was present in each linguistic unit. That is, for each student answer I obtained, how many text segments were coded as, say, up or down orientation? This output can be organized in a spreadsheet for statistical analyses and other calculations. Second, the UAM CorpusTool system can query and list all of the textual examples of a particular code, including the frequency when texts' contents coincided. For example, a query of all the texts coded as landmarks and their frequency can be obtained for understanding the lexical items that are more frequent in students' explanations using landmarks. I used these two forms of outputs as basis for all statistical computations.

### **Limitations of the Study and Validity**

There are several sources that limit the conclusions of this study. Some of these relate to the nature of corpus-based research, the nature of the data to be used, and the coding procedures. Validity issues in content analysis have been already discussed, and I provide some more insight into the validity of this study.

Corpus-based research has the limitation of looking only into segmented text, losing other aspects of the meaning-making processes, such as bodily expressiveness. Another limitation of corpora is that they do not directly present abstract linguistic patterns, such as intonations (see foreword in Gonzalez-Marquez et al., 2005). Despite these limitations, the inferential process described in this study is limited to the use of language in the context of school-written academic tasks, in which abstract linguistic patterns are less prominent. Another limitation of corpus-based research is the exclusion of linguistic units, or student answers, because of the design process that privileges well-formed linguistic units. In the case of this study, I selected student answers based on a criterion of completeness rather than syntactically correct answers. This way, the corpora I worked with includes certain components of language that provide a certain degree of naturalistic written student language.

In regards to the data used, I cannot assure that the texts will be representative of the whole set of naturally possible linguistic units to be found within the topic of explanations about water phenomena. This is not only a procedural limitation, but also a logistic one, given that the school-based data available for the study is triggered by a process of academic assessment, which constrains the possibilities of freely produced explanatory discourse. I have addressed this limitation by focusing only on open-ended assessment items, which increase the possibilities for student-produced language.

Coding is another potential limitation of this study. While corpus research pushes to be a collaborative effort (Grondelaers, Geeraerts, & Speelman, 2005), in this study I was the sole coder and maker of inferences. Given that this is a dissertation study, there is a practical constraint to including a second or third coder into the analyses of linguistic units as well as into the inferential processes that follow them. This limitation poses a reliability problem that I have

addressed by overlapping some of the linguistic phenomena to which each coding layer pays attention. At least in some respects, the analyses and outputs permit some correlations on independently coded but similar phenomena in order to judge the reliability of a sole coder. Despite this coding limitation, content methodologies are ample enough to include research done by an individual analyst interested in linguistic phenomena. Also, description of all coding procedures for other replications of the analyses is a viable way of addressing this limitation, as well as making the corpus available.

Finally, as mentioned before, the process of content analysis (through corpus-based research) should be validatable in principle. In this case, other inquiries about this type of data, in similar circumstances and addressing similar conceptual phenomena, should provide similar conclusions. Because this is validatable in principle, the design of other forms of inquiry into the same phenomena should be developed and tested against the results provided by this study.

The next three chapters provide more details on other methods of analysis, particularly, inferential processes associated to the scientific crosscutting concepts as presented in Chapter 2, and to answering each research question.

## **Chapter 4: What Embodied Experiences do Middle School Students bring to Understanding of Systems and Systems' Structures in Water Phenomena?**

In this chapter I report on my exploration of students' language regarding their embodied experiences for understanding systems and their structure. Student reasoning about systems and their structure is part of the crosscutting concepts emphasized by science education researchers for promoting scientific practices in K-12 schools (NRC, 2012). Defining a system requires an ability to recognize it and categorize it according to features that are salient depending on the problem addressed. In this dissertation study, I explored students' understandings of systems and their structure through the lenses of cognitive linguistics. As mentioned in previous chapters, the cognitive linguistic framework affirms that naturalistic language reflects cognition. The embodied cognition thesis holds that cognition is limited by the biological features of the human body, including perception and sensory experiences in the physical and cultural environment. In linking science education to embodied experiences, I focused on two main themes. First, I explored language to infer embodied experiences that students bring to classrooms in order to recognize and define systems. Second, I examined language for inferring students' embodied experiences that precede conceptualizations of systems' structures.

This chapter is organized as follows. I start with a description of the problem of study in relation to the literature about students' systems thinking. I follow with describing the research methods, including details about data analyses and inferential processes. I continue with the findings and discussion. I conclude the chapter summarizing the main points and signaling implications and possible avenues for future research.

**The Problem: Students' Embodied Experiences about Systems**

The problem of study relates to the embodied experiences that allow students to understand systems and their structures, as evidenced by linguistic patterns found in their writing of explanations of water phenomena. A first element to consider in the approach to studying systems is the definition of a system for purposes of scientific understanding. The academic edition of Encyclopaedia Britannica (2013) defines a system in physical sciences as a “portion of the universe that has been chosen for studying the changes that take place within it in response to varying conditions. A system may be complex, such as a planet, or relatively simple, as the liquid within a glass.” Likewise, scientists accept that systems are portions of the universe, as they define them in such form (e.g., Levine, 1978; Mortimer, 2000).

While students' thinking about systems has been reported in the science education literature, the definition of systems is implied. Several researchers have drawn attention to students' systems thinking, expanding our knowledge about students' forms of reasoning and developing several suggestions for teaching about systems and systems thinking. These researchers have provided implicit definitions of systems that are not clearly coincident with the view of systems as portions of the universe. For example, Ben-zvi-Assaraf and Orion (2005, 2010) describe a hierarchy of emergent characteristics of systems thinking in students' development of understanding, indicating that the starting point of the hierarchy is students' abilities to identify the components of a system. In addition, one of the emergent features of systems thinking is the recognition of processes within systems and relationships between a system's components (O. B.-Z. Assaraf & Orion, 2009). Because of their focus on complex and Earth systems, this perspective on systems thinking considers items like oceans, rivers, and other water places, as well as processes like evaporation and condensation, as components of a larger

system: the Earth. Orion and Ault (2007) affirm that systems thinking in science education is a key area of reasoning for understanding earth sciences. In this regard, they consider the Earth a complex system organized in cycles of different sorts, such as the rock cycle, the water cycle, and the carbon cycle, which they also regard as “systems.” Therefore, there are various forms of understanding systems that complicate how they should be taught for scientific learning.

Within all the definitional issues, the study of systems thinking in science education consistently shows students’ knowledge of systems to be at a ‘lower’ level because students only show evidence of identifying components of systems (Assaraf, Dodick, & Tripto, 2013; Ben-zvi-Assaraf & Orion, 2005, 2010; Kali et al., 2003; Orion & Ault, 2007). In the context of learning about systems in relation to water phenomena, Gunckel and colleagues (2012) found that most students identify familiar and visible connections among components of systems, and have difficulties in describing systems that are not visible (e.g. groundwater), or parts that are not visible (e.g., water vapor). While all the literature informs about important patterns in students’ knowledge about systems, the research has not paid attention to embodied experiences that might influence students’ understandings of systems.

Additionally, the mixed and non-explicit definitions of systems impact the conception of system structure. For example, the emphasis that Orion and Ault (2007) put on “cycles” as systems implies that conceptualizations of systems go beyond the mere physical components, including abstractions as systems. This view of systems extends the scientists’ definition of systems as “portions of the universe,” but might also provide certain degree of confusion. Beyond the physical structure of systems there lies another type of structure not yet explored in depth in the science education literature. Examples of these implicit distinctions of systems abound. For example, Niebert and colleagues (2012) constantly refer to the “conceptual system”

when discussing embodiment in science education. Other implicit systems identified in the literature are: *periodic system, word system, number system, symbolic system, solar system, environmental systems, human-engineered systems, biotic systems, drainage systems, water systems, ecosystems* (Gunckel, Covitt, et al., 2012; Niebert et al., 2012). Understanding the structure of systems has not been addressed in the science education literature, despite being an important aspect of current science education discussion (NRC, 2012). Because embodied experiences are influential in scientific understanding (Niebert et al., 2012), there is a need to describe empirically how these embodied experiences affect students' conceptualizations of systems thinking, particularly in terms of defining a system and describing the structure of systems. I explored these conceptualizations by attention to students' understanding of water phenomena. In particular, the research question I addressed for this chapter is:

- *What embodied experiences do middle school students bring to understanding of systems and systems' structures in water phenomena?*

In the next section I provide details about the methods I used to develop the inferences regarding answering this research question.

## **Methods**

As mentioned in chapter 2, cognitive linguistic phenomena are the primary basis for understanding embodiment and perception through language. In this section I describe the methods I used to develop inferences about students' embodied and perceptual experiences in recognizing systems and understanding their structure. I worked on the basis of the primary analysis undertaken in this study, which was the independent application of coding layers to students' answers (see Chapter 3). Students' recognition and identification of systems in relation to embodiment and perception is informed by the outputs of two coding layers: Role

Configurations, and Spatial Orientation. I paid particular attention to understanding student reasoning about systems through event schemas, image schemas, and conceptual metaphors.

Table 3 highlights the relevant relationships between coding layers and linguistic phenomena of interest in answering the research question.

Table 3. Relationship of coding layer to cognitive linguistic phenomena in explorations of student explanations. Highlighted cells indicate the focus of attention for the analysis of language in understanding students' embodied experiences in relation to systems and system structure.				
Coding Layer	Analytical Category or Linguistic Phenomenon			
	Event Schemas	Force Dynamics	Image Schemas	Conceptual Metaphors
Role Configurations	X	X		X
Events Relationships	X	X		
Spatial Orientation			X	X
Landmark Dimension			X	X

In my exploration, attributions of participant roles and event schemas inform students' conceptualizations or recognition of systems. Event schemas, image schemas, and conceptual metaphors inform students' conceptualizations of system structures. From these analyses, I inferred potential embodied and perceptual experiences that motivate students' conceptualizations.

In this methods section, I describe the analytical procedures for inferring students' embodied experiences relevant to recognition of systems, and the procedures for inferring students' embodied and perceptual experiences relevant to conceptualizations of system structures.

### Students Recognizing Systems

Two types of event schemas provided evidence about students' perceptions of systems as physical portions of the universe: the location event schema (T-L) and the moving event schemas. I explain the relationships of these event schemas to students' recognitions of systems.

I started examining the attribution of location and location event schema in relation to recognizing a system. The first identified linguistic feature of a system, as a portion of the universe, is its definition by a name. Semantically, a name establishes a shared reference frame for talking about an entity and its relation to other entities. Take the following example<sup>6</sup> answer to the Puddles question:

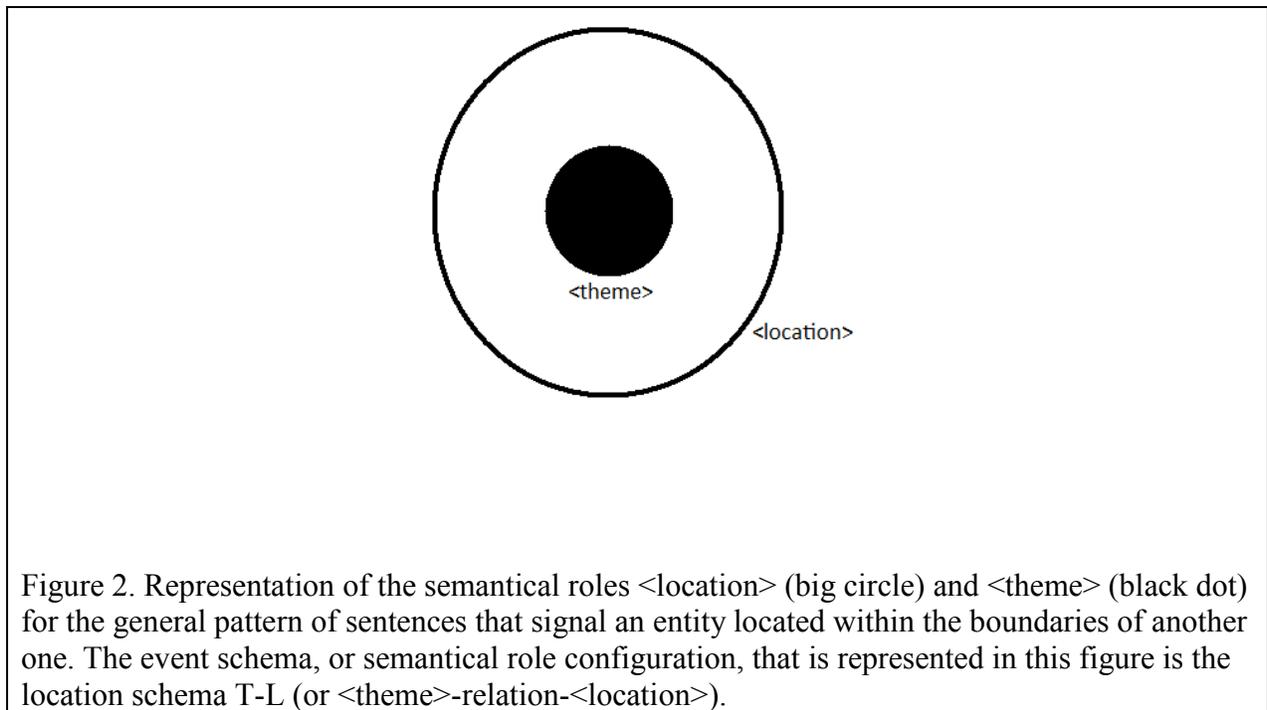
18. "The puddles that were on the grass drued out." [ID: 90313]

This answer invites to a couple of analytical remarks from the embodiment perspective. First, the student is establishing a connection of the entity "the puddles" to the portion of the universe "the grass." The "grass" is a name for a reference entity. The student is stating his/her perception of these entities. Because "the grass" is a portion of the universe brought to attention by this student in this explanation, I consider it a system for the purposes of this analysis. Second, "the grass" also provides a location for another entity, "the puddles." The semantical whole is an event that describes a state. I semantically assigned the roles <theme> to "the water puddles" and <location> to the segment "the grass." That means the configuration of semantical roles <theme> -relation- <location> in the segment "The puddles that were on the grass" constitute the arrangement of a *location schema* (T-L). A pictorial representation of this event schema is presented in Figure 2. Given that the <location> role indicates a reference entity that matches the criteria of signaling "a portion of the universe," I consider all text segments coded as

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<sup>6</sup> All student examples are presented as written by them.

<location> as conceptualized systems. As Figure 2 illustrates, in a T-L event schema, the <theme> is a constituting element of the <location> as a system.



As a second examination, another form of referencing portions of the universe is the dynamic arrangement of semantical roles. These events express processes rather than states. That is, one entity, (e.g., the <theme>) can interact with one or more locations in events where a motion of the entity is semantically noticeable or brought to attention. Semantically, these references work as destinations, paths or sources for a dynamic entity. To illustrate this idea of systems in dynamic descriptions, take the following two examples, both answers to the Puddles question:

19. “the water has evaporated” [ID: 23707]
20. “the water evaporated in to the air” [ID: 23514].

The first example (19) shows an intransitive form of the verb “evaporate,” which in this unit provides no linguistic evidence of conceptualization of systems as portions of the universe. I

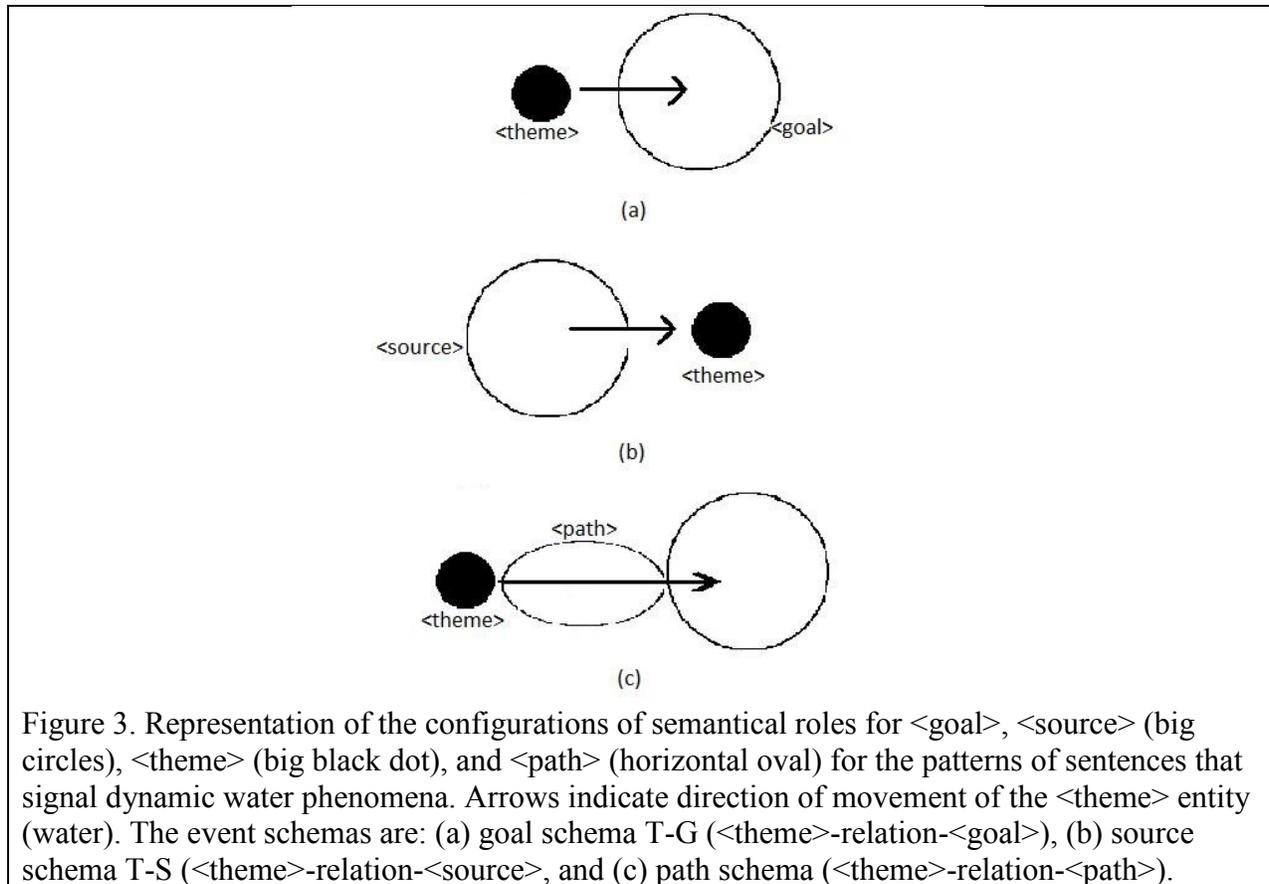
could not ascertain, from the roles expressed in the answer, to what location the water is evaporating. Differently, the second example (20) has an explicit text segment that signals a place to where the water moves, “in to the air.” In the analysis, I interpreted this type of text segments as <goal>, which is the semantical role attributed to locations to which an entity moves. I understood, from this evidence, that the student conceptualizes water moving to a “portion of the universe”—i.e., “the air”—different from the initial implicit one. This dynamic description of movement of water is not only limited to the recognition of <goal> entities, but also other entities that have a different role. Take this example answer to the Engin-systems question:

21. “it comes from the ocean and then goes through tubes” [ID: 10-23697]

In the example (21), the dynamic entity “it” is related to two events that highlight two other references: “the ocean” and “tubes.” The first one, “the ocean” is preceded by the preposition “from,” which signals the origin of the moving entity. This text segment, “the ocean,” plays the role of a <source>, the reference from which the moving entity comes. The second one, “tubes,” is preceded by the preposition “through,” which signals a path of the moving entity, towards a <goal> that is not explicitly stated in the answer. I semantically attributed the reference “tubes” a <path> role, which signals the intermediate motion between a <source> and a <goal>. These two roles—the <source> and <path>—represent two separate and discernable “portions of the universe” or systems. Therefore, I coded text segments that had the same type of structure accordingly and consider them students’ conceptualizations of systems.

In the previous examples, the moving entities, or <themes>, in interacting with <goal>, <source> and <path> entities, realize certain event schemas. Figure 3 shows a pictorial representation of the three isolated hypothetical (prototypical) situations or event schemas in the

case of references such as <goal>, <source> and <path>. These are moving event schemas: the goal schema T-G (<theme>-relation-<goal>), the source schema T-S (<theme>-relation-<source>), and the path schema (<theme>-relation-<path>). In the data of this study, these event schemas are representations of the basic semantical structures of the dynamic exchange of water among systems.



In addition to these moving event schemas, other schemas also include roles that represent systems. For example, the answer to the Engin-systems question:

22. “A water system send the water into the pipes.” [ID: 90414]

This answer shows a dynamic event that describes water moving somewhere else, but does not match the T-G event schema. In this case, the attributed roles are “the pipes” as <goal>, “the water” as <theme>, and “A water system” as an entity that exerts an action upon the

<theme>. I have coded segments like “A water system” as <agent>, because of its acting role upon another entity. This configuration of roles is an example of the caused motion schema (A-T-G). Other moving event schemas are illustrated by the examples:

23. “it slowly went to the ground” [ID: 07-26953]

24. “the water that is used in are school comes from the place of the toliet thay clean It all out and then give It to us!” [ID: 90524]

Example (23) instantiates the self- motion schema (A-G), where an <agent> “it” goes to a <goal>, “the ground.” The other example (24) illustrates the transfer schema (A-R-T), where “thay” (sic, interpreted as “they”) is an <agent> that transfers “It” (the water, <transferred>) to “us,” the <recipient>. In this latter case, I consider the semantic role of <recipient> as a “portion of the universe,” or conceptualized system. There are several other special cases of event schemas, but when the <goal>, <source> or <path> role were present, I considered the construals as moving event schemas.

Understanding students’ perception through these event schemas implies that both the location and the moving event schemas include in themselves linguistically discernable *portions of the universe*. Those portions are illustrated by the attribution of <location>, <goal>, <source> and <path> in students answers. Because of this, students are likely to describe systems as *perceivable* objects of study in the physical space, such as: “the grass,” “the ocean,” “pipes.”

A third examination for understanding students’ recognition of systems is the relation between their use of location schemas and moving schemas. Given that the system labels for describing static and dynamic relations, such as <location> and <goal>, are not mutually exclusive for one student answer, I was interested in understanding the likelihood that students’ explanations would use locations and goals altogether or not. That is, were students more likely

to describe systems in static rather than dynamic relations or events? To understand students' likelihood of using location or moving event schemas, I borrowed a tool from the assessment literature in Item Response Theory (IRT): *construct map* (Wilson, 2009). A construct map is an order of (qualitatively defined) levels of performance according to one particular characteristic (Wilson, 2009). These levels of performance are statistically defined by using IRT techniques (Wright & Masters, 1982), which allow considering not only the level at which a student performs in a certain task, but also the statistically calculated difficulty of the task, modeling predictions of student performance given these difficulties. In my study, I considered as a level of performance the total number of systems codes within a linguistic unit, limited to locations and goals. I created operational "items" or tasks by adding the location and goal semantical labels for responses to each question. As a result, I considered four operational items for the construct map: two for the Puddles question (locations and goals) and two for the Engin-systems question (locations and goals). The operational levels of performance are: 0 for no label, 1 for 1 label, 2 for 2 labels, and 3 for more than 2 labels. Using these criteria and tools for IRT analysis<sup>7</sup> (Wilson, 2004), I transformed linguistic inferences into information about the likelihood that students recognize systems and relationships to other entities in static or dynamic events, or both.

In the findings section I provide the results of these explorations of event schemas and roles, and indicate how these results inform findings about students' embodiment and perception in relation to recognizing systems.

### **Students' Conceptualizations of Systems' Structures**

To understand students' conceptualizations of the structure of systems and their relation to embodied experiences, I performed three sets of analyses. First, I explored conceptual metaphors among the system codes, which are signaled in coding by the roles of <location/state>

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<sup>7</sup> I use the software ConstructMap, downloadable from <http://bearcenter.berkeley.edu/software/constructmap>

and <goal/state>. I provide details about this coding below. Second, I searched for patterns in the set of entities students used as systems for explaining water phenomena. That is, I evaluated the lexical content of each text segment students provided as conceptualized systems (texts coded as <goal>, <source>, <path>, <location>, <goal/state> and <location/state>) and established categories of systems based on similarities. The third set of analyses implied operations on the coding of spatial orientations, as they relate to entities moving among systems; they provided information about systems' structures in space. Additionally, I performed an inferential analysis of spatial relationships using image schemas. These analyses of conceptual metaphors and image schemas inform students' embodied and perceptual experiences in relation to the structure of systems. Below I describe the details about each analysis.

### *Conceptual Metaphors*

Physical perception of systems can be used to extend the notion of system toward abstract ones. Systems that show the same linguistic properties of roles such as <location> and <goal> might have less discernable physical attributes. An analysis of location and moving event schemas could indicate students' conceptualizations of interactions between entities and abstract systems. Students can write about location when referring to physically unperceived entities.

Take the following contrasting examples:

25. "I no why thers no water no more because all the water that was on the grass dries up." [ID: 23517]

26. "The water evaporated. Some of it was sucked up by grass, but most of it is already in a gaseous state." [ID: 100145]

In the first example (25), the text segment "the grass" plays the role of a physical entity that provides a location for the <theme> "all the water." The second example (26) shows a rather

different view of location. The student is using the segment “a gaseous state” to locate the <theme> “most of it.” In this case, the “gaseous state” is *understood as* a physical space in which water can be located, realizing one of the conceptual metaphors widely described by Lakoff and Johnson (1980): STATES ARE LOCATIONS. I coded text segments that showed similar properties as <location/state>. While the location is not physically perceivable, the representation in Figure 2 applies as a guide to understand this text segment as the nominalization of a system, where “the water” is understood as being located in the location “gaseous state.” The “gaseous state” has the property of a system.

Similar to the <location/state> semantical role for describing abstract systems, goals also represent abstract systems. Take for example the response to the Puddles question:

27. “The water has evaporated and turned into continsation.” [ID: 23504].

In this linguistic unit, the text segment “continsation” (sic) represents an abstract space that is signaled by the preposition “into.” I interpreted that the student is conceptualizing an abstraction, the process of condensation, as a space that represents a system, realizing the conceptual metaphor: PROCESSES ARE LOCATIONS. I coded the text segment that followed this pattern as <goal/state>.

### ***Categories of Systems***

To develop inferences about students’ conceptualizations of systems’ structures through their lexical content, I examined all the text segments I coded as system roles and classified them into emerging categories of systems. The UAM CorpusTool software has a function for retrieval of text segments according to assigned codes. System codes were already described as <location>, <goal>, <path>, <source>, <location/state>, and <goal/state>. Through this categorization I grasped common elements defining the nature of the choices students make to

talk about systems when explaining water phenomena. The resulting categories provide clues about structures of systems as students use them.

### ***Image Schemas***

The coding procedures of spatial orientation provide a sense of how students locate entities' movements in a vertical direction. Image schemas inform about spatial properties of entities serving as references. I inferred up-down image schema in events where entities move. Take the following example, an answer to the Puddles question:

28. "some went back up in the sky, and the rest goes in the grass" [ID: 26966]

In example 28, the <theme> "some" shows two orientations to its movement: first, an up orientation, given by the segment "went back up in the sky," and second, a down orientation, given by the segment "goes in the grass." I coded an up orientation whenever I recognized similar segments, such as "into the sky," "into the clouds," "into the air," "from underground," given that the dynamics are moving *up*. In the same way, I coded as down orientation segments such as "soaked into the ground," "absorbed by the soil," "down the water," "goes to pipes underground." This way, I developed an inferential analysis of the orientation of systems and systems' categories through an organized hierarchy of systems in relation to the down-up orientation. This hierarchy highlights topological knowledge of systems related to experiences with the body.

In the next section, I describe my findings, resulting from my above-described explorations of student language.

### **Findings**

In this section I describe the main findings about embodiment and perception in students' conceptualizations of systems. I start with the analysis of students' recognition of systems. I

continue with students' understandings of system structure, linking them to embodied and perceptual experiences.

### **Students Recognizing Systems**

The main finding indicates that students tend to recognize systems as their explanations of phenomena are set in dynamic terms rather than static ones. Static relations means students using locations for entities that do not move, while dynamic relations means including locations (<goals>) for entities that move, or moving schemas. About one in five to one in four students conceptualize systems, “portions of the universe,” in static relations when explaining water phenomena. For the Puddles question, 19.78% of the 268 linguistic units had one or more <location> text segments, and 3.36% had a <location/state> text segment. For the Engin-systems question, 23.88% had one or more <location> text segments, while 4.85% had one or more <location/state> text segments. Chi-square comparison of distributions of student answers according to their number of location codes shows no significant difference between Puddles and Engin-systems ( $\chi^2(2) = 5.854, p = .05356$ ). In contrast, students' conceptualizations of systems in dynamic relations show that about two out of five students recognize systems when asked the Puddles question, while about seventeen out of twenty do when asked the Engin-systems question. I computed the frequency of students whose answers have one or more moving schemas for each question. For the Puddles question, 114 students (42.54%) used one or more moving schema, while for the Engin-systems question this number is 233 (86.94%).

That students recognize systems in static relations does not imply they do not recognize systems in dynamic ones. The coding of locations and moving schemas are not mutually exclusive. As the previous findings show, the analyses indicate students are more likely to provide dynamic rather than static relations. Additional evidence for this finding results from the

analysis of the number of systems through the Item Response Theory model to the static and dynamic system codes. This analysis provides students' likelihoods of describing phenomena in static or dynamic relations. The graphical representation of this analysis is a Wright Map. Figure 4 shows a Wright Map generated with the data of this study. The left side of the map is a histogram of the student distribution according to a measure of the aggregated likelihood of students to conceptualize one, two or more systems (in logits or units of difficulty, using ConstructMap jargon). The right side of the map shows each of the operational items in columns, for which three 'steps' are associated. The first step is represented by the blue square in Figure 4, and can be interpreted as the "jump" for students to conceptualize from zero to one system, while the green circle corresponds to the difficulty to conceptualize an additional system. The black triangle indicates the difficulty to conceptualize more than two systems within the same operational item. To compare how likely one student is to conceptualize systems as locations or goals (in moving schemas), the Wright Map needs to be read horizontally. For example, take the horizontal line at -1 logits in Figure 4 and compare across the operational items to the right. Less than 50 students are in the bar that shows their ability location in -1 logits. The Wright Map indicates that these students have a 50% or higher chance of not naming a location when answering the Puddles question, but have higher chances of naming one location in the Engin-systems question. Also, students in this ability range have a 50% or higher chance of naming one goal in both the Puddles and Engin-systems question. Therefore, students who conceptualize systems are more likely to do so in dynamic rather than static explanations of phenomena. The higher frequency bar (between -2 and -1 logits in Figure 4) shows that most students are likely to conceptualize at least one system in a dynamic explanation without conceptualizing a system in a static relation.

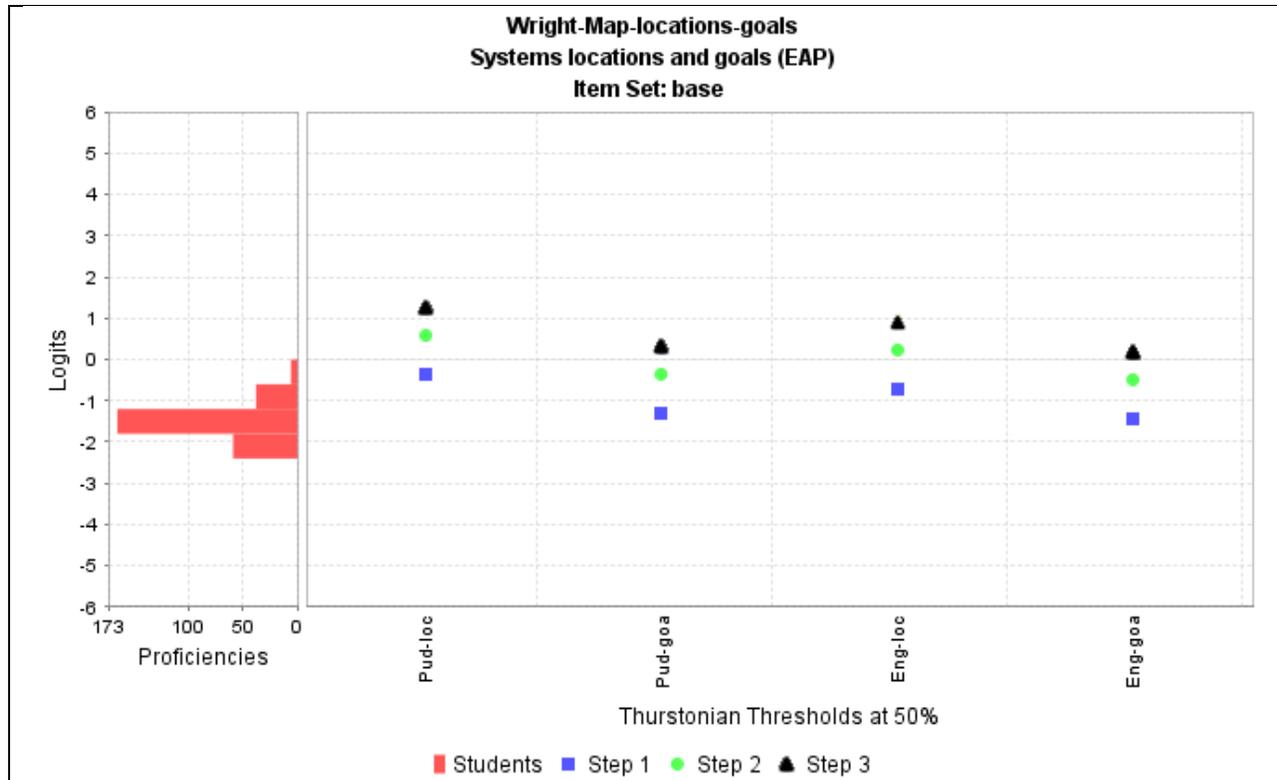


Figure 4. Wright Map of modeled student ‘steps’ for conceptualizing one, two, or three and more systems as locations and goals for answers to the Puddles and Engin-systems questions.

Summarizing, I have found that students explaining water phenomena are more likely to signal systems where water would move *from*, *through*, and *to* systems. Based only on the number of systems, I infer students not only are likely to conceptualize systems, but they do so in a way that indicates a germane understanding of the dynamics within and between them in relation to water. This finding is informed by the assumptions that a system is a portion of the universe, and the initial characteristic of students’ systems thinking is the ability to identify places. In addition, naming an entity whose semantical role is that of a location implies a cognitive process of defining some of its properties, which in this case implies the idea of physical boundaries and containment capacity. As such, students naming portions of the universe are conceptualizing some of the properties of systems.

### Students' Conceptualizations of Systems' Structures

A first finding in the exploration of students' conceptualizations of systems' structures is that students recognize systems sharing different structures. I deduced these structures from the analysis of the lexical content of the system codes, which relate to conceptual metaphors, image schemas, and other perceptual features. In total, 164 students (61.19%) made reference to at least one system code in the Puddles question, and 252 (94.03%) did so in the Engin-systems question. That yielded 250 system codes for the Puddles question and 686 for the Engin-systems. I analyzed each of these codes for its lexical content to group them under emergent categories of systems in iterative rounds of classification. These categories considered the reliance upon conceptual metaphors and image schemas. After several rounds, I found three major categories emerging as definitional criteria for systems, all of which include subcategories. The first category is *Topological* systems. Topology in this category refers to spatial relations of entities that represent systems. This category includes five subcategories: *Orientalional*, *Generic Ground*, *Invisible and Visible Atmosphere*, *Water Places*, and *Beyond Atmosphere*. Take for example the answer to the Puddles question:

29. "the water sunk into the ground and some of it almost avaperated into the air." [ID: 28267]

This linguistic unit (29) has two topological codes: "the ground" as *Generic Ground*, and "the air" as *Invisible and Visible Atmosphere*. *Generic Ground* illustrates systems that can be located in the ground as a space (e.g., "the soil," "dirt"). Likewise, *Invisible and Visible Atmosphere* groups system codes that can be prototypically located in the air or constituting the air (e.g., "clouds," "atmosphere"). Another subcategory in topological systems is the *Orientalional*, which I assigned to texts indicating the sole suggestion of a direction, such as

when students answer that the water went “up,” and “up” is coded as <goal>. The subcategory *Water Places* groups systems that suggest locations not readily asserted in direction, but generically understood, such as “oceans” or “rivers.” Entities such as “the sky” or “the sun” represent systems that are beyond the atmosphere, and as such are categorized as *Beyond Atmosphere*.

The second emerging category of systems is *Functional* systems. Functional refers to systems that have in themselves a function, attributed by interpretation. Take for example the answer to the Engin-systems question:

30. “Aquifers, rain goes through the Aquifers and into the pipes of the school.” [ID: 100108]

While I classified the text segment “the Aquifers” in a topological subcategory (Water Place, see above paragraph), I classified the text segment “the pipes of the school” as the functional subcategory *Human-Engineered* system. Likewise, I classified in the same category entities such as “the water fountain” or “the pipes,” which I have sorted as part of the functional subcategory *Human-Engineered*. I have also interpreted living organisms as functional entities (entities that live), and subcategorized them accordingly as *Biosphere*. Examples of text segments of the Biosphere sort are “the grass” or “us.”

The third emergent category of systems is *Abstract*. This category includes text segments whose lexical interpretations led me to consider them to not be directly or physically experienced, but are abstractly conceived. Abstract systems include the subcategories *Processes*, for text segments such as “condensation” or “the water cycle;” *Conditions-States*, for segments such as “water vapor” or “hot;” and *Time*, for segments such as “those days.” I used the category *Other* to classify entities whose meaning I could not assign to any of the above categories. Table 4 shows a heat map, a colored representation of the relative proportion of text segments

classified in each of the three major categories described above. Students provided significantly more references to topological systems in the Puddles question, while they provided more reference to functional systems in the Engin-systems question ( $\chi^2(3) = 204.881, p \ll 0.01$ ).

Table 4.

Heat map for distribution of codes according to major system categorization of text segments.

<b>System</b>	<b><i>Puddles</i></b>	<b><i>Engin-systems</i></b>
<b>Topological</b>	59.60%	14.87%
<b>Functional</b>	26.80%	74.05%
<b>Abstract</b>	8.00%	5.69%
<b>Other</b>	5.60%	5.39%

Having described major categories of systems in students' answers, I examined the structure of some of these. First, I have found that the abstract structure of systems is related to the conceptual metaphors that realize them. The data in this dissertation suggest students used the conception of *location* to understand abstractions such as processes and states. These are between 5.5% and 7.0% of the total systems' segments (Table 5). Two conceptual metaphors emerge from this analysis: PROCESSES ARE LOCATIONS, and STATES ARE LOCATIONS. For example, see the answer to the Engin-systems question:

31. "It comes from rain then put in a cycle that makes it fresh. The people that work with the water have a system to put water in the school water fountains." [ID: 23701]

This unit informs the use of the conceptual metaphor PROCESSES ARE LOCATION, where I coded the segment "a cycle" as a <location/state>, which I later classified as representing a process. In the example, I consider the *cycle* to be a system, not a physically perceivable entity, but an abstraction that exists because of the use of the conceptual metaphor by the student. A

way to compare this interpretation is to observe the segment “the school water fountain” in the same example 31, which is conceptualized as a physically perceivable location where water is put.

Table 5.

Heat map for distribution of codes according to system categorization of text segments. Green colors show relative higher frequencies, red color lower frequencies, and yellow intermediate frequencies for each question.

System category	System	Engin-systems	Puddles
Topological	<b>Orientalional</b>	3.06%	5.60%
	<b>Generic Ground</b>	9.18%	26.80%
	<b>Invisible and Visible Atmosphere</b>	2.19%	18.40%
	<b>Beyond Atmosphere</b>	0.44%	8.80%
	<b>Water Places</b>	16.18%	6.00%
Functional	<b>Biosphere</b>	1.46%	19.60%
	<b>Human-Engineered</b>	56.41%	1.20%
Abstract	<b>Process</b>	1.02%	1.20%
	<b>Condition-State</b>	4.52%	6.40%
	<b>Time</b>	0.15%	0.40%
	<b>Other</b>	5.39%	5.60%

Second, another source of difference in systems’ structures is their spatial orientation. Spatial orientation coding is informed by image schemas. The findings suggest that perception of *up* and *down* seems to be an important organizer of systems’ structures in students’ answers. In general, I found that 193 students (72.01%) indicated some orientation in their answers to the Puddles question, while 95.15% did so in the Engin-systems question. I coded 236 orientations in the Puddles question and 369 orientations in the Engin-systems question. Table 6 shows the percentage distribution of codes for up, down, metaphorical, and other orientations, considering as a base all the text segments.

Table 6.

Percentage distribution of text segment codes according to the spatial orientation coding layer and question. Values in parenthesis are frequency counts.

	Up	down	metaphorical	other	no direction or location
Puddles	(52) 16.88%	(119) 38.64%	(16) 5.19%	(49) 15.91%	(72) 23.38%
Engin-systems	(100) 26.32%	(42) 11.05%	(17) 4.47%	(210) 55.26%	(11) 2.89%

The results indicate that up and down orientations constitute over 50% of the text segments for the Puddles question, and over 31% for the Engin-systems question. Both tables 4 and 6 show that functional systems do not explicitly indicate orientation. Therefore, it is likely that segments coded as “other” in orientation would correspond to functional systems or *Water Places* in the system categories, unless they indicated an up or down orientation.

Image schemas, in their vertical association, are emergent in the organization of topological systems in the full set of students’ answers. As Table 4 showed, topological systems are relatively frequent in the students’ answers. Table 5 shows a heat map of finer grain categorizations, providing distributions among the internal categories of systems. From these results, the distribution for the Engin-systems question indicated the relevance of *Human-Engineered systems* and *Water places* for explaining water phenomena, and also, that topological systems are more important in the Puddles question. In both sets, a decreasing order of frequency is observed among the three most important topological categories: the *Generic Ground*, the *Invisible and Visible Atmosphere*, and the *Beyond Atmosphere* systems. Given this result, I suggest that the up-down orientation or image schema is a relevant pattern of experience that organizes one aspect of students’ conceptualizations of the structure of systems in space.

Finally, another important form of students' recognized structure of systems is the functional category. Table 4 shows that students conceptualize functional systems in higher frequencies when answering the Engin-systems question. Table 5 shows that human-engineered functional systems are more frequent in the Engin-systems, while living systems (biosphere) are more frequent in the Puddles question.

The findings above show some relevant patterns in students' conceptualizations of systems' structures. That is, systems seem to be structurally conceptualized by notions of systems as processes and as states or conditions; in topological organization in the up-down or vertical direction; and by perceptions of functionality. These inferences are supported in my inferential analysis of lexicon, and by the link to image schemas and conceptual metaphors.

The findings about students' recognition of systems and conceptualizations of their structure lead to a discussion about the most relevant embodied experiences that could motivate these conceptualizations. I discuss the findings in light of relevant literature and inferences regarding embodied and perceptual experiences in the following section.

## **Discussion**

Throughout the above text I have driven attention to students' linguistic patterns as they reflect embodied and perceptual experiences for recognizing systems and understanding their structure. In this section I provide a focused discussion of the connection of my findings to embodied and perceptual experiences, as well as the connection to what the field knows from previous research.

The evidence I have presented in this study indicates: i) students recognize systems in dynamic relations rather than static ones; and ii) students recognize at least three types of structures of systems.

The primary understanding of a system in science stems from defining the system as a portion of the universe with the purpose of studying its properties, its content, and the relationships within as processes or states. The perceptions of portions require in turn the perception of boundaries that delimit where the portions are to be recognized as such. This specification is explicit in the identification of *systems and systems models* included in the *Framework for K-12 Science Education* (NRC, 2012, p. 84). There is no doubt that children at middle school age had accumulated a broad range of perceptual experiences to define boundaries, from the walls of a cup to drink water, to the fence that surrounds a home or school, to the frame of a television screen or the markings on a sports field. With body locomotion, the boundaries of certain systems can be overstepped and other systems and their boundaries can be perceived. Crossing the street, stepping *into* the intersection and back *into* the walkway, or coming *out of* a store *into* the street and back home, are all experiences that are likely lived by middle school age students and younger. In this chapter, I provided inferences to support the assertion that students' explanations of water phenomena in dynamic forms lead to recognizing more systems as one entity interacts with them. Figure 5 shows a representation of the semantical role arrangements for static and dynamic (moving) schemas and the percentages of students who answered using each arrangement. This result suggests that fruitful attention to students' dynamic experiences about perceiving and defining boundaries is an opportunity for students to learn to recognize and define systems for scientific understanding of them. Therefore, these results point to locomotion and perception of change in physical location—two embodied experiences—as playing an important role in what Ben-zvi-Assaraf and Orion (2010) considered to be the initial step in students' development of systems thinking.

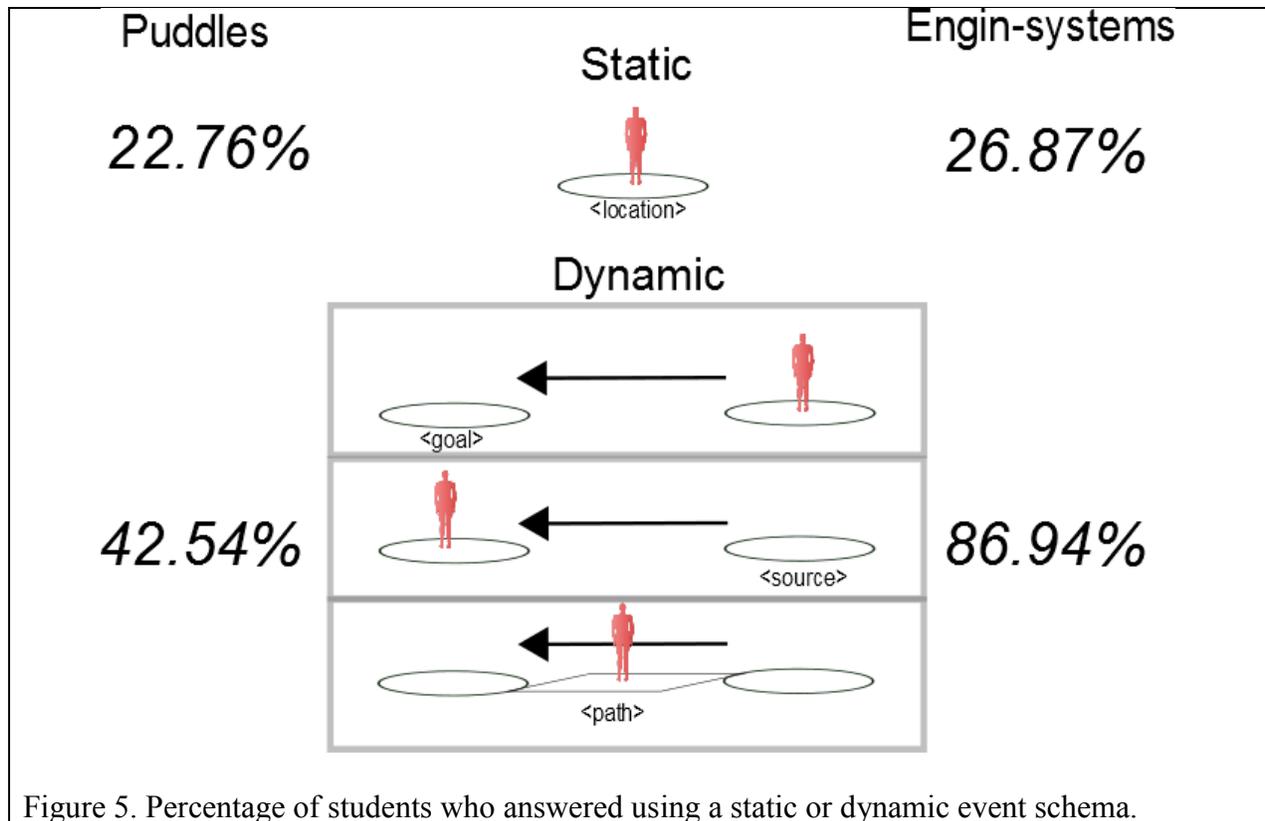
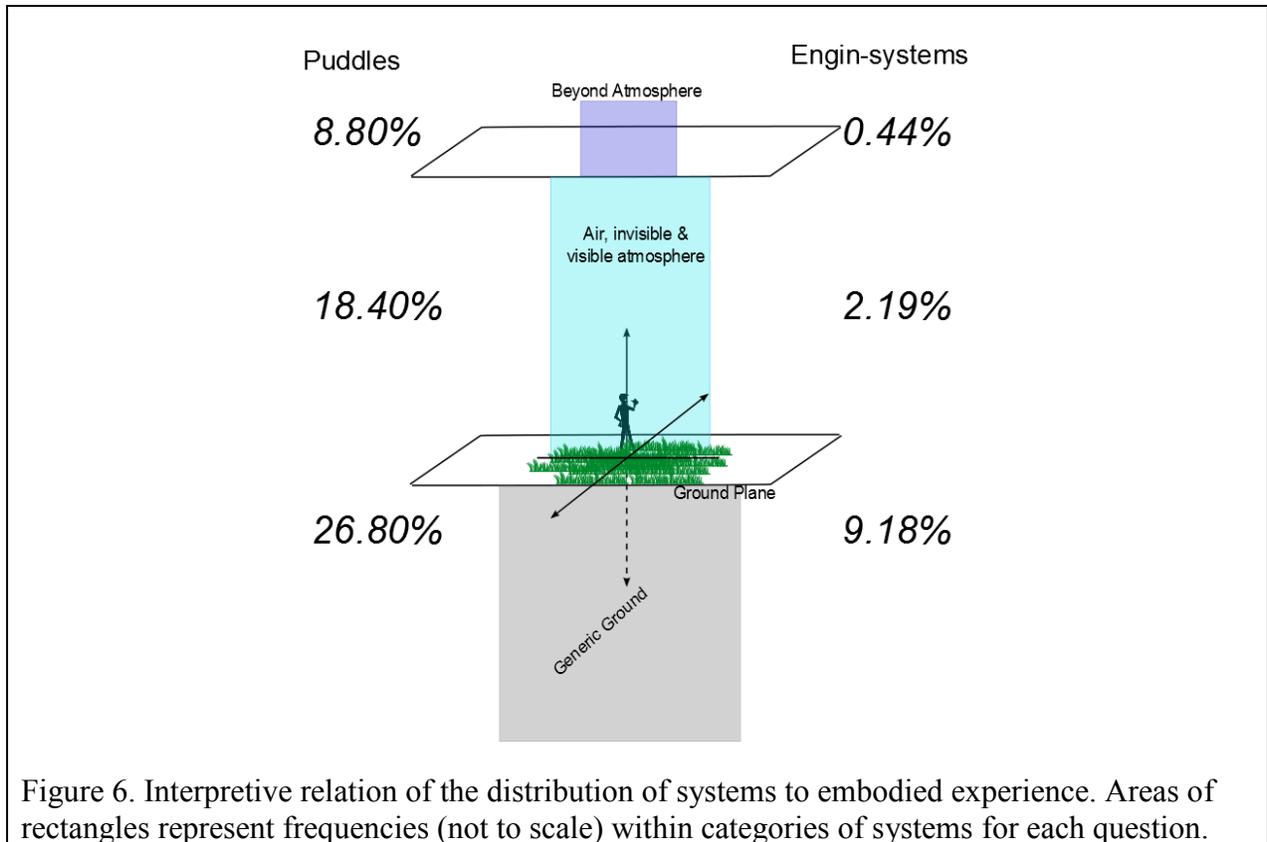


Figure 5. Percentage of students who answered using a static or dynamic event schema.

The systems included in students' explanations of water phenomena have different natures, which influences their structure. In this study, I have inferred students indicating three main forms or categories of systems: topological, abstract, and functional. Three forms of topological systems can be hierarchically organized along the vertical direction in relative decreasing frequency: Generic Ground, Invisible and Visible Atmosphere, and Beyond Atmosphere systems. In regard to embodiment, this finding reveals a pattern: the closer a system is to the prototypical location of the human body, the more frequent the conceptualization of the system by the students when explaining water phenomena. Students tend to recognize systems that are likely closer to their own bodily experience, and consider less the systems that are physically beyond their embodied perception (even when they can be perceived, such as *the sky*).

Figure 6 illustrates the ways in which students organize topological systems by highlighting the relationship of the body with some of the systems.



In the case of vertical orientation, the body relationship to the system types can be interpreted in several ways. First, the body can experience the ground directly by physical (tactile) exposure (touching, feeling the ground), equilibrium senses (standing or walking on the ground), and visual perception (distance, landscaping). Second, the body can experience the atmosphere as a system by tactile exposure as well (feeling the air and some components within), and visual perception (observing clouds, smoke, precipitation). And third, the body can normally experience beyond atmosphere only by visual perception or cultural exposure to models (the sun, the moon, the stars and planets, the sky, the solar system model). These opportunities for embodiment and perception in relation to the distribution of topological systems suggest that the

more opportunities for embodied experience a system has, the more likely it is that the system be part of students' sense-making of scientific phenomena. Attention to this vertical orientation is part of the argument for embodiment to understand science (Niebert et al., 2012), and I propose it as an important aspect to consider in students' experiences in order to recognize properties of physical systems that participate in water phenomena.

Perceptual experiences for defining and understanding a system's boundaries and embodied locomotion for understanding dynamics associated with systems provide the base for abstractions, which are relevant for science, and therefore, science education. In this chapter, I have provided linguistic evidence pointing to students' understandings of systems in abstract forms. I have highlighted how students use linguistic formalisms to talk about abstractions as physical locations. Conceptual metaphors such as STATES ARE LOCATIONS or PROCESSES ARE LOCATIONS are evident in a small percentage of students' references to systems. Researchers who study systems thinking use these metaphors to refer to systems as well, evidencing the ubiquitous nature of conceptual metaphors. Take the following examples, taken from studies regarding students' systems thinking:

32. "The rock cycle is a system including the crust of the earth, which is characterized by a cyclic and dynamic nature" (Kali, Orion, & Eylon, 2003, p. 546).

33. "the water cycle is a complex system" (Ben-zvi-Assarf & Orion, 2005)

Being that a system is a portion of the universe, both examples (32 and 33) showed implicit definitions of systems that realize the conceptual metaphor: PROCESSES ARE LOCATIONS, accepting also that SYSTEMS ARE LOCATIONS. These metaphors imply that the experience of a location is mapped into experiencing a symbolic representation of a process, which in turn is considered to be a system. Therefore, a meaningful understanding of the

structure of a system in terms of abstractions (such as a cycle) might require relevant embodied experiences with the source conceptual domain (system-locations). This perspective is different from the conclusions drawn by other researchers in systems thinking, who suggest teaching through studying “natural cycles” as they influence daily life (Ben-zvi-Assarf & Orion, 2005).

The structure of systems as abstractions is symbolic or representational in nature, and benefits from image schemas such as the *containment schema* and the conceptual metaphors already mentioned. For example, two segments illustrate this containment schema:

34. “it sank into ground” [ID: 07-28288].

35. “[water] put in a cycle” [ID: 23701]

In both cases, the students use a containment schema to organize the relationship between water and the perceived limits of the systems. The first container (34), “the ground,” can be perceived and at least one boundary can be physically defined only by perception. The second system (35), “a cycle,” also has the properties of containment, but in this case, the limits are not physically perceived and seem to be symbolical and representational. That is, they require a cultural experience to be considered a system, but still emerge, as structure, from direct experience with containment. Experiences with containment are built upon since infancy, and include the use of artifacts such as bottles, glasses, pots and pans, and backpacks, as well as the mobility to enter places such as rooms, vehicles and buildings. Students are likely to have extensive embodied experiences with physical containment, and the structure of abstract systems built upon these experiences signal elements of systems that are culturally constructed and relevant for scientific understanding.

The findings of this study affirm that embodied and perceptual experiences with motion, space, function and abstractions are important for scientific understanding of systems, as well as

for developing systems thinking. Orion and Ault (2007) consider that higher levels of systems thinking implies the use of abstractions that describe dynamic understanding of components of systems. The researchers suggest that dynamic relations in complex systems are represented by cycles, which they regard as systems as well. I have observed in this literature about systems thinking in science education a combination of undifferentiated references to physically perceived and symbolical systems; the latter are regarded as ‘higher’ level systems thinking. That is, the literature on systems thinking, as symbolic representations of complex phenomena in cycles—also called systems—confusingly presents systems as both physical entities (in the sense of ‘portions of the universe’) and abstractions (in the sense of ‘processes’ and ‘cycles’). The conceptual differentiation of systems in embodied and perceptual experiences and systems as symbolically represented entities can benefit the development of systems thinking in students.

Finally, another indicator of system structure and nature is related to perceptual properties of functionality. In this study I had shown that functional systems are frequent in students’ answers. The cognitive motivation for recognizing the functional structure of systems has not been addressed as such in the science education literature that examines systems thinking. The structure of functional systems might depend on perceptions of established purposes beyond embodiment (e.g. structures and artifacts), or purposes inherent to natural systems (e.g. living organisms). One possible indication about students’ motivations to understand systems as functional is the discussion of functionality coming from the field of engineering. For example, see Winsor and McCallum (1994) discussing functionality:

Concepts of function and functionality are ubiquitous in design. Any textbook will emphasize that design exists to satisfy some needs, and that the process is therefore driven by an aim of specifying an artifact which will achieve some purpose or function. It

will also make clear that as the process depends on being able to anticipate some future reality, it is necessary to be able to predict correctly how a design functions. (p. 163)

In this case, a design is an engineered entity—a system in my interpretation. The functional structure of the system depends on the purpose; thus, understanding a functional structure requires an experience where purposes are defined. Arguably, a purpose can constitute an embodied experience that provides relevant patterns for understanding the functional structure of a system.

In this study I have shown that students use ‘designs’ for indicating human-made structures (e.g., school, water plant) and engineered artifacts (e.g. faucet, water fountain), and that, expectedly, these are more frequent in the Engin-systems question. I have also shown that students refer to living organisms as entities that interact with water, either as a location or goal. Based on the definition of functionality (Winsor & MacCallum, 2009), I suggest that students’ access to judge the functionality of an entity might be a result of sensorial and perceptual representations embedded in cultural experience and requires further discussion. For example, to judge the function of pipes in water phenomena, students need access to perceptual experiences such as pipes in a house or a building. The function (or assigned purpose) of the pipes in these perceptual experiences is established, for example, as students interact with the need of transporting water in urban spaces. While the need for water is embodied (all humans feel thirsty), the need for pipes depends on a cultural experience.

## **Conclusion**

This chapter contributes elements and a novel perspective for studying students’ conceptualizations of systems and their structure. I proposed attention to embodiment and perception when describing both the recognition of systems, their dynamics, and their nature or

structural features. I have found that students use mostly embodied locomotion, including the perception of boundaries and changes in location, to recognize systems. Also, I have found that the perception of space in the vertical orientation (up-down), embodied locomotion, and the perception of purpose are key experiences that allow students to categorize systems and define their structure. The evidence is limited to generalizations by the context of studying only middle school students and by studying only the topic of water. There are also limitations to the proposal of embodied and perceptual experiences, which are inferential in this study. Therefore, this study should not be considered about particular embodied and perceptual experiences, but related to the features of embodied and perceptual experiences that explain certain patterns of linguistic organization of students' explicit and implicit knowledge about systems in water phenomena. Future research could explore two avenues to empirically support the claim that understanding science needs embodiment (Niebert et al., 2012). First, research could seek to understand the explicit links that students make from their embodied and perceptual experience to their understanding of systems and their structure. Second, the development of design-based research (Collective, 2003) could test differentiated embodiment-based learning experiences to develop theoretical and applicable models for teaching about systems and their structure in relation to embodiment and perception.

**Chapter 5: What Embodied Experiences do Middle School Students bring to Understanding Scale, Size and Representations in Water Phenomena?**

In this chapter I report on my exploration of students' language for their embodied experiences in relation to scale, size and representations. In explanations of phenomena, size and scale are influential to describe relevant changes that affect a system structure or performance. Size and scale also affect the shape of objects or living things, including its substructure, which determines many of its properties and functions (NRC, 2012). As the *Framework for K-12 Science Education* (NRC, 2012) suggests, scale and size are a topic of attention for developing understanding of science, including water phenomena. The concepts of scale and size are areas of reasoning closely tied to representations. I explored the links between embodiment and scale and size by examining students' choices of lexical items as reference entities in explaining water phenomena in light of projective scales. I also explored the links between embodiment and representations by examining the geometrical properties of these reference entities.

I organized this chapter as follows. I first describe briefly the problem of study and its history, and provide the rationale I developed for studying embodied experiences in relation to scale, size and representation. I then describe the methods or analytical procedures I performed for each of the sources of evidence. I end the chapter with the findings, a discussion on embodied experiences, and the conclusions of this section of my dissertation study.

**The Problem: Students' Embodied and Perceptual Experiences in relation to Scale, Size and Representations**

The problem of study is related to understanding students' conceptions of scale, size and representations through linguistic evidence. Several researchers have studied and evidenced the importance of studying scale, size and representations for fostering student learning in science,

and particularly about water phenomena. The literature on students' understanding of scale shows that students have difficulties conceptualizing scales when they are set in symbolic terms (absolute, numerical, or logarithmic scales); that there are multiple forms of understanding scales; and that relative size comparisons are more accurately grasped than absolute sizes. For example, Dickerson and colleagues (2005) concluded that students had a wide range of ideas regarding the range of the size for groundwater structures. They found that a portion of students conceptualized underground pore size as larger than a basketball. Delgado and colleagues (Delgado, Stevens, Shin, Yunker, & Krajcik, 2007; Delgado, 2009) developed a study of children's conceptions of size and scale using interviews and card tasks in order to generate a learning progression about size and scale. Delgado's research provides empirical evidence about students discovering the 'unseen world' by organizing it through reference points or 'anchors.' Sederberg and Bryan (2009) piloted a study of students' progression in learning about magnetism, providing insights into how magnetic properties and behavior of materials are impacted by the scale (size) of their constituting particles. Gunckel and colleagues (2012) indicate that a model-based scientific thinking about scale and representations in water systems includes tracing water—and substances within water—at multiple scales, and using representations as scientific models for explaining and predicting events in systems, rather than just describing the physical world.

Researchers operate their studies of learning about scales with definitions that comprise scale as absolute or relative. One definition of scale refers to the conventional numerical representational system of size, such as linear scales and logarithmic scales (Swarat, Light, Park, & Drane, 2011). Dickerson and colleagues (2007) studied secondary and post-secondary students' development of relative relations between hydrogeological structures, and found

students' inaccurately define relations between the scale of underground water and the scale of perceptual surface structures. In several studies, researchers studying scale conceptualizations focused on the idea of accuracy of (spatial) scale for absolute and relative estimations. They found that relative scale conceptions are more accurate than absolute scale conceptions, and that measures of spatial visualization, logical thinking, and conceptualizations of size and scale of objects correlate, suggesting that individuals use an underlying, yet unknown, cognitive ability to reason about different scales (Jones, Gardner, Taylor, Wiebe, & Forrester, 2010; Tretter, Jones, Andre, Negishi, & Minogue, 2006; Tretter, Jones, & Minogue, 2006). Jones and colleagues (2010) studied students' conceptions of magnification, and reported that students' ability to magnify is correlated with measures of logical thinking and ability for spatial visualization. Swarat and colleagues (2011) studied undergraduate students' conceptions of size and scale, and proposed four categories of conceptions of size and scale that students hold: fragmented (conceptions of scale separated for each 'world,' such as microscopic, submicroscopic), linear (objects' scales corresponding with physical experience or visual observations of size), proportional (scale in terms of comparisons of object sizes), and logarithmic (magnitude transformation for comparing extremely larger or smaller sizes).

Larger or smaller scales are linked to their modes of representation. Understanding what representations are poses a challenge. Hayward and Tarr (1995) developed a study of commonalities between spatial language and visual representations, concluding that the structure of visual representations might determine the linguistic encoding of space. Harvey (2005), in the context of discussing computer science and artificial intelligence, wrote about representation as "the concept of symbolic reference" (p.122). He explains that representations work by holding the assumption that "symbols are entities that can 'stand for' objects in the real world" (p. 122).

The limit to this view of representations, according to Harvey, is the level of explicit or implicit agreement among many “observers of the world” regarding the symbolic elements used that define the represented world. Concepts and what they represent can also be viewed in terms of a triadic relationship between the concept, a signifier, and a referent (Hubber, Tytler, & Haslam, 2010). For example, a concept such as ‘gravity’ is signified by the description of gravity; that is, that ‘all bodies attract to each other with a force that depend on their mass.’ The referent for this concept and its signifier is the experience of falling objects. Bruner (1966) extensively discussed the role of representations as models of experience. He explained three ways of representing experience: enactive, iconic and symbolic representations. The enactive imply representing experience through action, when words and imagery are not enough to make sense or construct a model of experience. For example, a gymnastics or circus act requires some degree of activity to be fully represented and become a model of experience. Iconic representations depend on visual and sensory organization; that is, patterns or paths that are organized through images or icons. For example, traffic signs are iconic representations. Symbolic representations constitute, for Bruner, the hallmark of words and language. He described symbols as arbitrary, remote in reference, and generative in the sense that they allow representation of action and events in the world and beyond by the use of governing rules (e.g. grammar).

Representations in science education have been extensively studied. Researchers agree that using symbolic elements (signifiers) for representations can be understood as practices, or “literacies of science,” where representations are seen as a necessarily multimodal; that is, requiring multiple forms of signifiers (Hubber et al., 2010; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Tang & Moje, 2010). There are also indications that symbolic representations are important in developing scientific reasoning. For example, Tytler and Prain (2007) found that

students' familiarity with representations of the water cycle influenced their understanding of pictorial elements at the molecular-level representations of evaporation. That is, in changing the scale of the representation, from the commonly large scale of the water cycle to the small molecular scale, students had translated meanings of signs which might influence their understanding of scientific explanations. Tytler and Pain argue for considering representations as tools through which children explore their own ideas and understandings, rather than promoting standardized models of representations.

The literature reveals that students have difficulties in understanding scales, particularly at the symbolic level. Scale and size merge symbolic and physical comparisons, and representations imply a differentiation of meaning that potentially impacts the scientific understanding of phenomena. Niebert and colleagues (2012) developed a reanalysis of published work on students' ideas in science. They concluded that understanding of science needs embodiment, and suggest experientialism (see Chapter 2) as a helpful theory that explains why students hold certain conceptions in science and the role of experience in them. What is missed from the research about scale, size and representations in science education is an examination of the embodied resources students bring to understanding the symbolic elements that provide meaning to comparisons of scale and size. In this dissertation study I focused on the study of embodiment and perception in relation to scale, as it contributes knowledge about the cognitive resources students might draw upon to accurately or inaccurately conceptualize scales. I explore linguistic phenomena as representations of embodied and perceptual experiences.

To address the problem, I concentrated on students' uses of landmarks in explanations of water phenomena. Landmarks are terms or words that indicate a familiar entity for clear communication about situations or contexts (e.g., see Radden & Dirven, 2007, p. 48). Landmarks

provide an organizational structure to facilitate the location of adjacent points in space (Sadalla, Burroughs, & Staplin, 1980). For example, a park as a landmark derives attention to whatever is closer to the park (e.g., the southwest side of the park, the children's play area). Landmarks are entities of reference signaling another entity's location or dynamic path in relation to a shared context (Evans & Green, 2006). For example, tables in a restaurant provide references to a waiter or waitress for locating dinner guests. Previous studies about students' conceptions of scale in science learning have made use of landmarks to understand the accuracy of scale estimations in student cognition (e.g., Delgado, 2009; Tretter, Jones, Andre, et al., 2006).

For the case of this study, I only analyzed size, scale, and representations in spatial relations, including projections of space and geometrical properties of landmarks in relation to scale. I understand that other elements of scale include numerically represented systems, such as amounts of energy flow and time spans (NRC, 2012); however, this study is limited to spatial scales and representations. For this chapter, I asked the question

- *What embodied experiences do middle school students bring to understanding scale, size and representation in water phenomena?*

In the next section I explain the rationale and logical relations that allowed me to develop inferences about students' embodied and perceptual experiences in relation to conceptualizations of scale, size, and representations.

## **Methods**

The abovementioned view about size, scale and representations can be related to students' embodiment and perception. This link to embodiment and perception is driven by inferences through cognitive linguistic phenomena. Two important aspects to study are: first,

evidence about students’ use and scale of landmarks to explain water phenomena; and second, evidence about students’ attribution of geometric properties of landmarks.

I analyzed generic school science written explanations of water phenomena. None of the explanations asked students to explicitly address conceptualizations of scale, size, and representation. I developed qualitative comparisons, and inferential projections, between the human body and types of landmarks students use. As mentioned in Chapter 2, image schemas are patterns of sensorimotor experience that organize knowledge about space in situations of the world. I used image schemas to develop inferences about scale projections.

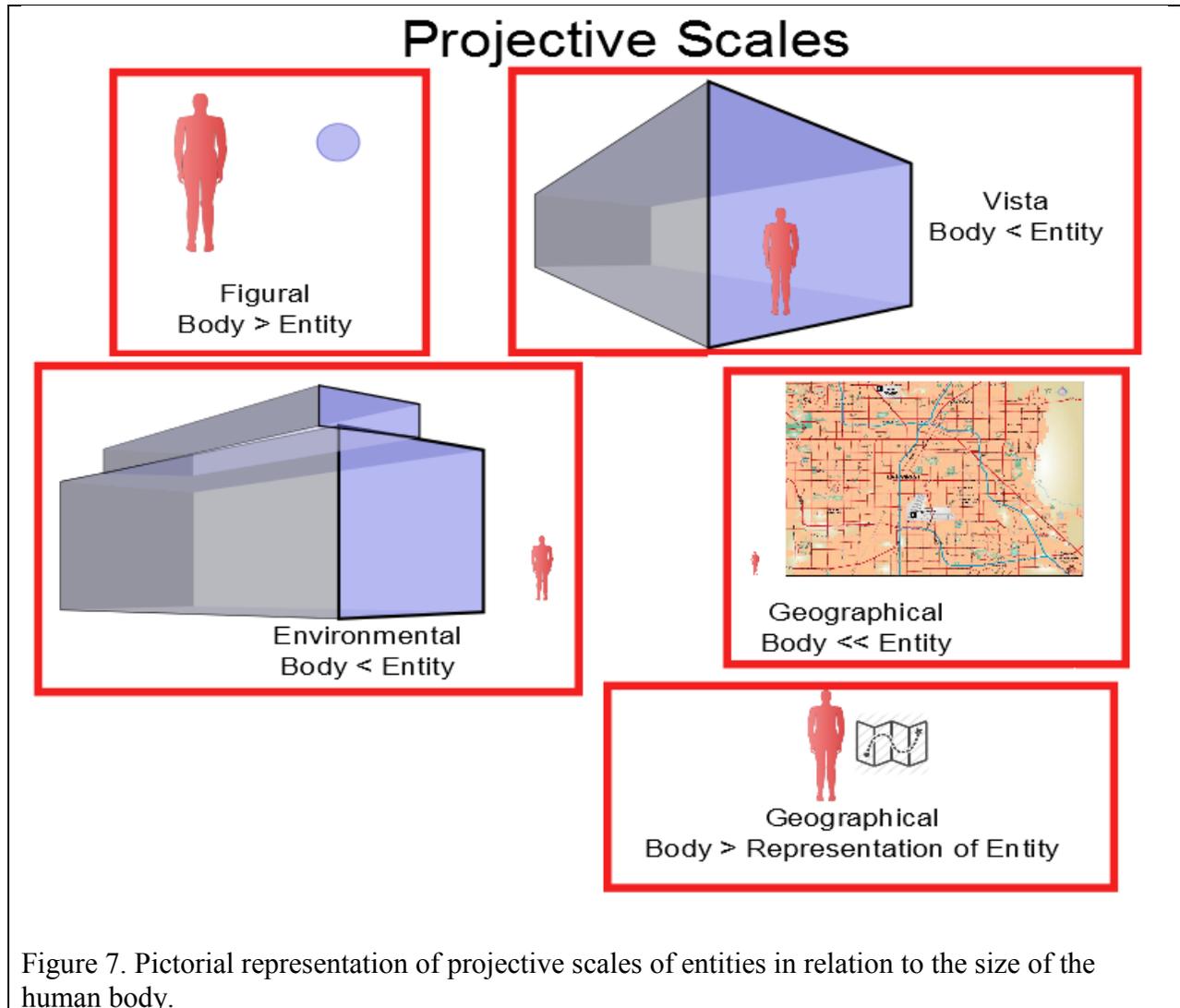
Through the application of the Landmark Dimension Coding layer (see Chapter 3), I analyzed both the characteristics of landmarks used by students in their explanations, and their geometrical properties given by image schemas (see Table 7). The outputs of this coding analysis were: i) two lists, one per assessment question, of linguistic terms deemed as landmarks by students in the sample, including their frequencies; and ii) a report of geometric properties (dimensionality) associated to each landmark. In the next subsections, I explain my inferences about embodiment based on procedures to these two coding outputs.

Table 7.  
Relationship of coding layer to cognitive linguistic phenomena in explorations of student explanations. Highlighted cells indicate the focus of attention for the analysis of language in understanding students’ embodied experiences in relation to scale, size, and representation.

Coding Layer	Analytical Category or Linguistic Phenomenon			
	Event Schemas	Force Dynamics	Image Schemas	Conceptual Metaphors
Role Configurations	<b>X</b>	<b>X</b>		<b>X</b>
Events Relationships	<b>X</b>	<b>X</b>		
Spatial Orientation			<b>X</b>	<b>X</b>
Landmark Dimension			<b>X</b>	<b>X</b>

### **Understanding Landmarks through Projective Scales**

Scales can be of two sorts: relative and absolute. Relative scales establish comparative relationships between entities, sometimes providing guidance about the magnitude of certain phenomena. Montello (1993) suggested four projective categories of scale in relation to perceptions of size in comparison to the human body. These are: Figural, Vista, Environmental and Geographical. *Figural scales* are smaller than the human body, and imply objects that can be manipulated without an appreciable change in position or movement of the body, such as small pictures, pens. *Vista scale* projects landmarks as larger than the human body, but still visually captured without moving the body, such as a single room, a train wagon. *Environmental scale* is also projected larger than the body and what surrounds it, but too large to be visually perceived without locomotion and time dedication. This is the space of a neighborhood and large buildings such as a school. *Geographical scale* is much larger than the body and cannot be captured directly by locomotion, but requires symbolic representations, such as maps or models, which in turn are at Figural scale. Cities, countries, and mountain ranges are examples of entities at Geographical scale. These projective scales provide an analytical perspective on the inferred perceptual size of landmarks in relation to the body. Using the projective scales to analyze landmarks in students' answers, I develop inferences about students' embodiment and perception in relation to conceptualizations of scales and size. Figure 7 shows a pictorial representation of the four projective scales.



A landmark is a spatial reference in students' explanations. Take for example the answers<sup>8</sup>:

36. "It went into the ground" [ID: 80409] (Puddles question answer)
37. "i think the water comes from the pacific ocean and i think it comes from connected tubes" [ID: 23707] (Engin-systems question answer)
38. "The water that was in the grass is gonr because it whent under ground to go to rivers and other water things." [ID: 05-23508] (Puddles question answer)

<sup>8</sup> All student examples are presented as written by them.

The first example (36) has one text segment I interpreted as landmark: “the ground.” The second example (37) has two landmarks or spatial references: “the pacific ocean” and “connected tubes.” The third example (38) has three landmarks: “the grass,” the “under ground,” and “rivers.” To analyze these landmarks’ scale and size, I classified them according to emergent categories, each of which I later associated to one of the four projective scales. Segments such as “the grass” are part of the category of *grass-roots-plants-humans landmarks*, which I considered to be at Figural scale because of the ability to manipulate them without locomotion in the context of the question. Landmarks such as “connected tubes,” “the pipes” and “school pipes” are part of the category of *Pipes* and I considered them at Vista scale. Landmark segments such as “under ground” and “the ground” are part of the category *ground landmark*, which I considered to be at Environmental scale. The segment “river” is part of the *river-canyon landmark* type, and I considered segments like those at Environmental scale. Similarly, “the pacific ocean” is part of the *ocean-lake-wetland* landmark category, and I considered it at Environmental scale. The above examples do not have a geographical scale landmark type. However, text segments such as “arizona” form part of the *city-state landmark* category, which I considered entities at geographical scales. As shown, my projective scale classification concerns types of landmarks rather than landmarks themselves, which helps with identifying larger scale patterns in lexical use, but has the disadvantage of categorizing some landmarks in scales that might not capture the embodied sense that the individual analysis of landmarks would render. I listed the resulting categories of landmarks in the findings section, with their associated inference about projective scale.

### **Establishing Landmarks' Geometrical Properties from Linguistic Evidence**

When scales are absolute, attention is driven to measurements that provide a precise magnitude of certain properties of an entity. For example, degrees inform about the magnitude of an entity's property: its temperature. Scientists have incorporated absolute scales to measure entities' temperatures: Celsius, Fahrenheit or Kelvin scales. In the case of size, magnitudes are expressed as units of distance along one, two or three dimensions. The perception of an entity's one, two or three dimensions precedes any determination of length, width or height. The number of an entity's dimensions constitutes its geometrical properties and provides information about students' perceptions of spatial extensions of landmarks (Evans & Green, 2006). I refer to the perception in the number of dimensions of an entity as *dimensionality*. In addition to the three categories of dimensionality (one, two and three dimensions), a fourth one emerges: zero-dimension. A zero dimensional entity does not have relevant contextual geometric properties other than those of a 'dot' (Radden & Dirven, 2007). I explored the dimensionality that students gave to landmarks in their explanations of water phenomena. This way, I can have access to students' geometrical representations of landmarks.

For understanding the dimensionality of a landmark, I largely counted on the use of prepositions, used in studies of language and spatial cognition (Herskovits, 1986). Take the following examples, answers to the Puddles question:

39. "the water evaporated in to the air." [ID: 23514]

40. "the grass absorbed the water" [ID: 28275]

The first example (39) has one text segment, "the air," that I interpreted as a tridimensional landmark because of the precedent preposition *into*, which suggests a tridimensional container or image schema. In the second example (40), I interpreted the segment

“the grass” as zero-dimensional because there is no indication of another dimension for this landmark. That is, in this case, “the grass” corresponds to a dot-like entity. In this dissertation, I inferred that the prototypical image schema associated with prepositions such as *into* or *in* suggests that embodied experiences with containment are important for students’ representations of entities in explaining water phenomena. Similarly, the prototypical use of prepositions such as *on* or *onto* suggests that embodied experiences of surface and support are important for explanations of water phenomena. Likewise, prepositions such as *at* and *to* suggest prototypical dot-like entities; that is, entities with zero dimensions are important for explanations of water phenomena. Embodied or perceptual experiences with zero dimensionality disregard the entities’ geometrical properties. Prototypical forms of categorization imply that a typical case allows evaluation of other cases and generates inferences about how they can be categorized (Lakoff & Johnson, 1999). In Table 8 I list the prepositions and associated meaning in terms of dimensions (Radden & Dirven, 2007)

Table 8.  
Prepositions that define prototypical attribution of dimensionality in language (Radden & Dirven, 2007).

<b>Dimensionality</b>	<b>Prepositions</b>
0-dimensional	at, by, near, close to, with, from, away from, for, toward, past, via
1-dimensional & 2-dimensional	on, on top of, off, of, onto, against, along, about, around
3-dimensional	in, within, inside, between, among, out of, outside of, into, through, throughout

Similar types of landmarks can have more than one dimensionality. For instance, I have coded segments such as “the grass” and “a cloud” as zero-dimensional when there is no semantical indication for a different dimension. Likewise, I have coded two dimensions for “the grass” when students use prepositions such as “upon” or “on” and three dimensions when students write “into the grass” or “in a cloud.” In example (38) “The water that was in the grass

is gone because it went under ground to go to rivers and other water things,” I coded three landmark dimensions: a zero-dimensional (“under ground”), a bi-dimensional (“rivers”), and a tri-dimensional (“the grass”). I considered rivers as bi-dimensional by default when no prepositions indicated otherwise.

To characterize the likely dimensionality of types of landmark, I proposed an index of dimensionality, *IDim*. The index is an artificial measure of represented dimensionality for a certain landmark type. I mathematically defined *IDim* as:

$$IDim_i = \sum_j \alpha_j, \quad j = 0, 1, 2, 3$$

where  $\alpha$  is the weighted contribution of the dimension  $j$  to the dimensionality of the landmark type  $i$ . The mathematical definition of  $\alpha_j$  is:

$$\alpha_j = \delta_j * \frac{n_j}{\sum_j n_j}, \quad j = 0, 1, 2, 3$$

where  $n_j$  is the number of occurrences of the dimension  $j$ , and  $\delta_j$  is a dimensional factor, which values I defined as 0.01 for  $j = 0$ ; 1 for  $j = 1$ ; 2 for  $j = 2$ ; and 3 for  $j = 3$ . Therefore, for each landmark type  $i$ , the computing formula for *IDim* is:

$$IDim_i = 0.01 * \frac{n_0}{n_0 + n_1 + n_2 + n_3} + 1 * \frac{n_1}{n_0 + n_1 + n_2 + n_3} + 2 * \frac{n_2}{n_0 + n_1 + n_2 + n_3} + 3 * \frac{n_3}{n_0 + n_1 + n_2 + n_3}.$$

One of the properties of *IDim* is that it ranges from 0.01 to 3. For a particular landmark type, the lower the *IDim*, the more likely the landmark type could be deemed zero-dimensional. Likewise, the larger the *IDim*, the more likely the landmark type could be deemed tri-dimensional. When there is equal likelihood that the landmark be used in any of the three dimensional categories,  $IDim = 1.5$ . While the intermediate values of *IDim* might indicate a mixture of dimensionality, the extreme tendency of students to attribute certain geometrical

properties to certain types of landmarks can still be examined through *IDim*. The findings section presents the computed *IDim* for each landmark type, and each projective scale.

## Findings

In this section I describe the main findings about students' conceptualizations of scale, size, and representations. I start with the analysis of landmarks and their relationship to projective scales. I follow with the analysis of dimensionality or geometrical properties of landmarks, and their relations to projective scales.

### Students' Landmark Types and Projective Scales

The first finding of this study is that students do not rely on a common projective scale to explain water phenomena. I found this by analyzing the types of landmarks students use in their answers and the projective scales these landmarks have.

In general, most students used one or more landmarks to explain water phenomena. On average, students used fewer landmarks in the Puddles question ( $M = 1.18$ ,  $SD = 1.01$ ) than in the Engin-systems question ( $M = 2.15$ ,  $SD = 1.47$ ). Most students answered the Puddles question indicating one landmark (44.03%), with a high frequency that used no landmarks (25.37%). That is, about three-quarters of the students answered the Puddles question using one or more landmarks. Differently, most students answered the Engin-systems question indicating one landmark (33.96%), with a small proportion of students responding with no landmark (5.97%). Thus, about 94.03% of students answered the Engin-systems question using one or more landmarks. The distribution in the number of landmarks according to the assessment question are significant ( $\chi^2(5) = 74.516$ ,  $p \ll .01$ ). Across all answers, students mentioned 304 landmarks in answering the Puddles question, and 557 landmarks in answering the Engin-systems question. These results indicate that landmarks were part of most students' answers in this sample.

I grouped emergent landmark categories in two types: natural landmarks and artificial or human-made landmarks. I listed all landmark lexical items and terms and their frequencies and grouped them according to emerging categories. Table 9 lists the resulting categories of landmarks with the percentage of segments that I included in each category. The table also presents a heat map to highlight the proportionately more frequent type of landmarks that students used in answering each assessment question.

Type	Engin-systems (n=557)	Puddles (n=304)	Total (n=861)
<b>Natural Landmarks</b>			
Ground	10.05%	18.42%	13.01%
Ocean-Lake-Wetland	5.92%	0.33%	3.95%
Aquifer/Groundwater	2.33%	2.30%	2.32%
Rain-Snow	0.72%	0.33%	0.58%
Sun-Sky	0.54%	14.80%	5.57%
Clouds	0.54%	10.20%	3.95%
Mountains-Watershed	0.54%	0.00%	0.35%
Air	0.18%	7.57%	2.79%
Grass-Plants-Root-Human	1.26%	34.54%	13.01%
Dirt-Sand-Soil	0.00%	7.57%	2.67%
Puddle	0.00%	1.32%	0.46%
River-Canyon	9.69%	0.33%	6.39%
<b>Artificial/Human-Made Landmarks</b>			
Building	21.18%	0.00%	13.70%
Fountain-Machine-Sewage-Artifact	22.44%	0.66%	14.75%
Pipe	17.77%	0.33%	11.61%
Water Plant	2.51%	0.00%	1.63%
City-State	1.62%	0.00%	1.05%
Field-Playground	0.00%	0.66%	0.23%
Other	2.69%	0.66%	1.97%

As Table 9 shows, the most frequent natural landmark type was the one that encompasses living organisms or parts of them, such as ‘grass,’ ‘roots,’ or ‘us.’ Also, natural landmarks making reference to the *Ground*, the *Sun or Sky*, and the *Clouds* were among the most frequent type chosen by students to explain water phenomena, particularly when answering the Puddles question. Artificial or human-made landmarks, frequent in answers to the Engin-systems question, included references such as a *building*, piping elements, and artifacts that make water available for use and disposal (fountain, sewage, sinks). Therefore, students tended to choose natural landmarks when asked the Puddles question and Artificial or Human-made landmarks when asked the Engin-systems question.

The analyses of landmark types in relation to projective scale indicate that students, as a group, locate their explanations of scientific phenomena at multiple scales. This suggests that several sources of embodiment and perception exist for students’ explanations of scientific phenomena. This finding is informed by the relationship between landmark types and my inferences about students’ embodied and perceptual experiences through projective scale. Table 10 shows the distribution of landmark types according to the four projective scale categories, by assessment question.

Table 10. Percentage distribution of landmark segments according to projective scale categories and assessment question. Frequencies are indicated in parenthesis of landmark text.		
Scale Category	Engin-systems	Puddles
<b>Figural</b>	(132) 24.4%	(134) 44.4%
<b>Vista</b>	(161) 29.7%	(59) 19.5%
<b>Environmental</b>	(224) 41.3%	(57) 18.9%
<b>Geographical</b>	(25) 4.6%	(52) 17.2%

The table shows Environmental scale was the highest in relative frequency for the landmark types in the Engin-systems question, while Figural scale was the most frequent for

landmark types in the Puddles question. In both cases, the less frequent scale for landmarks was Geographical, although it has a relatively larger proportion for landmarks mentioned in answers to the Puddles question. A Chi-square comparison shows that these distributions are significantly different when comparing the Puddles and Engin-systems question ( $\chi^2[3] = 102.54, p << .01$ ).

Students responding to the Engin-systems question referred mostly to landmarks that are larger than their bodies and perceived through locomotion (Environmental scale). They also referred in higher frequencies to landmarks which can be larger than the body and still perceived without locomotion (Vista scale), and then to landmarks that are in the reach of manipulation and are smaller than the body (Figural). These types of landmarks correspond to text segments such as “schools,” “pipes” and “water fountain,” respectively. Less frequent was Geographical scale, meaning that students considered less the scales beyond their perception for making sense of the water phenomena prompted by the Engin-systems question.

Students responding to the Puddles question referred mostly to types of landmarks that are smaller than the body and subject to manipulation (Figural scale). They also referred to scales larger than their bodies in similar frequencies, which imply that their perceptions through locomotion were important experiences for explaining water phenomena prompted by the Puddles question. The types of landmarks at Figural scale reflected in entities such as “the grass,” “the sand,” “the dirt,” or “the root.” Other frequent entities in answers to the Puddles question that are larger than the body and increasingly require locomotion for perception, or even symbolic references, were “clouds,” “the ground,” and entities such as “the sky” or “the sun.”

The above inferential findings suggest that students’ experiences with object manipulation, visual perception without locomotion, and with extensive locomotion provide them with knowledge of properties of scales.

## Students' Attribution of Geometrical Properties to Landmarks and Projective

### Scales

As previously mentioned, for the Engin-systems question, there were 557 landmark text segments, while 304 for the Puddles question. Using the Landmark Dimension coding layer, I analyzed each of these landmarks to assign them a dimensionality. Table 11 shows the resulting distribution of dimensionality according to assessment question. Differences in the distribution of dimensionality attributed to the assessment question are statistically significant ( $\chi^2[3] = 25.473, p \ll .01$ ).

Table 11.  
Frequency and percentage distribution of landmarks among dimensionality categories according to assessment question.

Landmark Dimensionality	Engin-systems	Puddles
Zero-Dimension	(368) 66.07%	(165) 54.10%
One-Dimension	-	(1) 0.33%
Two-Dimension	(69) 12.39%	(27) 8.85%
Three-Dimension	(120) 21.54%	(112) 36.72%
Total	(557) 100.00%	(305) 100.00%

In general, as Table 11 shows, students did not choose to represent landmarks as one-dimensional. That is, entities whose geometric property is that of a straight line were operationally absent from students' explanations of water phenomena.

The first finding in this section is that students attribute different geometric properties to similar landmarks. Further, this is evidenced through the analysis of dimensionality for landmarks corresponding to a similar type. I proposed *IDim* to explore this phenomenon in association to landmark types. Table 12 indicates the computed *IDim* for the aggregated natural and artificial landmark types. The table also shows the computed *IDim* for each landmark type whose frequency was equal or higher than 10.

Table 12. Indices of dimensionality ( <i>IDim</i> ) for each landmark type, classified by assessment question, and by Natural and Artificial groupings.		
Landmark type	Engin-systems	Puddles
	<i>IDim</i>	<i>IDim</i>
<b>Natural</b>	1.08	1.29
Ground	0.88	1.75
Ocean-Lake-Wetland	0.31	-
Aquifer/Groundwater	0.70	-
Sun-Sky	-	0.81
Clouds	-	1.26
Air	-	2.74
Living Beings	-	0.90
Dirt-Sand-Soil	-	1.27
River-Canyon	2.06	-
<b>Artificial/Human-made</b>	0.81	-
Building	0.50	-
Fountain-Machine-Sewage-Artifact	0.85	-
Pipe	1.27	-
Water Plant	0.01	-
City-State*	0.67	-
- Occurrences where less than 10.		
*Included with 9 occurrences overall.		

In general, Table 12 shows that students’ use of natural landmarks was shifted toward zero-dimensionality, but this was more likely in the Engin-systems question than in the Puddles question. Given the absence of one-dimensional landmarks, the *IDim* value of 1.29 indicates that natural landmarks are mostly zero-dimensional, but there was a large proportion of three and/or two-dimensional landmarks. This tendency is somewhat evident in the *Ground* landmark type, where landmarks could be represented mostly as zero-dimensional (*IDim* = 0.88 for Engin-systems), or have a higher proportion of two- and tri-dimensional properties (*IDim* = 1.75 for Puddles). The tri-dimensional property of natural landmarks is clearly evident in the *Air*

landmark type ( $IDim = 2.74$ ). Types of landmarks encompassing rivers and canyons were mostly two-dimensional (the default dimensionality), and present in answers to the Engin-system question ( $IDim = 2.06$ ). Students answering the Puddles question rarely used artificial or human-made landmarks, which is why I did not compute the  $IDim$  for this question. Except for pipes, students represented most artificial landmarks with zero-dimensional geometric properties.

A second finding is that students tended to rely on image schemas of containment for conceptualizing the geometric properties of landmarks larger than their bodies and perceivable without locomotion (Vista scale). Also, students were inclined to disregard the shape of landmarks when these were much larger than the body (landmarks at Geographical scale). These findings were informed by the analysis of projective scale in relation to dimensionality. I grouped landmarks by projective scale and analyzed their dimensionality. Table 13 summarizes the  $IDim$  for each projective scale category by assessment question.

Scale Category	Engin-systems $IDim$	Puddles $IDim$
<b>Figural**</b>	0.89	1.04
<b>Vista</b>	1.47	1.85
<b>Environmental*</b>	0.53	1.78
<b>Geographical</b>	0.61	0.82
* most frequent scale category for Engin-systems		
** most frequent scale category for Puddles		

Table 13 indicates several trends. First, landmarks at Vista scale, which are larger than the body but perceived without locomotion, tended to be represented as having dimensionalities that go toward two and three dimensions, rather than zero dimensions. Second, landmarks at Geographical scale, much larger than the body and requiring extensive locomotion to be perceived, tended to be represented as zero-dimensional ( $IDim = 0.61$  and  $0.82$ ). Third, students'

most frequent projective scale in the Engin-systems question, Environmental scale (larger than the body and requiring locomotion to be perceived), tended to have zero-dimensional geometrical properties ( $IDim = 0.53$ ). Students' most frequent scale in the Puddles question, Figural scale (smaller than the body and subject to manipulation), tends to be zero-dimensional but had high proportions of two- and three-dimensional geometric properties ( $IDim = 1.04$ ).

The findings in this section imply that geometries of landmarks were more or less important for students, but when geometrical properties of landmarks were important for their scientific explanations, embodied and perceptual experiences at the Vista scale can provide a source for relevant conceptualizations.

## **Discussion**

In this study I have shown that students explained water phenomena using landmarks that are at different spatial scales in relation to the human body. Linguistic analyses of these landmarks indicated that students represent, in language, landmarks with spatial geometric properties mostly as either dot-like entities or container-like entities.

The *Framework for K-12 Science Education* (NRC, 2012) affirms that recognition of scale is critical to understand a system's structure and function. Given that scale impacts understanding of the structure and function of systems, students' differential emphases on scale of landmarks might affect judgments about the scientifically sound explanatory power of their answers. While differences evidenced as a result of the assessment question were expected by design, the findings indicate that there are some common themes to point to in order to develop a discussion of the relation of scales, sizes and representation to learners' embodiment and perception. These are: scales as projections of the body, and geometric properties in relation to embodiment and perception.

### **Scales as Projections of the Body**

The main assumption of cognitive linguistics is that language is motivated by cognition, and cognition is dependent upon the sensorimotor properties and limitations of the human body (Evans & Green, 2006; Dirk Geeraerts, 2006; Lakoff & Johnson, 1999). Therefore, the use of projective scales helps in understanding students' access to embodied and perceptual experiences that work as resources for making sense of water phenomena. One finding indicates that students do not show a common projective scale to explain water phenomena. One possible explanation to this finding is that students relied on several perceptual experiences, connecting scales somehow. Take example 38, answering the Engin-systems question: "i think the water comes from the pacific ocean and i think it comes from connected tubes." In this case, the student explained water phenomena using one landmark at Environmental scale ("the pacific ocean") and then another one at Vista scale ("connected tubes"). That is, the student might have relied on a perceptual experience of "the ocean" at a scale that implies some locomotion, deeming an ocean location (e.g., beach) to be named "the pacific ocean." This assumption is consistent with the attribution of scale to landmark types (rather than landmarks terms), but has the limitation of possible interpretations of landmarks at other scales. Such is this case, where "the pacific ocean" could be understood at Geographical scales also. Regardless of this limitation, the student started his or her explanation by signaling a landmark larger than the body and requiring locomotion to be perceived, and then shifted to a scale where perception of the entity "connected tubes" does not need locomotion, and does not necessarily imply manipulation. As a group, when students answer the Engin-systems question they are more likely to show this scale change. When students answer the Puddles question, they are less likely to show this scale change because most students provide one single landmark, and therefore, one inferred projective scale. With either

change or no change in scale in their explanations, students' references to a landmark indicate some level of profiling or deriving attention to certain aspects of the scale, which is a general cognitive ability (Evans & Green, 2006). The shift from larger to smaller scales has been studied as 'magnification.' Jones and colleagues (2010) reported that students' ability to magnify correlated to their ability for logical thinking and to scores on tests of spatial visualization. I have shown that this ability to change the scale of phenomena, or to zoom in and out, is also expressed in students' linguistic choices. The evidence of this dissertation study supports the assertion that linguistic choices reflect other cognitive abilities, and suggests that embodied and perceptual experiences with size provide some level of understanding for spatial scale differences.

In previous research, students have shown that accuracy of scale interpretations declined at larger scales but remained relatively high at smaller scales, up to the point of going beyond the visible (Tretter, Jones, & Minogue, 2006). The researchers report that students from elementary to high school increased their accuracy of estimation of size when presented with entities whose sizes ranged from millimeters to 100 meters (Tretter, Jones, & Minogue, 2006). These findings relied on instruments and procedures that targeted spatial thinking about scale. In the case of this study, I used linguistic information to extract students' notions of embodied scale. Students' most frequent projective scales in this study—Figural, Vista, and Environmental—coincides with the range of accuracy for size estimations previously reported in the literature (Tretter, Jones, & Minogue, 2006), suggesting that the range of accuracy in size estimations can be a function of embodied and perceptual experiences.

The findings in this chapter indicate that experiences with object manipulation and visual perception with and without locomotion play an important role in a learner's knowledge of scales. Walking around a building, perceiving the size of a room, and manipulating pens or a

water faucet are embodied experiences likely to be lived by students at middle school age. The organization of scales through these experiences could lead to students' explanations of water phenomena at different scales. Other perceptual phenomena, such as observing the sky, clouds, or the Sun, or understanding geography in cities, states, or other major landscape landmarks, are less used by students as reference entities to explain water phenomena, which coincides with ranges of less accuracy in size and scale estimations.

### **Perception and Representation of Geometric Properties**

The second theme in this discussion points to students' representations of geometric properties of landmarks through language. This study showed that students attributed different geometric properties to similar landmarks. One of the elements of analyses in this regard is the application of image schemas to students' use of landmarks. As mentioned, image schemas are sensorimotor processes that provide knowledge of spatial relations (Gibbs Jr. & Colston, 2006). In the case of geometrical properties, image schemas can be associated to meaningful experiences with organization of space, such as those of support surfaces (two dimensions) and containment entities (three dimensions). For this study, I extended these notions of space to include dot-like spaces and line-like spaces, or zero-dimensional and one-dimensional entities (Radden & Dirven, 2007). This notion of spatial properties provides tools for understanding students' language about perceptual or embodied features of landmarks.

This dissertation study showed students either disregarded landmarks' shapes (most frequent in the Engin-systems question) or students attributed more containment character to landmarks (most frequent in the Puddles question). Research indicates that cognitive consequences are likely related to students' conceptualizations of geometry of entities. Jones and colleagues (2010) showed that students' ability to visualize and manipulate three-dimensional

objects correlated with measures of conceptualizations of scale. In relation to dimensionality, students' attribution of zero-dimensionality to landmarks indicates that they disregard the landmark's shape in their explanations of water phenomena (Radden & Dirven, 2007).

When relating geometric properties to scales, I inferred that students tended to rely on their embodied containment experience to signal landmarks that are larger than their bodies, but perceivable without locomotion (Vista scale). Also, students tended to disregard the shape of landmarks (represent them as dots) when these are much larger than the body and require extensive locomotion to be perceived (that is, at Geographical scale). Students disregarding geometrical properties of landmarks at much larger scales might indicate that perceptions of external representations can be the experiences students draw upon for considering geographical landmarks in their explanations. This interpretation is consistent with the argument stating that grasping larger-scale entities requires representing them at Figural scale, such as maps (1993). This interpretation is also consistent with previous research suggesting that spatial structure in visual representations might influence linguistic expression (Hayward & Tarr, 1995). Students are very likely, by middle school, to have experiences with extensive locomotion and representations of large-scale sites through maps. Also, they are very likely to experience situations where differences in geometry are salient and entities are at close perception to them, such as being inside a room, or observing a table or a school white board. The findings of my study suggest that these embodied and perceptual experiences might influence students' attribution or representation of geometric properties of landmarks through language.

Overall, this discussion points toward considering what embodied experiences are relevant in students' understanding of scale, size and representations. The data of this study has a particular form of representation: written text of explanations of water phenomena and generic

school science vocabulary. These data are not targeting a study of scale, but I have inferentially linked these forms of representation to embodied and perceptual experiences that could cognitively motivate them. This way, I could describe student learning as a result of some patterns of embodied and perceptual experience.

### **Conclusion**

This chapter has contributed some insights into understanding students' embodied and perceptual experiences in relation to their conceptualizations of scale, size and representations. There are two ideas here. The first is that object manipulation, visual perception, and visual perception with locomotion are experiences that reveal patterns of embodiment, fruitful for conceptions of scale that lay beyond perception. The second is the inference that students attributed geometric properties to entities depending on their projective scale. Entities larger than the body and perceivable with locomotion (at Vista scale) are attributed tri-dimensional properties, while entities much larger than the body and requiring extensive locomotion (at Geographical scale) are mostly represented as dots. The findings are limited by my estimations made for analysis and the inferential nature of this research. One limitation is that instead of analyzing scales for each landmark, I analyzed scales through landmark types, which misses the fine-grained relevant features of landmarks that each student could present, but provides larger patterns of spatial organization in regard to scale and embodiment. Another limitation is that I explored geometric properties of landmarks through a constructed index (*IDim*), which works as a rough estimation of dimensionality. The more accurate estimations for dimensionality occur at the extremes values of *IDim*. In the middle range of *IDim*, one value might show different patterns of dimensionality, providing unclear judgments about the most likely dimensionality of

landmarks. Because one-dimensional landmarks were absent in this study, the judgments of dimensionality based on *IDim* at middle ranges could be less inaccurate.

I located this research as an initial exploration of what matters about embodiment and perception in science education, extending the notion provided by Niebert and colleagues (2012) that science understanding requires embodiment and previous knowledge is not sufficient to understand certain scientific concepts. Future research could explore both analytical features of these explorations as well as adventuring teaching experiments to understand the role of embodiment and perception in developing students' scientifically accurate conceptualizations of space in terms of scale, size, and representations. Analytically, estimations of student projective scales could be linked directly to landmarks rather than landmark types, to understand how students represent these landmarks in comparison to potential embodied and perceptual experiences. The relevance of understanding landmarks in scientific explanations and its relation to scale relates to the semantically asymmetrical relation these have with other elements of explanations (e.g. water in these answers). For example, in an explanation landmarks are geometrically more complex to treat than other objects (Talmy, 2000), which provides an opportunity to understand students' cognitive resources when describing and explaining scientific phenomena, and to relate them to embodied and perceptual experiences. Moreover, in-depth explorations of actual student experiences (e.g. clinical interviews or other targeted instruments) could provide more principled understandings of their embodiment and perception. In relation to teaching, understanding cognitive resources and their relationships to embodiment and perception could provide principles for designing instructional environments to promote understanding of scale, size, and representations. Researchers have proven the success of interventions such as the zooming-in and -out perceptions of space (Jones et al., 2010). In adding

to these successes, exploring in more detail other designs that take into account embodied experiences to foster understanding of scales can contribute more examples of successful development in teaching these concepts.

## **Chapter 6: What Embodied Experiences do Middle School Students bring to Understanding Causality in Water Phenomena?**

In this chapter, I report on my exploration of students' language in regard to their embodied and perceptual experiences for understanding scientific principles. Model-based scientific reasoning about water includes reasoning about causes for moving water and substances in water, recognizing driving forces and constraining factors that influence pathways for water moving, and following natural laws, such as conservation of matter (Gunckel, Covitt, et al., 2012). Establishing causal relationships, simple and multifaceted, is a major activity of scientists, implying the respect for scientific principles that allow tracking fluxes of energy and matter through systems (NRC, 2012). I explored the links between embodiment and perception to linguistic patterns about causality. To develop these links, I examined students' written explanations for patterns in events relationships and role configurations.

I have organized this chapter as follows. I start by describing the problem of study and specific research questions. I continue with the rationale of analytical procedures and methods I used to develop the exploration. I conclude with the findings, a discussion of them, and conclusions for this chapter.

### **The Problem: Students' Embodied Experiences about Causality**

The use of the term "scientific principles" in current science education discussion evidences a focus on overarching 'big ideas' in science (NRC, 2012). Dilworth (1994) provides a distinction between scientific principles, laws and theories. One example of a formulation for a scientific principle is that of "the perpetuity of a substance" (Dilworth, 1994), which manifests in the conservation principles, such as the principle of conservation of matter in chemistry or conservation of energy in physical chemistry. The idea of a principle as a formulation is

consistent with some interpretations of science education researchers. For example, Ben-zvi-Assaraf and Orion (2010) outlined three scientific principles in their development of a curriculum, which write as:

“(1) dynamic relationships exist between the earth’s spheres (biosphere, geosphere, atmosphere, and hydrosphere systems) on the globe; (2) the effects of the interaction between the earths’ systems arise from the energy and substances that pass between and within the systems –biogeochemical cycles; (3) sustainable development will preserve the capacity of the environment to support life” (p. 543)

As such, a scientific principle is a justified formulation of an ideal (or paradigm) that constrains or determines scientific activities, including modes of reasoning. Model-based scientific reasoning about water using scientific principles includes reasoning about causes for moving water and substances in water, recognizing driving forces and constraining factors that influence pathways for water moving, and following natural laws, such as conservation of matter (Gunckel, Covitt, et al., 2012). This indicates that principles also relate to the establishment of causal relationships. For example, Gunckel and colleagues (2012) proposed causal operations as conceptualized driving forces (or drivers, such as gravity or pressure) and constraining factors (constraints, such as topography or permeability) that move water and substances within or limit water movement and substances within, respectively.

Studies in student causal reasoning can be rooted to Piaget (1974, cited in Wolfinger, 1982), who defined causality as a relation between a child’s mind and the external world, as a means for reason on the origin of naturally occurring phenomena. Piaget identified seventeen types of causality, two of which were isolated by Wolfinger (1982) to study the effects of instruction in students’ conceptions of causality. The types of causality Wolfinger isolated were

animism and dynamism, presented as sequential ‘stages’ in students’ development of ‘true’ causal reasoning. Animism is defined as the association of living and conscious status to objects, while dynamism arises with the ‘elimination’ of dynamism and implies confusing life and force. An example of these two ideas is the association of causality to natural events, such as ocean waves moving from being the result of the ocean’s ‘intentions’ (animism), to understanding it as the result of natural processes of force that still require some recognition of the ocean as ‘living.’ Wolfinger found that, after instruction, more students provided causal dynamism than animism. In a study of commonsense causal thinking about motion, Whitelock (1991) proposed a model where experiences (*primitives*) of effort and support became central to understanding of causes of motion. For example, three sources of effort are: an agent action on an object; an object generating effort; and the effort of an object. These primitives provide models for causes of motion. Muruyama (1994) described the normative theory of causality and the field theory of causality. The normative theory of causality establishes causality in terms of ‘sufficient and necessary conditions.’ That is, it establishes that certain conditions are required to be controlled systematically to explain causal mechanisms. The field theory of causality establishes that causality emerges from the perception of an anomaly that requires a causal explanation, and takes into consideration elements of the environment that help discern the best possible cause given a particular situation.

A comprehensive review of causal mechanisms and their effect in students’ understanding of science was reported by Perkins and Grotzer (2005). The authors argued that a source of difficulty in understanding causal mechanisms of different sorts is the learner’s unfamiliarity with types of causal models. They proposed an analysis of four dimensions of complex causality: mechanism, interaction pattern, probability, and agency. Mechanism deems

causal mechanisms as explanation of phenomena. Interaction pattern refers to interactions of cause and effects, where complexity could be seen as a movement from sequentiality to simultaneity between causes and effects, or going from linear to non-linear patterns. Probability refers to the level of certainty in regard to causal relations. Agency implies the salience of acting entities and their immediate influence. Along the four dimensions, the researchers indicated that a progression to more complex understanding is discernable, and instructional interventions that focus on complex causality are effective to support students' scientific understanding. Probability knowledge is strongly linked to students' statistical reasoning, which is arguably the most important and complex for explanations in science (Braaten & Windschitl, 2011).

While the abovementioned studies focused on student understanding, in this dissertation study I explored linguistic units for scientific understanding of causality based on embodiment and perception. In that respect, Andersson (1986) proposed what he called a "common core" for organizing the results of the growing research on students' alternative frameworks in science, by using the concept of *experiential gestalt of causation*. The experiential gestalt of causation "involves direct physical contact between agent and instrument and between instrument and object" (p. 157), and is presented as a way for fully understanding students' knowledge in learning science. This overarching idea is consistent with Niebert and colleagues' (2012) recent argument that understanding science needs embodiment. In regard to causal reasoning and linguistic evidence, Lakoff and Johnson (1999) dedicated an extensive argument for defending the existence of primary experiences that organize causal reasoning, through prototypical forms of causation and conceptual metaphors.

In this dissertation study I attempt to contribute to the emergent literature on embodiment for scientific understanding by exploring students' linguistic patterns in order to infer embodied

and perceptual experiences in relation to causal reasoning. These patterns can be explored by examining students' structures of narrative events, as well as students' proposition of agents in explanations of water phenomena. The research question I asked for this chapter is:

- *What embodied experiences do middle school students bring to understanding of causality in water phenomena?*

In the next section I explain the rationale for developing inferences about students' causal reasoning from linguistic analyses of their written responses to questions about water phenomena. I focus on two linguistic patterns: students' organization of causal narratives and students' explicit attribution of causality.

### **Methods**

I explored the linkage between students' language and embodied experiences related to causation through two sources of evidence. First, I explored the organization of events and their relationship to causality; and second, I explored the semantic roles of agency and cause in students' answers. I coded each student answer using the Events Relationship coding layer and the Role Configuration coding layer (see Chapter 3). For each case, I extracted the relevant elements of the linguistic phenomenon of force-dynamics from students' answers. Leonard Talmy's (1988) notion of force-dynamics offers a perspective of 'causation.' Talmy sets 'causing' in a framework that includes "'letting,' 'hindering,' 'helping'" (p. 50) and other notions. Talmy asserted that force-dynamics have clear and direct grammatical representations and can be studied by understanding the semantics of participants, tendencies, balance of force, and the result of the interacting forces of participants. I also used some of the conceptual metaphors for causation and causality described by Lakoff and Johnson (1999) in order to derive

embodied experiences linked to causal reasoning. In Table 14 I illustrate the connection of coding layers to the cognitive linguistic phenomena that informs my exploration.

Table 14.  
Relationship of coding layer to cognitive linguistic phenomena in explorations of student explanations. Highlighted cells indicate the focus of attention for the analysis of language in understanding students' embodied experiences in relation to causality.

Coding Layer	Analytical Category or Linguistic Phenomenon			
	Event Schemas	Force Dynamics	Image Schemas	Conceptual Metaphors
Role Configurations	X	X		X
Events Relationships	X	X		
Spatial Orientation			X	X
Landmark Dimension			X	X

### Organization of Causation through Events

One assumption about a student answer is that their grammatical and lexical choices represent salient elements in their reasoning about causes of phenomena. In that sense, a student's answer can be a narrative of events that provides an *a priori* attribution of causes when there is a demand for explanation. Trabasso and Van Den Broek (1985) studied causal thinking in narrative events and mentioned that the importance of an event is due to "its causal and logical relations, its role in an episodic structure, or its level in a hierarchy or any combinations of those factors" (p. 628). As such, any event in a student's answer can be considered as a causality argument. This justifies my attention to the structure of events as elements of analyses for understanding students' causal reasoning. That is, a student answer is a causal narrative. In this study I explored the structure of students' causal narratives based on events relationships within their answers.

I developed inferences about students’ embodiment and causality by processing the output of the Events Relationship coding layer (see Chapter 3). This coding layer has three major coding categories: single event, events sequences, and events likelihood. A single event can be deemed certain or likely. For example, observe these student answers to the Puddles question:

41. “the water evaporated in to the air.” [ID: 23514]

42. “it probily eveporated.” [ID: 05-23503]

Both answers (41, 42) show a single event, but their structure is different. In the first one (41), the student is establishing the event as a certain narrative: an apparently natural tendency for water to evaporate into the air. Differently, the second one (42) shows a single likely event with a likely character, given by the qualifier ‘probibly’ (sic). Using Talmy’s (1988) force-dynamic analysis and graphical notations for “force entities,” “intrinsic force tendency,” “resultant of force interactions,” and “balance of strengths” (Table 15), I inferred the relationships of causality in students’ answers.

Table 15.  
Graphical notations (Talmy, 1988) for defining roles in force-dynamics events.

Force Entities		Intrinsic Force Tendency		Balance of Strengths		Resultant of Force Interactions	
Agonist (Ago)	Antagonist (Ant)	Towards Action	Towards Rest	Stronger Entity	Weaker Entity	Action	Rest
							

In both examples (41 and 42), I assumed there is a tendency of the agonist (“the water,” “it”) toward action (“evaporated”). While the resultant of the force interactions is directed toward action, the balance of strengths is different between the two linguistic units. No explicit antagonist is indicated, but its inferred relative force is larger in the likely event. Figure 8 illustrates an analysis of this interpretation for both sentences.

“the water evaporated in to the air.”

<p><b>Ago</b> “the water” has an <b>intrinsic force tendency towards action</b> “evaporated”  <b>Ant</b> is implicit, has an <b>intrinsic force tendency towards rest</b>  <b>Ago is stronger than Ant</b>  <b>Action of Ago results</b> from the interaction</p>
“it probily eveporated.”

<p><b>Ago</b> “it” has an <b>intrinsic force tendency towards action</b> “evaporated”  <b>Ant</b> is implicit, has an <b>intrinsic force tendency towards rest</b>  <b>Ant has strength to impede Ago action</b>  <b>Action of Ago results</b> from the interaction</p>
Figure 8. Comparative analysis of force-dynamics for a single certain event and a single likely event.

The above analysis shows that lexico-grammatical patterns in students’ answers can show differences in the causal structure of events. While implicit, the single likely event example (42) shows a causal pattern that is different from the certain event example (41), but it is not discernable by only observing the resulting event (the action of the agonist). The student’s lexico-grammatical choice in the likely event example indicates a conceptualization of the event as the resultant of effects disregarded when the conceptualization is that of a certain event. In this dissertation study, I captured these differences in students’ answers by coding single events for certain and likely events.

Students can provide more complex event structures in their answers. Their narratives can include events in sequences or events as possibilities. I captured this complexity by coding lineal sequences of events (events sequences) or likely events (events that might or not happen). The codes are not mutually exclusive. Take for example this answer to the Puddles question:

43. “Some of the water soaked and some evaporated. That is how the water disappeared.” [ID: 80121]

The linguistic unit in 42 has three events: two likely events and one single-certain event. The two likely events constitute the first sentence, where the student presents two possibilities for water pathways: “soaking” or “evaporating.” The second sentence illustrates a certain event: that the two possibilities in the precedent sentence explain how water disappeared. Therefore, the student is recognizing two causal relationships: one, there is an antagonist that influences the outcome of water’s final state, providing two options; and another one, there is a natural tendency for those two possibilities to occur. The inference I made is that certain events in sequential order structure a causal chain narrative, while likely events represent a narrative of statistical causality. These two forms of structuring events are dimensions of students’ development of causal reasoning (Perkins & Grotzer, 2005). Lastly, based on the results and using the force-dynamics schema, I inferred embodied experiences that students bring to understand causality in the context of this study.

### **Attribution of Cause and Agency**

The Role Configuration coding layer provides categories for interpreting students’ explicit attributions of causes, event schemas that are organized as causes, and agentive entities. Three codes represent these semantical relations: codes for events deemed as cause <Ev-cause>;

codes for text segments of entities set as explicit cause, <cause>; and codes for acting entities <agents>.

For illustrating the first two codes, explicit attribution of cause, take the two examples below, answers to the Engin-systems and Puddles question respectively:

44. “the sewer because the pipes go down there.” [ID: 80323].

45. “The grass field had no water a week later because it desolves in the ground.” [ID: 100137]

In both cases (44 and 45), the semantical marker of explicit cause is given by the text segment “because.” The causal attribution in these answers indicates that events are causes: “the pipes go down there” and “it desolves in the ground.” For this reason, the code I gave these segments was <Ev-cause>. This code indicates an event that has a cause. I coded the cause with the label <cause>. Other examples of <causes> in answers to the Puddles question are:

46. “The water went in the ground cause thats what it does.” [ID:90519]

47. “The water rose up out of the field and into the sky to the clouds and it happens because the sun is powerful and bacily lifts it up.”[ID:100129]

The content of the <cause> codes in examples 46 and 47 are qualitatively different. The first <cause> segment “that’s what it does” represents a cause of a teleological type: things happen because they happen. The second <cause> segment “the sun is powerful and bacily lifts it up” highlights two ideas: a condition of an agent (the sun as “powerful”) and its action upon another entity (lifting), which results in the predecessor event. To document these qualitative differences among students’ explicit attribution of cause causes, I developed a grounded categorization of <cause> text segments.

To illustrate the third association of causal reasoning to semantic roles, I explored the <agent> text segments. These are entities whose role in the students' explanations is to perform an action. Rather providing direct causal relationships from students' explanations, I analyzed the nature of agents students used in light of a grounded typology and the frequency of use of these typologies. This leads to understanding the perceptual and embodied experiences students might rely upon for providing certain types of entities with action-capabilities in explaining water phenomena.

### **Findings**

In this section, I describe the main findings regarding students' conceptualizations of causality as scientific principles. I start with analysis of causal narrative structures, as provided by the coding of Events Relationships. I follow with the analyses of explicit and implicit causal links. I build conceptual links to embodied and perceptual experiences students bring, as evidenced by the linguistic patterns of their answers.

#### **Students' Organization of Causal Narratives**

Assuming that the importance given to an event within a narrative is partly an attribution of a causal relation (Trabasso & van den Broek, 1985), I have found that students rely on simple events of certainty and sequential events, suggesting they mostly conceptualize causality as a simple relation or a chain of relations. In general, 98.13% of students answered with one or more events relationships codes to answer the Puddles question, while 98.88% did so in the Engin-systems question. Second, 19.40% of students had at least one uncategorized text segment in the Puddles question, while 17.16% had them in the Engin-systems question.

To discern students' causal patterns of reasoning in single events, I computed the frequency of students who only had one event and observed the distribution among certain

events, likely events, and not classified events. Table 16 shows these distributions by assessment question. For units that only had one event, the frequency count of events is the same as the number of units. As Table 16 shows, about two out of five students answering the Puddles question did so with a unique certain event, while less than one-third did it for the Engin-systems question. Only a few students constructed answers with single events indicating some recognition of possibility. For both questions, most students tended to consider single events as certain events. That is, the analysis of causal narratives for single events suggests students' causal reasoning is organized in a direct and single cause for an event rather than weighting of possible causes leading to the same event.

Table 16. Percentage distribution and frequency of linguistic units with only one event relationship, by assessment question.				
Assessment question	Likely event	Certain event	Other relationship	Total (base: total sample)
Puddles	(4) 1.49%	(103) 38.43%	(1) 0.37%	(108) 40.30%
Engin-systems	(3) 1.12%	(73) 27.24%	(12) 4.48%	(88) 32.84%

For more complex causal narratives, that is, having two or more events in one answer, I counted the frequency of events in each causal category for students who answered two, three, four, and five and more events. There are 160 students who answered with two or more events when asked the Puddles question and 180 who answered the Engin-systems question in the same form. The minimum estimated total number of event segments classified in the likely, certain, sequential in complex narratives is 441 for the Puddles question and 613 for the Engin-systems. Table 17 shows the number and percentage of students whose answers indicate two and more events in their causal narratives.

Table 17. Distribution of event text segments according to the number of events in the linguistic unit and causal narrative categories (likely, certain, sequences). The last bin groups linguistic units with 5 and more events.						
Total Events in unit	Likely event	Certain events	Event sequences	Events Likelihood	Other relationship	Estimated Probability of likelihood relation
<b>Eng-systems</b>						
2	(1) 0.37%	(4) 1.49%	(45) 16.79%	(5) 1.87%	(10) 3.73%	0.08
3	(1) 0.37%	(8) 2.99%	(43) 16.04%	(1) 0.37%	(9) 3.36%	0.02
4	(0) 0.00%	(3) 1.12%	(34) 12.69%	(6) 2.24%	(4) 1.49%	0.13
5 +	(0) 0.00%	(8) 2.99%	(29) 10.82%	(2) 0.75%	(11) 4.10%	0.04
<b>Puddles</b>						
2	(0) 0.00%	(3) 1.12%	(33) 12.31%	(38) 14.18%	(29) 10.82%	0.34
3	(1) 0.37%	(7) 2.61%	(19) 7.09%	(6) 2.24%	(2) 0.75%	0.17
4	(0) 0.00%	(0) 0.00%	(17) 6.34%	(8) 2.99%	(9) 3.36%	0.23
5 +	(0) 0.00%	(0) 0.00%	(17) 6.34%	(7) 2.61%	(11) 4.10%	0.20

Table 17 indicates that students' causal attribution was rarely based on statistical reasoning. That is, only a minority of students considered explanations of events due to more than one possibility. About 14% of students showed evidence suggesting probabilistic causal reasoning in their narratives when answering the Puddles question. Because two or more events in a causal narrative can be independently coded, I computed the probability that a student would use events likelihood to explain water phenomena considering the number of events in each answer (see Table 17). For example, from all the students who answered using two events in the Engin-systems question, there is a 0.08 chance that these events had a 'likely' character. This probability was more than four times higher for students answering the Puddles question with two events.

This perspective on establishing causal relationship based on narrative or argument structures of students does not provide information about their explicit attribution of cause, which is examined in the next section. In the discussion section of this chapter I expand on the embodied and perceptual experiences associated with these findings.

### **Students' Attribution of Causal Links and Agency**

One finding is that a small number of students create narratives with explicit attribution of cause. When explicitly stated, students tended to attribute causal links to events and the action and condition of entities. Explicit causes tend to be more frequent in the Puddles question and less frequent in the Engin-systems question.

I developed a grounded categorization of students' attributions of causes by listing, interpreting, and counting the lexical content of students' explicit attribution of causes. In the Puddles question, 13.43% of students used an <Ev-cause> event, whereas 2.99% did so in the Engin-systems question. The codes for <cause> text segments follow a similar pattern: 14.18% of students presented these codes in the Puddles question and 3.73% in the Eng-systems question. Overall, students' explicit attribution of cause is represented in 39 text segments in the Puddles question and 12 text segments in the Engin-systems question. This indicates that a small percentage of students signal explicit causal links when explaining water phenomena.

The typology of causes resulting from my interpretation of them is listed in table 18. For example, in example 47 “The water rose up out of the field and into the sky to the clouds and it happens because the sun is powerful and bacily lifts it up.” the <cause> label has two qualities: the condition of the sun (“powerful”) and its action (“lifts”) upon another entity (“it”). The typologies of these causes are *Entity Condition* and *Entity Action*. *Entity Existence* refers to cause attributed to the mere presence of a physical or abstract entity. *Entity Need* is a cause linked to

established needs of certain entities (e.g., “because the grass needed water”). *Event Existence* corresponds to events framed as causing another event. *Indefinite* causes include unclear references to causes (e.g. “[because of] that”). *Teleological* cause refers to explanations of an event based on some naturalistic orientation for it to happen (e.g., “[because] that’s what it does”).

Table 18.  
Frequency and percentage distribution of <cause> text segments according to typology of cause expressed and assessment question.

<b>Typology of Cause</b>	<b>Eng-systems</b>	<b>Puddles</b>
<b>Entity Action</b>	1	8
<b>Entity Condition</b>	4	6
<b>Entity Existence</b>	2	5
<b>Entity Need</b>	2	4
<b>Event Existence</b>	3	12
<b>Indefinite</b>	0	2
<b>Teleology</b>	0	2
<b>Total</b>	12	39

As Table 18 shows, the two most frequent types of explicit causal attributions are the existence of an event and the condition of an entity. This suggests that students who attribute explicit causes might rely on perceptions of change in events based on logical, maybe implicit, relations to previous events or might perceive that changes occur when conditions change (e.g., “heat”).

Regarding attribution of agency, less than half of students show <agent> codes. In the Puddles question, 108 students had one or more <agent> text segments in their answers, while 107 students did so in the Engin-systems question. The total of <agent> codes is 130 codes for the Puddles question and 134 for the Engin-systems question. Similarly to causes, I listed and grouped similar types of agents according to emergent categories. For example, the category

*Plants* included segments such as “grass” and “the grasses roots,” and the category *Sun-Energy* included segments such as “the sun” and “heat.” The Puddles question prompts students to attribute a causal role to natural entities, while the Engin-systems question prompts students to attribute a causal role to humans and engineered systems. Table 19 lists the resulting typologies of agent roles and the frequencies by question. For the Puddles question, the most frequent agents are *Plants*. For the Engin-systems question, the most frequent typologies of agents are *Humans*, *Machine-Facilities*, and *Pipes*.

Typology of agent	Puddles	Engin-systems
Plants	39	1
Machine-Facility	0	20
Sun-Energy	25	0
Water	15	5
Ground-Dirt-Sand-Soil	12	3
Clouds	3	0
Human	4	69
Pipe	0	14
Location-River-Wetland	0	8
Indeterminate	32	14
Total	130	134

Relationships between the most frequent agents and the most frequent causes are worth noting. For example, the Sun-Energy agency and the Entity Condition cause might be linked in the logical form: an agent (e.g. “the sun”) changes the condition of an entity (e.g. “heats it”). While these relationships might be explored in more detail, around 60% of students did not construct explanations with an evident causal relationship in it, which limits any analyses. In the next section I discuss the findings of this study.

### **Discussion: Causality and Embodiment**

I have explored students' language to understand their conceptualizations of causality. With two analytical procedures, I explored two types of evidence about causality. First, the evidence about students structuring of events suggests students tended to reason about causality by attributing simple causal relations in single events and providing causal chains in multiple events. Second, the evidence about students' attributions of cause shows that only a few students provided explicit attribution of cause, but that about half of them provided agency to entities. I explore the connections of these findings to embodied and perceptual experiences.

### **Event-Structure, Causal Reasoning and Embodiment**

One of the first assumptions regarding the exploration of events in students' answers is that their explanations are in themselves an argument of causation. That is, an event, in students' answers, has in itself logical and causal relations and is inserted in an episodic structure (Trabasso & van den Broek, 1985). The narratives in students' answers are mostly a simple logical relations or a sequence of simple relations. A statistical relationship of events is rare, except for in 14% of students answering the Puddles question with two events. This suggests that embodied experiences behind causal chains are important for students' making sense of the water phenomena at hand.

How are embodied experiences derived from this causal structure of events? For Lakoff and Johnson (1999) the forms of causal reasoning, or theories of causation, emerge from two sources: "a causal prototype and a wide variety of metaphors for causation" (p. 177). The prototypical causation is the direct application of force that results in a physical change, either in motion or form. In a prototype view of categorization, there is a radial distribution of the forms of causation, which might go from more direct to less direct theories of causality. The common feature of these theories is that a cause is a determining factor for the occurrence of an event. The

variety of metaphors lies in the radial zones of the prototype causation. These metaphors include STATES ARE LOCATIONS and CONDITIONS ARE LOCATIONS (see Chapter 4). A change in state can be attributed to a cause, which is semantically structured in the same way as change in location. The same goes for conditions that work as causes. The metaphor for the event that describes a change is CHANGES ARE MOVEMENTS, which implies that a cause for a change is a direct force that acts to produce a change in location.

As mentioned, force-dynamics analyzes how language structures interactions of entities in relation to force. As such, it does provide an initial step to understand how experiences with direct force structure causal reasoning at abstract levels, such as the scientific level. The direct force and change of motion is highly likely to be an embodied or perceptual experience lived by middle school age humans. By middle school, students surely have experienced the exertion of force to change the location of an object. Manipulating utensils, bringing a backpack to school, throwing a ball: all of these experiences imply direct contact with objects that result in a change in their location. These actions are exertions of force upon entities whose natural tendency is to rest, so the change is to change their location or put them in motion. More than one direct physical contact can happen consecutively, resulting in several changes of location. Throwing a ball to a glass window to see the glass shattered in pieces, bringing something to school to a friend who then bring it to his/her home, observing collisions of objects that result in changes in the surroundings, all represent experiences likely lived by students at middle school age. The findings in this study suggest that experiences with direct force might stimulate the structure of most of students' causal narratives in their answers.

Still, there are students who provide a different structure of causal narrative, and propose possibilities for explanations, which I have highlighted as statistical causality. As already

mentioned, causal statistical explanation is deemed as the most complex form of scientific reasoning (Braaten & Windschitl, 2011). In the case here presented, I infer that students' consideration of more than one likely option to explain a resulting condition operates as an indication of statistical reasoning about causes. While this type of reasoning is not highly evident, there are indications that some students do reason using some form of statistical consideration. Are there different sorts of embodied experiences for developing this statistical reasoning? One clue might lie in the argument of Muruyama (1994):

“[P]erception of causality depends on dynamic information, such as temporal or spatial contact, or detachment in collision (...) Our perceptual system is thus attuned to the conservation law of momentum, or natural motion in the absence of external forces; deviation from this natural motion is highlighted as anomaly (...) An anomalous event presupposes a natural event. (...) Naturalness is acquired through observation. The ability to detect patterns, therefore, plays a critical role in causal understanding” (p. 202-204)

Embodied and perceptual experiences about the ‘naturalness’ of tendencies of entities seem to play a role in students’ probabilistic modes of explanation. Hilton (2002) suggests that common-sense causal explanations are the result of the perception of an abnormal event, and Muruyama (1994) suggests that natural events are difficult to define and do not require to be explained. The exception is science, where “the occurrence of natural events must be explained in a principled way” (Muruyama, 1994, p. 205). Take example 43: “Some of the water soaked and some evaporated.” In this case, the arguably natural change in location of water needs to be explained, and the student opts for signaling two natural tendencies that could explain the natural change in location.

Consider the force-dynamics of example 43. First, the resultant event is toward action (water puddles are no longer in the initial location). Second, the intrinsic tendency of the agonist (water) appears to be toward action. Figure 9 illustrates this situation using Talmy's (1988) notation. The complexity in this case is that action can have two forms: soak or evaporate. The antagonist for each case is implicit, but different. What could impede the intrinsic tendency to soak or to evaporate? In this balance of forces, the difference of strength of the antagonists implied in each possibility might determine which causal link is stronger to explain the final result of the interaction. But in any case, I inferred the student is reasoning about two possibilities within one causal narrative. The student chose to use a probabilistic principle to explain the natural phenomenon. This form of reasoning is qualitatively different than the causal chain most students have shown to use. However, it is based in the same embodied experience: the exertion of force to produce motion. The construction of probabilistically reasoned arguments can be related to students' considerations of multiple pathways for water moving, which is considered to be a feature of model-based scientific reasoning (Gunckel, Covitt, et al., 2012).

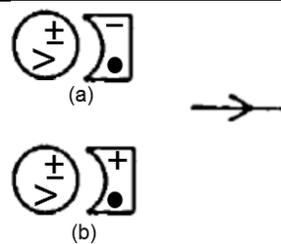


Figure 9. Force-dynamic analysis of the answer to the Puddles question: “Some of the water soaked and some evaporated.” In each case the resulting condition is the same.

(a) Ago the water has an intrinsic force tendency towards action soak. Ant is implicit and has an intrinsic force tendency towards rest. Ant has less strength to impede Ago action. Action of Ago results from the interaction.

(b) Ago the water has an intrinsic force tendency towards action evaporate. Ant is implicit and has an intrinsic force tendency towards rest. Ant has more strength to impede Ago action.

Action of Ago results from the interaction.

The force-dynamics model presented above also includes the proposition of agency. That is the topic of the discussion in the next section.

### **Causes, Agency, and Embodiment**

When intrinsic (or natural) tendencies of entities are perceived to not happen, agency emerges as an explanation (Murayama, 1994). An agent can be conceived as an effortful entity that hinders, blocks or helps a natural phenomenon to occur (Talmy, 1988). Agency can be a cause: an entity which causes the natural event to not happen. Previous work on water and causal mechanisms suggests that conceptualizations of agency are in terms of drivers and constraints (Gunckel, Covitt, et al., 2012).

I have found categories of entities playing the semantical roles of cause and agent. The existence of, condition of, and actions of entities are the most frequent explicit causes in the few student answers that provided them. Causal attributions are unsurprisingly more frequent in the Puddles question, which might be explained by the differences in the demands of the questions: the Puddles question asks for explanation of a natural phenomenon, while the Engin-systems question asks for tracing water to previous locations.

Differences regarding the question asked are evident also in attribution of agency. Natural agents causing some explanatory event are more frequent in the Puddles question. Agents such as plants, energy, the sun, and heat are characteristic in the Puddles question. Differently, agents such as machinery and facilities, and humans, are mostly responsible for events described in the Engin-systems question.

The embodied experiences for agency are based on the same force-dynamics previously described for event-structures. That is, agency is related to experiences of direct force to provoke a physical change in an entity, either in realms of motion or form. The entity exerting direct force

is an agent, and all actions are recognized from that standpoint. For example, in the answers to the Puddles question:

48. “it evaporated in to the air because the sun heated it up.” [ID: 28264]

49. “the sun dries it up.” [ID: 80306]

50. “The sun sucked up the water” [ID: 23704]

None of these cases imply a direct explicit exertion of force from the agent “the sun.” However, all of the actions might be understood with base on an exertion of force. To “heat something up” is to change its state from a lower to higher temperature. To “dry something up” is to remove water from its original place; that is, changing the location of the water. This idea of changing location also applies to the segment “sucked up the water.” As Lakoff and Johnson (1999) expressed it, these actions require metaphors that map exertion of force. Examples 48-50 show two metaphors STATES ARE LOCATIONS and CAUSATION IS FORCED MOVEMENT. That is, the sun *moves* the water from a state of lower to a state of higher temperature. The sun also *moves* the water from one location (the entity: the puddle) to another indefinite location, resulting in a dried entity (no puddle). The agency of the sun is based on its capacity to project an exertion of force.

The experiences of physical force exertion structure other relevant forms of causation for determining agency in scientific explanations (e.g., attribution of cause to certain forms of energy). An agent is explicitly the cause of a change when a direct causal link can be attributed. As Lakoff and Johnson (Lakoff & Johnson, 1999) extensively exemplify, causes and causation are domains representing metaphorical projections of force and forced movement. The consequence of accepting this metaphor is that scientifically sound causal explanations require

the examination of force as more than a topic for studying in mechanics, but as an organizing embodied and perceptual experience for developing more complex accounts of causal reasoning.

### **Conclusion**

Understanding causal relationships and scientific principles is an important, if not key, aspect of scientific endeavors. In this chapter I have contributed insights into understanding common embodied experiences in relation to students' conceptions of causal reasoning. I have shown that students' episodic or narrative structures in their explanations of water phenomena rely on simple causal relations and sequential causal links. Very few students show relations of causality where statistical reasoning could be inferred. Also, I have shown that explicit attribution of cause and agency was common for about half of the students in this sample. I suggested that relevant embodied experiences in relation to causality are the ones represented in mappings of conceptual metaphors to the physical exertion of force for provoking motion of entities or change in their form. These findings are limited to generalizations about student thinking by two reasons. First, as the design did not target to prompt students' causal reasoning directly, the sample has only limited amount of data to describe causal links. This limitation is less important under the assumption that any narrative provided as explanation is an argument of causation. Second, the scope of theories of causality is not explored in this study, which might show differential patterns in relevant embodied experiences. This limitation is arguable, considering Lakoff and Johnson's (1999) assertion that all causal reasoning is not possible without considering two sources for it: the central prototype of causation (direct force) and the conceptual metaphors of causation.

This research does not add other theories of causation, but estimated important and relevant sources of embodiment and perception for the development of causal reasoning in

students' learning science in school. As such, the findings of this study can be located as a contribution to the emergent science education literature that asks to move beyond describing students' previous knowledge and searches for patterns of embodiment in learning scientific concepts (Fuchs, 2007, 2010; Niebert et al., 2012). Future research could expand empirically on details about how embodied experiences of students relate to other perspectives regarding causality. Also, teaching experiments that use embodiment and perceptual experiences could provide information about change in students' causal reasoning, including developing complex forms of causal reasoning, such as statistical causality.

## Chapter 7: Discussion and Conclusion

My purpose in this dissertation study was to explore students' naturalistic language in common academic school science to find cognitive patterns that could point toward relevant experiences in embodiment and perception. The recent development of the field of cognitive linguistics offered an opportunity to start this exploration, by using some of the analytical tools and well-described linguistic phenomena. My dissertation study can be located in a first wave of efforts targeting the documentation of relevant embodiment and perception in students coming to learn science. As such, I aim at expanding the constructivist view of learners' previous knowledge toward documenting learners' previous patterns of experience, as suggested by Niebert and colleagues (2012) and Fuchs (2007, 2009, 2010). In doing that, I have presented three research questions, which combine the previously mentioned focus on embodiment with current emphases in science education (NRC, 2012):

1. What embodied experiences do middle school students bring to understanding of systems and systems' structures in water phenomena?
2. What embodied experiences do middle school students bring to understanding scale, size and representations in water phenomena?
3. What embodied experiences do middle school students bring to understanding causality in water phenomena?

The nature of the work and findings I have presented in this dissertation is highly interpretative; that is, inferential in the sense that my own interpretations of students' linguistic intentions and meaning play a role in how the findings emerge from the evidence. While this might be a limitation for generalization of the findings, the reliance on well-documented linguistic phenomena provides a source for corroboration and future re-examination in light of

possible alternative interpretations. Also, while I gathered information about students' first learned language, the use of this variable in the report of results is beyond the scope of this study.

As a conclusion, I provide a general discussion about the findings, highlighting an element I did not discuss in the previous chapters: the influence of the assessment question. I continue with implications for research and for teaching that I identify as a result of my work in this dissertation.

### **The Embodied and Perceptual Experiences of Middle School Students**

The embodied cognition thesis proposes that the conceptualizations developed by humans are limited by the possibilities offered by the human body to interact with the environment (Evans & Green, 2006). Language, as inseparable from cognitive structure, represents whatever reality exists out of the body through a mediation by human cognition (Lakoff & Johnson, 1980, 1999; Lakoff, 1987). I have relied on these principled assumptions to propose forms or patterns of embodied and perceptual experiences that explain students' understandings of systems and their structure; scale, size and representations; and scientific principles of causality. In Table 20 I present a summary of the research questions, the findings, and the interpretations of these as they relate to embodied and perceptual experiences.

The linguistic evidence I have provided throughout this dissertation suggests several embodied and perceptual experiences that might represent the motivation for students' conceptualizations. The outlined findings (Table 20) suggest that experiencing movement in several forms is an organizing pattern for recognizing systems, developing abstract notions of systems, establishing geometrical properties of entities larger than the body, and attributing causal mechanisms when movement results from direct application of force.

Table 20. Summary of research questions, findings, and relation to embodied experiences.	
<b>Research Question: What embodied experiences do middle school students bring to understanding of...</b>	<b>Main Findings =&gt; relation to embodied and perceptual experiences</b>
...systems and systems' structures in water phenomena?	<p>- ... recognize systems more frequently when describing dynamic water phenomena. =&gt; perception of boundaries and change in location.</p> <p>- ... attribute structure of systems based on topological, metaphorical, and functional features. =&gt; perception of spatial organization in the up-down direction; physical conceptual source domains (location and movement); perception of purpose.</p>
...scale, size and representations in water phenomena?	<p>- ... do not rely on a common projective scale to explain water phenomena, but provides multiple scales. =&gt; discernable experiences with object manipulation and perception of size with and without locomotion.</p> <p>- ... attribute different geometric properties to similar entities, tending to: tri-dimensional for perceivable larger-than-the-body entities, zero-dimensional for unperceivable much larger entities. =&gt; when geometrical properties are important, embodied experiences of perception of tri-dimensional entities larger than the body seems to be relevant.</p>
...causality in water phenomena?	<p>- ... mostly establish direct causal links of events in causal narratives and rarely establish causal relationships based on statistical causal. =&gt; experiences with direct force resulting in perception of movement and sequential movement.</p> <p>- ... in less than half established explicit attribution of cause or agency, focusing on causes such as existence of events and entities or conditions; and agency in natural entities such as plants, and in humans and entities such as energy or the sun. =&gt; direct force to provoke a change in an entity, either motion or deformation.</p>

Similar to embodied movement, perceptions are also important organizers of experience for students, particularly for describing systems' boundaries; assigning systems' functional structures; projecting relative size; establishing geometrical properties; describing changes in location; and describing an entity's change in form.

Lastly, the possibility of experiencing and perceiving with the body seems to impact the consideration of entities in explanations. That is, the more possibilities to experience an entity, the more likely it is that the entity is to be part of the students' explanations. These experiences are also particularly important for defining the direct exertion of force, which seems to play an important role in the conceptualizations of scale (e.g., manipulable objects) and in the conceptualizations of causality.

### **The Question as a Variable**

Throughout this dissertation I have presented information about the differences in students' patterns of cognitive linguistic phenomena according to the assessment question: Puddles or Engin-systems. Most of these comparisons indicate significant differences, which reflect the design decision to select two questions that highlight different aspects of students' reasoning. The most noticeable differences between the two are: the Puddles question demands open explanation while the Engin-systems demands tracing water to sources the student defined; the Puddles question asks for reasons and mechanisms (how and why) while the Engin-systems question only asks for mechanisms (how); and the Puddles question is situated in explaining natural phenomena while the Engin-systems question is situated in a human-made or artificial context. All of these differences can explain some patterns in the answers. For example, explicit causal attributions were more frequent in the Puddles question, which asked for why-type explanations. Another example is the types of systems, types of agents and types of landmarks,

which similarly showed that students responded more frequently with natural entities to the Puddles question and more frequently with human-made entities to the Engin-systems question.

Because I conducted this study with students' answers to only two questions, there is a limitation for generalizing the relationship of embodiment and perception to a broader scope of possible forms of explanation. Braaten and Windschitl (2011) points that from a pragmatic perspective the context is highly relevant in the request for explanations in order to count it as satisfactory. That is, "the adequacy of an explanation stems not just from the features of the explanation, but from the question initiating the explanation as well as the context surrounding the question" (p. 648). I did not focus on scientific adequacy or accuracy of explanations, but on understanding students' embodied and perceptual experiences for constructing these explanations. Yet, an analysis of an extension of the corpus to include different types of demands for explanations could report how different the patterns of embodiment can be.

### **Implications for Research**

In the literature review I developed for this study, I found just a small pool of studies that addressed some aspect of cognitive linguistics analyses for science learning (Brookes, 2007; Nehm et al., 2010; Niebert et al., 2012). Most of the previous work addressed some aspect of science or potential use of certain linguistic categories for learning scientific concepts (e.g., Bradie, 1999; Brown, 2003; Hoffman, 1980), but none had addressed students' conceptualizations through this perspective. My dissertation has two potential implications for future research. First, further research should engage in the systematic development of analytical categories for understanding students' embodied and perceptual experiences in learning science. This could render a novel organizing framework for understanding previous knowledge in science learning. For example, the systematic study of systems using this perspective could lead

to explaining why reports on systems thinking have found consistently that most students at different levels level do not achieve systems thinking beyond the ability to recognize or identify components of systems (O. B.-Z. Assaraf & Orion, 2005, 2009). The lower levels of achievement are linked to a student's favoring of structure of the systems over processes within (O. B. Assaraf et al., 2011). I had shown in this dissertation study that students' understanding of the structures of systems might be motivated by three different uses of embodied experiences: topological organization, conceptual metaphors, and perceived functionality. Adding these elements to current understandings about systems thinking might lead to describing processes as conceptual abstractions whose base source domain corresponds to the 'lower' levels of performance, indicating that students recognize and identify components of systems. Likewise, students' understandings of complex scientific concepts such as evolution show that accuracy of the use of words such as 'force' and 'pressure' does not match the scientific meaning attributed to natural selection theory (Nehm et al., 2010). A focus on embodied and perceptual experiences can explain the use of these words by analyzing what the elements of direct experience with force represent. That is, by explaining student understandings of force from embodied and perceptual experiences, other elements of conceptualizations might emerge, including some notions of scale, agency and causality in abstract terms.

Second, the question about relevant embodied experiences is still open. Written academic language is purposefully addressing some contextual demands for students. The development of corpora to explore other forms of language in relation to the same topics is necessary to increase the range of evidence that can support assertions about the influence of embodiment in learning science. These corpora could include texts from clinical interviews with experts and students, magazine articles and children books, and published academic papers. The development of

relating multiple scientific topics and concepts to embodied experiences could provide an organizing framework for understanding patterns of embodiment and perception that motivate the development of complex scientific thinking.

### **Implications for Teaching**

I had mentioned in the previous chapters that the potential contribution of this study is the development of teaching experiments, or the design of learning environments. An active and dialogical relation between the potential theoretical contributions of research in student learning in science through cognitive linguistics and the impact in teaching experiences requires particular frameworks. Fortunately, researchers have developed research approaches that address these needs for pedagogical intervention and theoretical understanding, such the design-based research (Barab, Dodge, Thomas, Jackson, & Tuzun, 2007; The Design-Based Research Collective, 2002). In a design-based research initiative, teaching constitutes an intervention that responds to certain principles of design, and these principles are tested in specific contexts and enactments. The resulting inquiry about the outcomes of the interventions can provide new theoretical insights and new principles.

In my search of the literature in science education, I have not found examples of pedagogical designs based on cognitive linguistics research. However, the field of Teaching English as a Second Language (TESL) has examples of pedagogical designs based on cognitive linguistics research. Researchers in TESL point to the importance of highlighting the motivation for linguistic phenomena, looking into the representation of embodied phenomena as sources from students to develop explicit linkages between meaning and forms in a second language (Boers & Lindstromberg, 2008; Pütz, 2007). They propose that attending to what *motivates* linguistic expressions can be fruitful as a form for acquiring a second language.

For teaching science, the principles derived from cognitive linguistics research and TESL pedagogy can be examined under the assumption that science is indeed a new language students need to learn in school. This view is sustained by several accounts of scientific learning, which span from sociocultural theories of engagement in communities of practice, to theories that view learning as acquisition of knowledge and new ways of argumentation and vocabulary (e.g., Bruna & Gomez, 2009; Darian, 2003; Gee, 2005a, 2005b; Krajcik & Sutherland, 2010; Lemke, 1990; Roth, 2005; Snow, 2010). From the findings of this dissertation research, I suggest that some embodied and perceptual experiences can provide principles to develop teaching interventions. For example, one principle could be that, in order to understand systems, students should analyze what constitutes a boundary in physical-spatial form before moving to a boundary in an abstract form. This principle is based on the assumption that a physical-spatial experience with a system (e.g., a defined location) provides a source domain for understanding systems in terms of abstractions (e.g., a cycle). Another example includes the embodied experience for representations in relation to scale. Gee (2005a) claims that an effective connection between science and its learning requires embodied experiences as contexts to situate the meanings of words and phrases in science, and that understanding a language requires access to simulations of the uses of the language. For the case of scale, and considering the findings of this study, a principle could be derived as: representations of entities whose scale is larger than the body and beyond immediate perception need to be produced by students through and after an embodied experience, such as locomotion. This principle is supported by work suggesting that magnification using visual experience can be a successful approach to understand scales (Swarat et al., 2011) and that students with opportunities to dynamically control their level of spatial

resolution zooming “in and out of the world” is also effective (Goldstone & Wilensky, 2008).

The evaluation of these principles in action in light of different contexts is a matter of research.

**Appendix A - Sample of Full Assessment form Given to Students**

**Soccer Game Questions**



Your soccer game gets canceled at half time due to a massive down pouring of rain. As you run for cover, you notice that there are large puddles forming on the grass covered playing field, but no puddles forming in the sand covered playground just a few steps away.

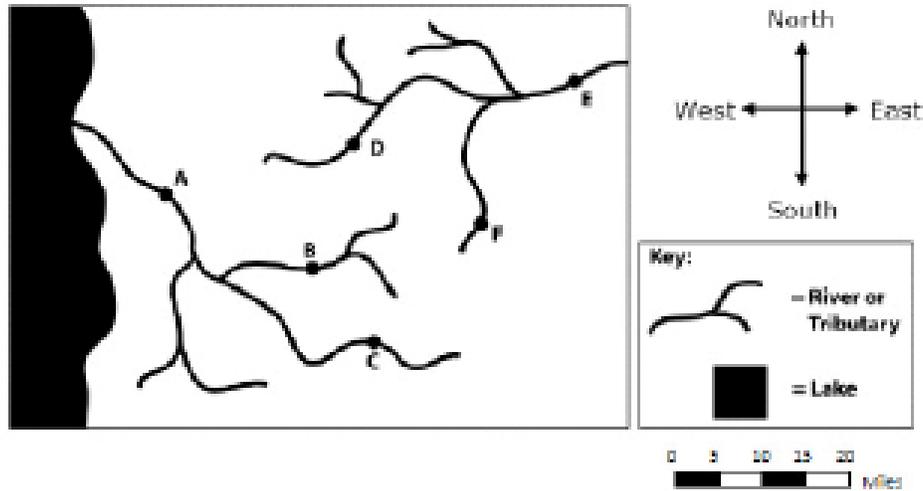
1. Why are there puddles on the grass and not on the sand?

2. Explain what happens to the water that lands on the sandy playground? Be sure to explain how and why.

3. The next week you come back to the soccer field and you notice there is no water on the grassy field. Explain what happened to that water? Be sure to explain how and why.

**River Map Questions**

Use the map below to answer questions 4, 5, & 6.



4. Can pollution in the river water at Town B get to Town C? (circle one)

Yes                      No

Explain why or why not.

5. Describe the direction the water is flowing away from Town F.

6. How do you know the water is flowing this direction?

**Substances Questions**

The picture below shows part of a school campus with several grassy playing fields near a river. Use the picture to help you answer the next three questions.



7. A. If the playing fields were treated with fertilizer, do you think that some of the fertilizer could get into the river?

(Circle one) YES NO

If you think yes, describe how fertilizer could get into the river. If you think no, describe why fertilizer would not get into the river.

What is in the fertilizer that could get in the river? (In other words, what is fertilizer made of?)

8. If some of the fertilizer got into the river, how would the fertilizer affect the river water and living things in the river?

**Engineered Systems**

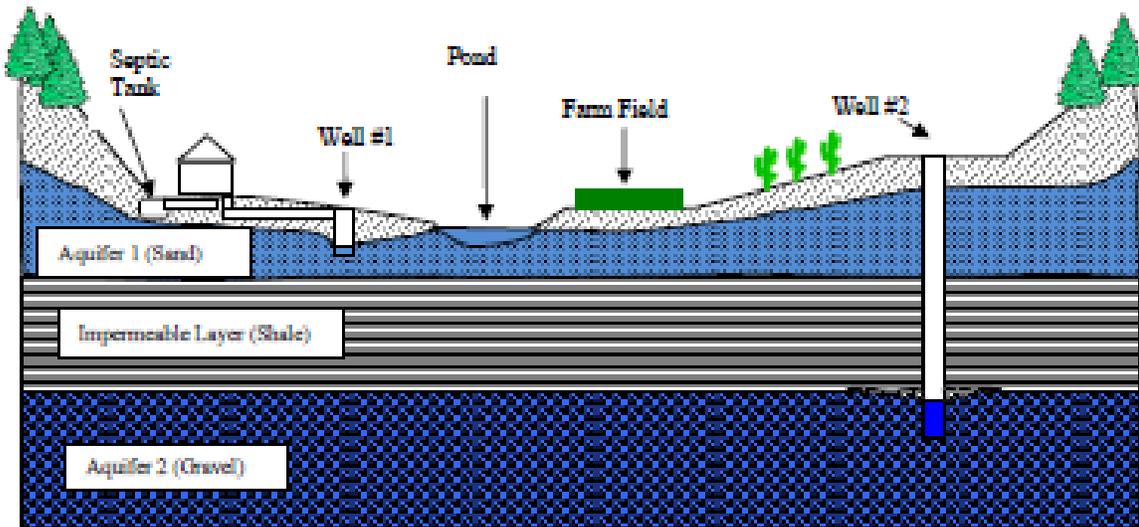


9. Where does the water that is used in your school come from? Please explain how it gets to your school. Trace back as many steps as you can.



10. Where does the waste water from sinks and water fountains in your school go? Please explain how it gets to where it is going. Trace forward as many steps as you can.

**Groundwater Questions**



Use the above diagram to help you answer the next two questions. Assume the wells are solid pipes except at the bottom.

11. How does the water get into the pond? Explain as many pathways as you can.

12. Could pumping from well #1 affect the water in the river? (Circle one) **Yes** **No**

Could pumping from well #2 affect the water in the river? (Circle one) **Yes** **No**

Explain your answers.

Appendix B – Copy of IRB Approval Form



<b>FORM: Human Research Determination</b>		
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- Only electronic submission will be accepted (see directions for electronic submission at the end of this form)

**PROJECT TITLE:** Water-Related Students' Language: A Corpus-Based Cognitive Linguistics Exploration to Describe Language for Addressing the Challenge of Teaching Science to Diverse Students

**INVESTIGATOR**

Principal Investigator Name, Degree(s): Ivan Salinas, Ph.D.(c)

Status/Rank: Graduate Associate

Department/Center/Section: Teaching, Learning and Sociocultural Studies

College: College of Education

Contact phone: 520-309-1549 Fax: 520-621-7877

Official University Email: [isalinas@email.arizona.edu](mailto:isalinas@email.arizona.edu)

Mailing address: P.O. Box 210069 / 1430 E. Second St. Tucson, AZ 85719  
(Campus PO Box/Mailstop)

**ADVISOR CONTACT INFORMATION (REQUIRED FOR ALL STUDENTS AND RESIDENTS)**

Name, Degree(s): Kristin L. Gunckel, Ph.D.

Contact phone: 520-621-7851 Fax: 520-621-7877

Official University Email: [kgunckel@email.arizona.edu](mailto:kgunckel@email.arizona.edu)

Mailing address: 1430 E. 2nd St  
P.O. Box 210069  
Tucson, AZ 85721  
(Campus PO Box/Mailstop)

**ALTERNATE/COORDINATOR CONTACT INFORMATION**

Name: \_\_\_\_\_

Contact phone: \_\_\_\_\_ Fax: \_\_\_\_\_

Official University Email: \_\_\_\_\_

Mailing address: \_\_\_\_\_  
(Campus PO Box/Mailstop)



FORM: Human Research Determination		
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The purpose of this form is to help you to determine whether your project should be classified as Human Research, as defined by OHRP. Upon completion, sign and submit to the designated Scientific/Scholarly Reviewer. If the Scientific/Scholarly Reviewer agrees that the proposed activity does not constitute Human Research, forward the documents to the HSPP Office. (Click [here](#) to review the OHRP Human Subject Regulations Decision Charts, in particular Chart 1)

- Contact HSPP staff about how to proceed if your project includes Native Americans or International Indigenous Populations.
- If you have any questions on how to answer the items on this form, please contact the HSPP at (520) 626-6721.

If at any point your answers lead you to the conclusion that your project does constitute Human Research, please STOP filing out this form and complete the appropriate HSPP initial application form. If this form indicates that your project does not constitute Human Research and will not require IRB review, please proceed with the following:

- Attach a project summary, along with materials supporting the answers that led to that conclusion. See SECTION 2 of this document to provide specific details of the project protocol.
- Speed up review by providing an explanation to support your answers to the subsequent questions.
- Submit this form and supporting materials to your (internal) designated Scientific/Scholarly Reviewer.
- Following Departmental approval, submit all materials to the HSPP for FINAL approval.

**NOTE: PROJECTS INVOLVING DRUGS OR MEDICAL DEVICES WILL ALWAYS REQUIRE IRB REVIEW AND APPROVAL**

1. Is the project a Systematic Investigation designed to develop or contribute to generalizable knowledge?

- Systematic: having or involving a system, method or plan.
- Investigation: a searching inquiry for ascertaining facts; detailed or careful examination.
- Generalizable: generalizability is the extent to which research findings and conclusions from a study conducted on a sample population can be applied to the population at large. Please note that use for a thesis, dissertation, publication, or poster presentation does not automatically mean that the work is generalizable.

<input type="checkbox"/> No STOP: Go no further! The project is not considered research; IRB review is not required.  <input checked="" type="checkbox"/> Yes - Go on to question #2	Provide Explanation: This project uses methodologies intended to investigate in systematic way the use of language in school science.
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2. Does the research involve obtaining information about living individuals?

- This includes secondary data analyses of existing data that was not obtained by the investigator of the proposed project.

<input type="checkbox"/> No STOP: Go no further! The project is not considered Human Research; IRB review is not required.  <input checked="" type="checkbox"/> Yes - Go on to question #3	Provide Explanation: Information has been obtained in previous research projects through interviews and classroom assessments about school science.
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3. Will the research obtain data through intervention or interaction with individuals (including use of surveys where the investigator and the participant never meet or talk)?

- When there is an intervention or interaction with a living individual for the primary purpose of obtaining data regarding the effect of the intervention or interaction, the data are considered to be about the living



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individual.)	
<input type="checkbox"/> <b>Yes</b> STOP: Go no further! The project IS considered Human Research and IRB review WILL BE required. Complete the appropriate Human Research Form.  <input checked="" type="checkbox"/> <b>No - Go on to question #4</b>	<b>Provide Explanation:</b> The data to be used has already been collected under a U of A IRB-approved research project and a project previously judged not to be human subject research, which data has been collected following another institution's IRB protocols. The researcher will not interact with individuals for this study.
4 Can individual identities be readily ascertained (or associated with the data), by the PI or project staff? • Examples of items that would make an individual readily identifiable include, but are not limited to, any of the following: first and last name, social security number, current street address, telephone number, email address, driver's license number, medical record number, **see this <a href="#">website</a> and <a href="#">45 CFR §164.514(b)</a> for the full list of HIPAA identifiers.**	
<input type="checkbox"/> <b>Yes</b> STOP: Go no further! The project IS considered Human Research and IRB review WILL BE required. Complete the appropriate Human Research Form.  <input checked="" type="checkbox"/> <b>No - Go on to question #5</b>	<b>Provide Explanation:</b> Data is de-identified. Any linkage to individual information has been removed according to procedures described in the IRB-approved project Number: 10-0552-02 (Reasoning Tools for Understanding Water Systems). Data available from the other institution's project is accessed through secure web-server and has been de-identified. Therefore, no individual information about identities can be ascertained from the data.
5 Is the data collected considered "private" information? • Is it specific information/data that the individual can reasonably expect will not be made public, or is it in a context in which the individual would otherwise expect that no observation or recording was taking place? Review this <a href="#">CHRP guidance</a> on research involving coded private information.	
<input type="checkbox"/> <b>No</b> STOP: Go no further! The project is not considered Human Research; IRB review is not required.  <input checked="" type="checkbox"/> <b>Yes - Go on to question #6</b>	<b>Provide Explanation:</b> The collected information is part of normal school/academic activities intended to be seen by education staff, such as class work, and student assessment responses. De-identified interview transcripts represent information about academic subjects given by participants.
6 Do individual records have a unique identification number? (Review this <a href="#">link</a> and contact HSPP staff for confirmation.)	
<input type="checkbox"/> <b>No</b> The project <u>may not</u> involve human subjects and <u>may not</u> require IRB review; confirm with HSPP staff.  <input checked="" type="checkbox"/> <b>Yes - Go on to question #7</b>	<b>Provide Explanation:</b> Individual records are a number for a test or interview event and/or for an individual. Only a number has been assigned automatically to the individuals and/or the events.
7 Is the identification code attached to or replacing any data items that make the individual readily identifiable? • This includes cases where there exists a master list connecting individuals and unique identification numbers, which is called "coded information."	
<input checked="" type="checkbox"/> <b>No</b> STOP: Go no further! The project is not considered Human Research; IRB review is not required.	<b>Provide Explanation:</b> There is no master list available that connects individual with any of the data. The data has been de-identified according to the procedures from the research projects they are obtained from.



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<input type="checkbox"/> Yes - Go on to question #8	
<p><b>8 Do any of the project personnel have access to this information?</b></p> <ul style="list-style-type: none"> <li>One way to substantiate No is to sign a <i>Data Use Agreement</i> with the owner or source of the data, prohibiting anyone on the staff of the project from having access to personal identifying information. The IRB is not required to review this agreement, although it must go to the Privacy Officer. Other ways include legal requirements preventing disclosure, or IRB-approved written policies and operating procedures that prohibit release of data under any circumstances.</li> </ul>	
<input type="checkbox"/> Yes The project <b>IS</b> considered Human Research and IRB review <b>WILL BE</b> required. Complete the appropriate Human Research Form.	Provide Explanation:
<input type="checkbox"/> No The project is not considered Human Research; IRB review is not required.	



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## SECTION 2. PROTOCOL

Complete all the following sections, addressing each of the bullet points in paragraph format. Please provide a lay summary for all items below. When you write a protocol, keep an electronic copy. You will need to modify this copy when making changes.

**\*\*Note that any changes made to this protocol after receiving HSPP confirmation will need to be re-submitted and reviewed.\*\***

### 1. Objectives:

*a. Describe the purpose, scientific aims, or objectives of the project.*

This project is a study of students' talk about an academic topic (science) in the context of school. The researcher will use theoretical frameworks to analyze grammatical and lexical patterns in students talk, aiming at obtaining knowledge about students' cognition. The researcher will also study the effects of being an English language learner in the analysis of student talk about science in school.

*b. State the hypotheses to be tested*

Students who have a linguistic background different from English have similar patterns of cognition in English when talking about a science topic in school.

### 2. Background:

*a. Provide the scientific or scholarly background and rationale for the project bases on the existing literature*

Today's classrooms show an increasing cultural and linguistic diversity that poses challenges to teaching science. While educational researchers have learned from multicultural perspectives that it is important to understand and include different cultures and cultural knowledge (e.g. language) in the designs of teaching (e.g., González, Moll, & Amanti, 2005; Moje, Collazo, Carrillo, & Marx, 2001), I propose that a different and fruitful perspective rests in attending to commonalities of languages.

Regardless of the language, pre-linguistic experiences influence how people conceptualize phenomena in the world in principled ways. Cognitive linguistics is a field of study in cognitive science that attends to the ways in which pre-linguistic experiences and/or interactions with the physical world shape the language humans use to communicate and make sense of more abstract endeavors, such as science (Pinker, 2010). Whereas linguistic diversity is emphasized in multicultural perspectives, cognitive linguistics offers a frame to search for general principles of cognition that are expressed in different languages. These principles are observable in the grammar and lexical choices that people use in order to communicate, and are structured as *schemas*. Schemas should be understood as an abstract characterization of patterns of experience that holds meaning. I propose to study how these schemas or patterns of cognition are present in linguistically diverse middle school students' language when learning science.



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*b. Describe the relevant prior experience and gaps in current knowledge.*

Several authors have initiated work using the cognitive linguistics framework to address problems of teaching and learning in science education. Nehm and colleagues (2010) have studied the use of lexical items that relate to “force” in college students’ language about evolution, focusing on understanding the accurate or inaccurate use of the word for explanations of evolutionary concepts. Brookes and Erika (2007) have used cognitive linguistics analyses to study the role of language in students’ learning of quantum mechanics. They concluded that the grammar and lexicon physicists use to represent phenomena has implications in students’ learning of quantum mechanics, and that students struggle to interpret some of the language patterns used by physicists for teaching scientific concepts.

Cognitive linguistics, cross-linguistic, and cross-cultural studies point to the need of exploring not only embodied experiences, but also some of its cultural products (Sinha & De López, 2000). Recently, Niebert and colleagues (2012) have argued that understanding and thinking about science, and teaching science, are not possible without some conception of embodiment. These authors take the analytical category *conceptual metaphor* and show their importance for understanding science. Conceptual metaphor is a mapping between an abstract (target) domain to a concrete (source) domain of experience (Lakoff & Johnson, 1980). For instance, the authors talk about the implications of using the conceptual metaphor “The gene is a code” for teaching about DNA because of the ambiguity of the source domain (code) and its lack of embodiment. A collection of theoretical essays and conference presentations that have recognized the potential for cognitive linguistics in science education adds to this small sample of literature (Fuchs, 2007, 2009, 2010), and also show how germinal this work is. Work in science education with the purpose of describing students’ learning or cognition has yielded progressions of student science learning throughout their school years (Gunckel, Covitt, Salinas, & Anderson, 2012; Gunckel, Mohan, Covitt, & Anderson, 2012; Mohan, Chen, & Anderson, 2009). These authors have mentioned distinctive forms of discourse that are associated to schematic patterns such as those that talk about actors and enablers as explanatory for scientific phenomena in water and carbon cycling. For example, they show how students at the lower levels of the progression describe phenomena in terms of natural tendencies or human actors (e.g., “sunlight goes into the leaves” [to contribute to plant growth]; “clouds separate the salt from the water”). While all of the research is germinal, the field of science education can benefit from understanding the cognitive patterns of student talk from the perspective of cognitive linguistics. These benefits can stimulate new ways of addressing teaching science to linguistically diverse students.

*c. Describe any relevant preliminary data.*

While there is preliminary data on the IRB-approved project Number: 10-0552-02 (Reasoning Tools for Understanding Water Systems) and the Learning Progressions for Water project (no U of A number), none of it has been analyzed for the specific purposes stated on this research summary. Being a proposed new use of the data, preliminary relevancy is not available.



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- d. Explain the significance of the project in terms of why this project is important, how it will add to existing knowledge, and the importance of the knowledge expected to result.*

This study can have an impact on the educational problem of teaching science to linguistically diverse students. Description of students learning and cognition from linguistic evidence can provide new perspectives for judging students' work and scientific knowledge about water. Principles of teaching derived from the conclusions of this exploratory study can provide insights to teaching interventions in water. The science education and research community will learn more about diverse students in science classrooms.

### **3. Setting of the Project:**

- a. Describe the setting and location in which the project will be conducted.*

The whole set of analyses for this project will be conducted in the dependencies of the University of Arizona.

- b. If the project will be conducted outside of Tucson, AZ, describe:*
- i. Site-specific regulations or customs affecting the project.*
  - ii. Local scientific and ethical review structure.*
  - iii. Composition and involvement of any community advisory board.*

### **4. Procedures involved in the project: Describe and explain the project, including its design.**

The research design of this study benefits from a mixed methods approach. I rely on content analysis (Krippendorff, 2004) of student spoken and written language. I will have a collection of texts that are samples of students written and spoken language in the context of their learning about water. I will examine the texts using analytical categories such as grammatical patterns, semantical patterns, and lexical categories. Each text will have a linkage to relevant information about the producer (such as first language or grade level). Also each text, after the analysis, will have a set of descriptors (codes) that will characterize the relevant attributes for the cognitive linguistic analysis. Statistical comparisons will be performed in the basis of relevant variables that result from the exploratory analysis.



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**SECTION 3: SIGNATURES**

It is against Federal regulations to conduct research involving human subjects without prior IRB approval. Projects that do not require IRB/HSPP oversight may still have other requirements.

- Projects involving Native Americans or international indigenous groups, including the use of existing information or specimens, may require review and approval by the tribe(s) involved, prior to beginning your project.
- Projects involving deceased persons and involving Protected Health Information may fall under HIPAA regulations. Contact the HIPAA Privacy Officer, Jeniece Peole at (520) 621-1465. If at the SAVAHCS, contact the Privacy Officer, Donna Wilson at (520) 792-1450, option 1, extension 4347.

If you have any questions or are unsure how to answer these questions, please contact the HSPP office at (520) 626-6721 BEFORE beginning your project. Violating Federal regulations is a serious matter and may result in the suspension of your research and/or loss of federal funding.

Please note: if you determine that this activity is not considered human research and, therefore, does not require IRB review, such determination cannot for any reason be reversed or revoked at a later date for any part of the project. Further, data derived from this project may not in any way be presented as Human Research. \*\*Note that any changes made to this protocol after receiving HSPP confirmation will need to be re-submitted and reviewed\*\*

**1. PRINCIPAL INVESTIGATOR (REQUIRED)**

By signing below, I, the Principal Investigator, certify that I have accurately answered the items listed and believe that the proposed activity does not constitute engagement in Human Research according to DHHS or FDA regulations.

		Ivan Salinas, Teaching, Learning and Sociocultural Studies
Signature	Date	Print Name & Department Kristin L. Gunkel, Teaching, Learning and Sociocultural Studies
		Print Name & Department
Advisor Signature	Date	

**2. SCIENTIFIC/SCHOLARLY REVIEW (REQUIRED)**

Based on the information provided by the Principal Investigator, I have determined that this project does not constitute Human Research.

Signature	Print Name
Title	Date

**3. HSPP REVIEW**

Based on the information provided by the Principal Investigator, I have determined that this project does not constitute Human Research.

Mariette Marsh

Digitally signed by Mariette Marsh  
 DN: cn=Mariette Marsh, o=HSPP,  
 ou=Chair Designee,  
 email=marsm@email.arizona.edu, c=US  
 Date: 2013.01.04 13:46:33 -07'00'



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### Submitting documents to the IRB

The required method of submission is electronic. Maintain electronic copies of all information submitted to the HSPP office in case revisions are required. Guidelines have been established and must be followed to make the electronic submission and triaging work smoothly.

1. Documents must be submitted to the [VPR-IRB@email.arizona.edu](mailto:VPR-IRB@email.arizona.edu) account and not to individual staff email accounts. After contact by a staff member future correspondence may be communicated directly to the staff member.
2. If acknowledgement of receipt is needed, please request a "Read Receipt" through your email server. If you use Microsoft Outlook 2007, this is accomplished by clicking "Options" and choosing the "Request a Read Receipt" checkbox in a new email. One submission request per email (e.g. one continuing review plus attachments).
3. All submissions must have signatures. An email acknowledgement in place of a signature will not be acceptable.
4. Word documents are preferable for items that may be modified or revised by the IRB (e.g. consents, applications, and protocols). PDFs may be submitted for documents that typically are not revised by the IRB (e.g. Investigator Brochures).
5. Email subject line must include: PI Last Name, Department, IRB # (if assigned one), and type of submission (Modification, New Project, etc.).
6. The email must provide a list of the documents submitted for review. While the documents attached do not have to adhere to a specific naming scheme, it is requested that each document be named to clearly reflect what is inside.
7. Submissions not following these guidelines will be returned not reviewed.

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