

AN ABSTRACT OF THE DISSERTATION OF

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Title: Teacher Argumentation in the Secondary Science Classroom: Images of  
Two Modes of Scientific Inquiry

Abstract approved:

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The purpose of this exploratory study was to examine scientific arguments constructed by secondary science teachers during instruction. The analysis focused on how arguments constructed by teachers differed based on the mode of inquiry underlying the topic. Specifically, how did the structure and content of arguments differ between experimentally and historically based topics? In addition, what factors mediate these differences? Four highly experienced high school science teachers were observed daily during instructional units for both experimental and historical science topics. Data sources include classroom observations, field notes, reflective memos, classroom artifacts, a nature of science survey, and teacher interviews. The arguments were analyzed for structure and content using Toulmin's argumentation pattern and Walton's schemes for presumptive reasoning revealing specific patterns of use between the two modes of

inquiry. Interview data was analyzed to determine possible factors mediating these patterns.

The results of this study reveal that highly experienced teachers present arguments to their students that, while simple in structure, reveal authentic images of science based on experimental and historical modes of inquiry. Structural analysis of the data revealed a common trend toward a greater amount of scientific data used to evidence knowledge claims in the historical science units. The presumptive reasoning analysis revealed that, while some presumptive reasoning schemes remained stable across the two units (e.g. 'causal inferences' and 'sign' schemes), others revealed different patterns of use including the 'analogy', 'evidence to hypothesis', 'example', and 'expert opinion' schemes. Finally, examination of the interview and survey data revealed five specific factors mediating the arguments constructed by the teachers: view of the nature of science, nature of the topic, teacher personal factors, view of students, and pedagogical decisions. These factors influenced both the structure and use of presumptive reasoning in the arguments. The results have implications for classroom practice, teacher education, and further research.

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Teacher Argumentation in the Secondary Science Classroom: Images of Two  
Modes of Scientific Inquiry

by  
Ron E. Gray

A DISSERTATION

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degree of

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presented on November 24, 2009.

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Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Ron E. Gray, Author

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# Teacher Argumentation in the Secondary Science Classroom: Images of Two Modes of Scientific Inquiry

## CHAPTER 1 INTRODUCTION

### *Introduction to Inquiry in Science and the Science Classroom*

The term “scientific inquiry” has multiple meanings (National Research Council [NRC], 2000). Within science, it refers to “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” ([NRC], 2000, p. 1). It is the process by which the “final form” science (Duschl, 1994) found in textbooks is constructed. In science education, however, the term also refers to a teaching approach for instruction in the traditional content. These two definitions, inquiry in science and inquiry in the classroom, while focusing on different outcomes, are linked. If the reason for engaging in inquiry in the classroom is to provide students with the most authentic experiences of scientific inquiry possible in that context, any developments in our conceptions of inquiry in science would necessarily impact our use of inquiry in the classroom.

As described in detail in the next chapter, our understanding of inquiry in science has broadened dramatically in terms of our understandings of the variety of methodologies employed in the sciences and the intersubjective nature of science itself. In other words we have expanded our understanding of the actual manner by which scientific knowledge is constructed in the various sciences as well as the communal nature of this activity (Latour & Woolgar, 1979).

In the science classroom the description of the methods of science has been traditionally reduced to a systematic progress through the steps of the “scientific method.” For example, a recently published high school biology textbook explains the “steps” as the following: observing, making a hypothesis, collecting data, publishing results, forming a theory, developing a new hypothesis, and revising the theory (Biggs, Gregg, Hagsins, Kapicka, Lundgren, and Rillero, 2002).

However, recent scholarship into scientific inquiry within the diverse disciplines and fields of science has called into question the traditional “scientific method” still prevalent in today’s science textbooks and classrooms (Rudolph, 2005). This narrow, positivistic view of scientific inquiry presents hypothesis testing and experimentation as necessary elements of scientific knowledge construction, to the exclusion of other modes of inquiry. Recently, however, science educators have begun to examine alternatives to the traditional view of the scientific method by exploring the diverse range of methods of inquiry prevalent in modern science with the intent of informing inquiry in the classroom (Ault, 1998; Dodick, Argamon, & Chase, 2009; Dodick & Orion, 2003; Rudolph, 2005).

Relevant to this study is a distinction made by Dodick et al. (2009) between scientific topics justified by differing methodologies. The researchers propose two distinct categories of sciences: experimental and historical. These two categories are distinguished by differences in their methodologies that justify their knowledge claims. These categories allowed the researchers to examine the distinctions using a linguistic analysis (described further in Chapter 2) and are

used in this study to represent distinctions made by research in the history, philosophy, and sociology of science.

Experimental and historical sciences differ in terms of the general methodologies employed to answer different types of scientific questions. For example, experimental sciences, such as chemistry and physics, are those justified primarily by experimental methodologies in which predictions can be made and nature is manipulated in order to test a model or theory. Scientists in those fields attempt to answer questions about current phenomena that can be examined and manipulated in real time. Historical sciences such as paleontology and cosmology, on the other hand, primarily rely not on experimentation but on the logical coherence of explanatory models in regards to available evidence. Scientists in these fields attempt to explain events, often in the past, that cannot be recreated for experimentation (e.g. the big bang). Thus explanatory accuracy replaces predictive accuracy in the historical sciences.

As scientific knowledge is justified by its methodologies, having a restricted conception of the methods of scientific inquiry can cause misunderstandings to form. For instance, it is well documented in the science education literature that students hold naïve realist perceptions of the nature of scientific inquiry and often privilege demonstration and experimentation over other forms of reasoning (Ryan & Aikenhead, 1992). This leads to a prevalent misunderstanding about the legitimacy of historical sciences that attempt to recreate past events through methods that do not map well onto the traditional scientific method (Gould, 1986; Dodick & Orion, 2003). Some historically-based

topics include continental drift, the meteorite-impact extinction of the dinosaurs, and the big bang origin of the universe; all of which are commonly seen as less scientific by many scientists and the public alike (Cleland, 2001).

This misunderstanding of the legitimacy of these sciences in comparison to experimental sciences is most prevalent in the debates over evolution in the science classroom. It is this connection to the evolution/creationism debates that periodically appear in the science education landscape that led to my interest in this topic. I believe it is essential that students are presented authentic images of historical sciences in order to fully understand how these sciences are justified within the scientific community. To do so, research has shown the importance of language in doing and learning science (Lemke, 1990; Pera, 1994).

### *Language in the science classroom*

Our understanding about how scientific knowledge is constructed and how students learn science has changed dramatically over the past century. In both cases, the dominant views in each of these fields have taken an intersubjective turn (Bakhtin, 1986; Giere, 1988). This shift in focus from the individual knower to a community of learners, whether within the scientific community or a classroom community, has shaped the way in which science educators present the work of scientists. Vital to this intersubjective view is the use of language and discourse in scientific knowledge construction and student learning.

This study stems from a social constructivist framework that views thinking and learning as intersubjective in nature. This perspective is best



exemplified by the work of Lev Vygotsky and Mikhail Bakhtin. Central to this perspective is the assumption that higher mental functioning, or those functions that allow us to move from impulsive behavior to instrumental action, in the individual derives from social life (Vygotsky, 1978). Learning then involves a passage from social to personal planes and is consequent upon individual sense-making by the learner. Vygotsky (1978) states:

Every function in the child's cultural development appears twice: first on the social level, and later on the individual level; first, between people (interpsychological) and then inside the child (intrapsychological). This applies equally to logical memory, and to formation of concepts. All higher functions originate as actual relationships between individuals. (p. 57)

Language and other semiotic mechanisms (such as mathematical symbols, diagrams, gesture, etc.) mediate this process and, following the process of internalization, provide the tools for individual thinking. In this way talk and thought are portrayed as being intimately related.

Bakhtin went further and developed an account of discourse as a situated event mediating the interactions of speakers and listeners (Bakhtin, 1986). To Bakhtin, all discourse, including spoken and written, is inherently “dialogic” as each utterance is linked in a “chain of communication” as it “refracts” previous voices while anticipating the response of others. He referred to this process as addressivity.

In analyzing the content of language and thought, Vygotsky (1986) distinguishes between “spontaneous” (or “everyday”) concepts and “scientific” concepts. Spontaneous concepts are taken as those which are learned without

conscious attention, through normal day-to-day interactions, while scientific concepts are those formal concepts which originate in particular disciplines (such as physics, history or psychology) and which can only be learned through instruction.

The differentiation of the content of talk and thought has been elaborated by Bakhtin (1986) who further described the language-mediated passage between the personal and social planes. Bakhtin refers to the different *social languages* used by specific communities of people for particular purposes. For Bakhtin, a social language is, “a discourse peculiar to a specific stratum of society (professional, age group, etc.) within a given system at a given time” (1981, p. 430). Thus, science can be construed as the social language that has been developed within the scientific community. In terms of education, learning science involves learning the social language of the scientific community, which must be introduced to the learner by a teacher or some other knowledgeable figure (Vygotsky, 1986). Interestingly, this intersubjective view of learning maps well with recent developments in our understanding of the intersubjective nature of the social construction of scientific knowledge (Driver, Newton, & Osborne, 2000).

#### *Argumentation in the science classroom*

The study of discourse practices in science education rests on a definition of discourse as using language in social contexts (Bakhtin, 1981). Of the many discourse practices prevalent in the science classroom (e.g. questioning, small

group discourse), argumentation is used in this study due to its central importance to the social construction of scientific knowledge.

Argumentation is a genre of discourse central to doing science (Driver, Newton, & Osborne, 2000; Kelly, Chen, & Crawford, 1998; Kuhn, 1992; Lemke, 1990). Three distinct forms of argumentation are recognized in the sciences—analytical (or formal); dialectical (or informal); rhetorical (or persuasive) (van Eemeren, 1996). Analytical arguments are grounded in the theory of logic and include, for example, syllogisms and mathematical reasoning. Dialectical arguments are those that occur during discussion or debate and involve reasoning with premises that are not evidently true. They involve coming to a consensus amongst the participants. Rhetorical arguments, on the other hand, are oratorical in nature and are represented by the discursive techniques employed to persuade an audience. In contrast to the other two forms of argument where the consideration of evidence is paramount, rhetorical arguments stress knowledge of audience as a prerequisite for successful persuasion.

Whereas final scientific reports such as those in journals and textbooks typically portray science as purely analytical, research in science studies reveal that much of science involves dialectical and rhetorical argumentation schemes as well (Dunbar, 1995; Latour & Woolgar, 1979; Longino, 1994; Gross, 1996). These forms of argumentation are also those most commonly found in classrooms (Driver et al., 2000). For example, a lecture in which a teacher marshals evidence and constructs an argument for a scientific topic is largely rhetorical in nature in that it is merely presented to students. On the other hand, a group discussion in

which multiple participants (teachers and students) provide and engage with evidence, both shaping the argument in an effort to reach agreement, is dialectical in nature. Both of these modes of argumentation are typically found in science classrooms.

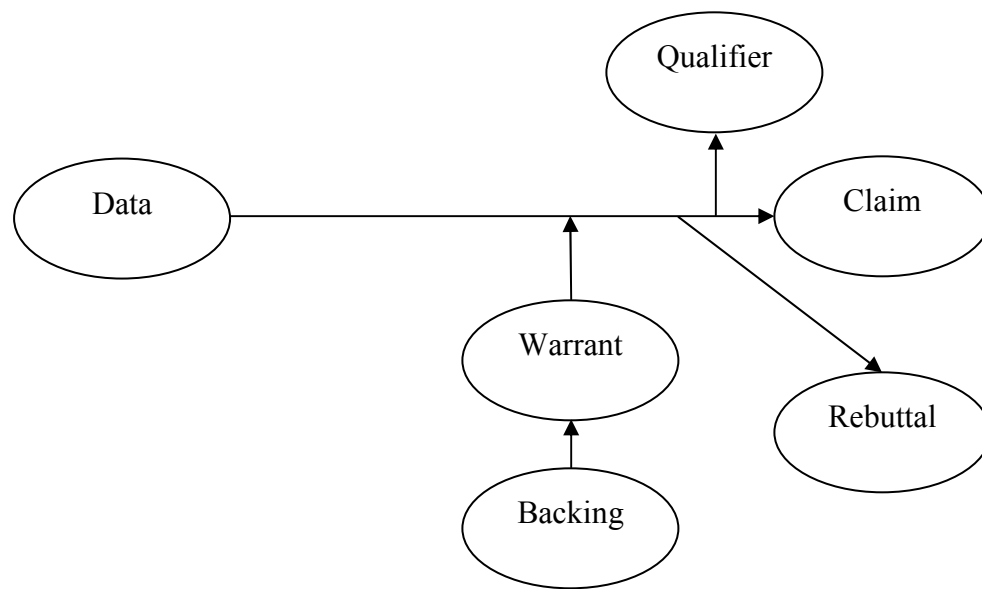
While much of the early research on argumentation focused on analytical argumentation, Toulmin (1958) sought to describe how to explain everyday, or informal, argumentation in terms of rhetorical and dialectical arguments. According to Toulmin, an argument is “a movement from accepted data, through a warrant, to a claim.” Toulmin’s model of argumentation was considered the first to challenge the “truth” seeking role of formal argumentation. Instead, Toulmin’s model focuses on the rhetorical elements of argumentation and their justificatory functions (Osborne, Erduran & Simon, 2004).

In *The Uses of Argument* (1958), Toulmin proposes a model containing six interrelated components for analyzing arguments (Figure 1.1):

1. Claim: An assertion put forward publicly for general acceptance.
2. Data: Facts or evidences which provide support for the claim.
3. Warrants: Statements which provide a link between data and a claim.
4. Backings: Generalizations making explicit the body of experience relied on to establish the trustworthiness of the ways of arguing applied in any particular case.
5. Rebuttals: The extraordinary or exceptional circumstances that might undermine the force of supporting arguments.
6. Qualifiers: Phrases that show the degree of reliance to be placed on the conclusions, given the arguments available to support them.

According to Toulmin, a claim is the base for all arguments. Toulmin indicates that a good argument needs to provide good justification for a claim, which can be achieved by providing warrants (explicit justifications) or backings (implicit

justifications). This focus on the structure, as opposed to the content, of the argument allows for an analysis of the differences in arguments among different scientific disciplines as well as within different contexts (i.e. science and school science) (Driver et al., 2000). For instance, the warrants and backings used to make claims are shaped by the guiding conceptions and values of the field. This is due to the fact that in science what counts as evidence and the theoretical assumptions driving the interpretations of that evidence are socially agreed by the community.



*Figure 1.1 Toulmin's Argument Pattern (Toulmin, 1958)*

Toulmin indicates that claims, data, warrants, and backings are the essential components of practical (simple) arguments, while “qualifiers” and “rebuttals” may be needed in more complex arguments. Toulmin’s argumentation model generated interest among researchers from many different areas including

science education because of its utility in differentiating quality of arguments reflecting reasoning behind them.

Analyses of arguments constructed by students using Toulmin's argument framework have primarily examined how students provide warrants for claims, when they do so, and on what basis (e.g., Jimenez-Aleixandre, Rodrigues, & Duschl, 2000; Kelly, Druker, & Chen, 1998; Osborne, Erduran, & Simon, 2004). These studies have provided a great deal of information about the form of student talk or writing in various settings but have provided little information about how well students engage in argument construction in terms of content quality. As a result, analytic methods that examine argument quality solely from a structural perspective provide little or no information about how students' conceptual ideas about the subject matter influence how they coordinate theory with evidence as they construct an argument in support of a particular viewpoint (i.e. the content of the argument).

Another avenue has sought to focus on the logic and content of dialogue for the analysis of argumentation discourse in science classrooms and the underlying presumptions in the argument. Walton (1996) has identified 25 schemes of argument which are commonly used in the construction of arguments in what he terms presumptive reasoning. He defines presumptive reasoning as that reasoning which occurs during a dialogue when a course of action must be taken and all the needed evidence is not available. Argumentation schemes that focus on presumptive reasoning focus on the evidence and premises a person uses and force the respondent to examine the premises held by the other. They shift the burden of

proof from the individual advancing the claim to the respondent as, in essence, the argument is true until proved otherwise. Such reasoning is rooted in the idea that “if the premises are true (or acceptable), then the conclusion does not follow deductively or inductively, but only as a reasonable presumption in given circumstances, subject to retraction if those circumstances should change” (Walton, 1996, p. 13).

The use of presumptive reasoning can be employed as a framework to analyze classroom arguments because it reflects quite well what typically happens in science classrooms (Duschl & Osborne, 2002). It also complements the weakness of the Toulmin model in that it focuses not on the structure, but the content of the argument. By using these two frameworks for an analysis of a teacher’s argument, differences in terms of both the structure and the content of the arguments can be examined and compared to our understandings of the differences between arguments for experimental and historical sciences.

Within the past two decades, science education researchers have conducted many studies of argumentation in the classroom. The majority of these studies, however, have involved the use of argumentation by students during inquiry investigations (e.g. Erduran, Simon, & Osborne, 2004) or discussing socioscientific issues (e.g. Sadler & Donnelly, 2006). These studies have used mainly Toulmin’s argumentation pattern to assess the quality of student arguments during activities designed to prompt scientific argumentation in the classroom.

Relatively few studies have been conducted on argumentation by teachers (Carlsen, 1997; Russell, 1983). These few studies focused on how teachers use

authority to control classroom discourse. In addition, analysis of teacher argumentation in the classroom has not been used to examine the manner by which teachers present images of scientific inquiry to their students or the factors that mediate those images. Thus, this exploratory study marks an initial step in a research program to improve secondary science teachers' instruction on the methods of scientific inquiry.

Purpose of the Study:

The purpose of this study is to examine the differences between the arguments constructed by secondary science teachers during instruction of science topics that rely on different modes of inquiry. The study will also examine the factors influencing those differences.

Research Questions:

1. What structural differences exist between scientific arguments constructed by secondary science teachers for experimental and historical science topics?
2. What differences exist in terms of the types and/or frequency of presumptive reasoning schemes in arguments constructed by secondary science teachers for experimental and historical science topics?
3. What factors affect the arguments constructed by secondary science teachers?



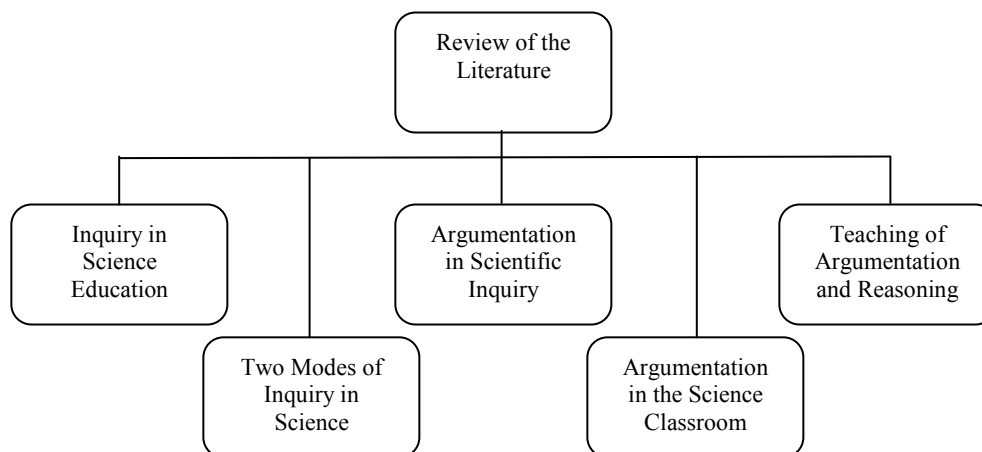
### Significance of the Study

This study is significant in two important ways. First, the study is designed to advance knowledge in the field of science education. In particular, the results of this study fill a gap in the literature in terms of our understanding of the way in which secondary science teachers justify their scientific knowledge claims to their students while teaching topics that rely on diverse modes of inquiry. This study will provide evidence in terms of the structure and use of presumptive reasoning schemes for the arguments the participating teachers construct for their topics as well as the factors mediating those arguments. These results will have implications for classroom practice, teacher education, and research.

Second, this study extends the methodology previously applied to argumentation analysis. Whereas most studies have been conducted on the level of a section of classroom conversation or, in one instance, across a single class session, the analysis of this study is at the level of an instructional unit. This allows for a more complete view of the image presented to students for each topic. Therefore, this study design extends not only our knowledge of teacher argumentation in the classroom, but the possible methods that can be used to answer similar questions in the future.

## CHAPTER 2 REVIEW OF THE LITERATURE

This review of the literature examines developments in our understandings of inquiry in science education as well as different modes of inquiry in science. This is followed by an examination of research into the role argumentation plays in science and the science classroom. The review ends with an examination of the link between argumentation and reasoning.



*Figure 2.1: Organization of Chapter 2*

### *Inquiry in Science Education*

While the current focus on inquiry in science education was born in the curriculum reform movement of the 1950s and 60s (Schwab, 1958), the present resurgence in recent science education reform manifests as the standards-setting publications *Science for All Americans* ([AAAS], 1990) and the *National Science Education Standards* ([NRC], 1996). Not surprisingly, this emphasis on inquiry

has coincided with a renewed emphasis on the nature of science which encompasses both an appreciation of what happens in science communities at the micro level (e.g. the lab bench) as well as the macro level (e.g., the organization of science in society) ([AAAS], 1990; [NRC], 1996). These two levels intersect in the classroom: inquiry as the instructional model and the nature of science as a learning goal.

The state of contemporary research into the definition of the nature of science is complex and contested terrain (Bianchini & Solomon, 2003). Some researchers have generalized the perspectives from science studies including the philosophy, history, and sociology of science as well as the results of research on “science-in-action” (Latour, 1988) to a lower-level core set of universal statements around which a consensus among educators can be constructed (Abd-El-Khalick & Lederman, 2000; Matthews, 1994; McComas, 1998; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). For example, Abd-El-Khalick and Lederman (2000) define the nature of science as: (a) tentative (subject to change); (b) empirically-based (based on and/or derived from observations of the natural world); (c) subjective; (d) partially based on human inference, imagination, and creativity; and (e) socially and culturally embedded. In addition, they include the distinction between observation and inference, and the functions of, and relationship between, scientific theories and laws.

Recent developments in science studies, however, have begun to call into doubt the reliability of universal characterizations of the nature of science (Galison & Stump, 1996). A view of science is forming in which it is best understood as a

kind of situated practice, dependent on the interactions of communities of researchers and historical circumstances within fields of study and even individual research groups (Buchwald, 1995; Galison & Stump, 1996; Knorr-Cetina, 1999; Pickering, 1995a, 1995b; Rouse, 1996). According to Pickering, this new understanding of science as situated practice is based upon the realization that to “make sense of science one has to think about both scientific knowledge and the practice with which it engages” (1995b, p. 42). In other words, we should “see science more accurately as an array of multiple, heterogeneous practices that are informed very little by the various universalist accounts” (Rudolph, 2000, p. 408).

Some science education researchers have taken this view of science as situated within a community of practice and focused on the context-dependent nature of scientific inquiry (e.g. Rudolph, 2000). This notion goes back to the writings of John Dewey (1933) and later Joseph Schwab who claimed that scientific knowledge was “unintelligible or misleading” unless it is understood in “the context of inquiry which structured and bounded the matters” to which it refers (1958, p. 375). This, coupled with a view of science taken from the literature of the science studies community, allows educators to provide a reasonably authentic context in which to situate their curricular knowledge claims for their students.

### *Two Modes of Inquiry in Science*

Providing a reasonably authentic context for science learning requires a greater understanding of the actual methods of inquiry as practiced in diverse

disciplines. Beginning in the late 1970s, ethnographic methods from sociology and anthropology were employed to document the activities in a variety of sciences. These include biology (Latour & Woolgar, 1979), biochemistry (Knorr-Cetina, 1981), chemistry (Law & Williams, 1982), neurobiology (Lynch, 1987), and various fields within physics (Collins, 1992; Pickering, 1995a; Traweek, 1988). In addition, cognitive scientists became interested in the process of science in the 1990s. At first in the psychology laboratory (Klahr & Dunbar, 1988), then analyzing research artifacts (e.g. research notes and diaries) (Giere, 1988; Nersessian, 1992), and finally in the science laboratory setting (Dunbar, 1995; Nersessian, 2005), these researchers focused on exposing the underlying reasoning and thinking processes of scientists. With few exceptions (e.g., Roth & Bowen, 2001), however, the vast majority of these studies have been in laboratory-based, or experimental, disciplines as opposed to field-based, or historical, disciplines giving the mistaken impression that the two types of disciplines function in a similar fashion.

Science educators have begun to mine other fields to describe a diverse array of disciplines focusing on the diversity of goals, methodologies, and justifications. For example, Ault (1998) has sought to explain inquiry in the geological sciences. Often in geological science fields, the criteria that define inquiry include the key understanding that geological reasoning relies on contingency and ambiguity in explanations of phenomena and does not attempt universal explanation or prediction (Ault, 1998). As he points out, “geology is not physics” (p. 190). The goal of geology is to reconstruct geologic features and

processes that cannot be recreated in a laboratory. Expert understanding in geology requires restricting the ambiguity inherent in inquiry about unique events and their products which can be achieved through methodologies such as comparative analysis and a theoretically grounded taxonomic structure that provides a basis for case-dependent explanations. Geologists use their understandings of not just categories, but exceptions to categories, to produce contingent explanations that constrain, but do not erase, ambiguity and expectation. These knowledge claims are justified not by experimental evidence, but by explanatory power. Similar explorations have been conducted in evolutionary biology (Rudolph & Stewart, 1998; Passmore & Stewart, 2002) and genetics (Cartier & Stewart, 2000; Dodick & Orion, 2003), among others.

In order to compare the methods of inquiry found in science, Dodick, Argamon and Chase (2009) surveyed the relevant literature to find common criteria within the disciplines. Extending the distinctions set forth by Diamond (1997), they proposed two modes of scientific inquiry: experimental and historical sciences. Distinguishing between these categories depends on the answers to the following questions:

1. Is evidence primarily gathered by manipulation or observation?
2. Is research quality measured by effective prediction or explanation?
3. Is the goal of research to find general laws or statements or ultimate (and contingent) causes?
4. Are the objects of study uniform entities (which are interchangeable) or are they complex entities (which are unique)?

Experimental sciences (e.g., chemistry and physics) gather knowledge by controlled experimentation in which natural phenomena are manipulated in order

to test a model (or theory) (Table 2.1). The quality of such a model is measured by the consistency of its predictions with such experiments, and ideally, such a model expresses a general statement or causal law that is applicable to a wide variety of phenomena in many contexts. Finally, the form of such research is dictated largely by the study of uniform entities such as atoms or genes; the fact that such entities are identical, or nearly so, makes the formulation of general laws possible in principle, and experimental reproducibility a reasonable requirement in practice.

In contrast, historical sciences (e.g., paleontology and cosmology) investigate ultimate causes buried in the past, and whose effects are interpreted only after very complex causal chains of intervening events (Mayr, 1985) (Table 2.1). Accordingly, evidence is gathered by observation of naturally occurring traces of the phenomena, since manipulation is usually impossible (e.g., one cannot wait millions of years to wait for the results of a geological experiment!). This focus on past causation further implies that the ultimate test of quality in historical science is explanatory adequacy, rather than prediction because the phenomena under investigation are complex, unique and contingent, with a very low likelihood of repeating exactly. In other words, reasoning in historical sciences consists largely of reconstructive reasoning (retrodiction), as compared to predictive reasoning (Diamond, 1997; Gould, 1986).

*Table 2.1: Comparing Experimental and Historical Sciences*

	Experimental Science	Historical Science
Primary method of gathering evidence	Manipulation of nature	Observation of nature
Standard of measurement of research quality	Effective prediction	Effective explanation
Goal of research	To find general laws or statements	To find ultimate and contingent causes
Nature of objects under study	Uniform and interchangeable entities	Complex and unique entities
Example topics	Physics, chemistry, molecular biology, geophysics	Evolutionary biology, cosmology, paleontology

Researchers in science studies have consistently pointed to the essential role of language and its specific usages by practicing scientists (Dunbar, 1999; Graves, 2005, Halliday and Martin, 1993). This suggests that a focus on the patterns of language use may provide useful evidence of differing methodologies and justifications between these two modes of sciences. In other words, an understanding of these two different modes of reasoning and justification should be reflected in different modes of scientific communication.

#### *Argumentation in Scientific Inquiry*

While a recognition of the importance of language in science can be traced back to the 1960s (Bruner, 1960), it was not until the late 1980s when researchers began a serious discussion of the role language plays in science and science education (Aikenhead, 1991; Gee, 1996; Lemke, 1990; Sutton, 1992; Pera, 1994). Foundational to this research is the belief that knowledge is socially constructed and situated among participants in a community of practice. Lemke (1990) put



forth perhaps the most influential argument for the importance of language in science education. To Lemke, learning science is learning to talk science. Thus, science education can be conceptualized as students learning how to use the specialized language of science, given the constraints of their social and cultural contexts. This has led to research into discourse practices, and specifically argumentation, in both science and the science classroom (Kelly, 2007).

Argumentation is a genre of scientific discourse that refers to the ways in which evidence is used in reasoning (Kelly, 2007) and is now seen by many to be at the heart of science and central to the everyday discourse of scientists. Since the 1980s, the role of argumentation and of discourse more generally, has been studied in the domain of science. Contemporary views in the philosophy of science emphasize that science is not simply the accumulation of facts about how the world is, but it involves the construction of models, theories, and explanations about how the world may be (Giere, 1988). These explanations are open to challenge (Popper, 1959) and are constructed through dispute, conflict, and argumentation rather than through general agreement (Kuhn, 1962; Latour, 1988). As Pera (1994) states, science should be transferred “from the kingdom of demonstration to the domain of argumentation” (p. 47).

Researchers in science studies have utilized ethnographic methods to study science-in-action to further elucidate our understanding of the epistemological foundations of science and how practicing scientists actually do and think about science (e.g., Gieryn, 1988; Latour & Woolgar, 1979; Nersessian, 1992). For example, an anthropological perspective was taken by Latour and Woolgar (1979)

in their trend-setting study *Laboratory Life* which investigated biochemists' production of "facts... on an assembly line" by analyzing the written products of research activities as "inscriptions".

Related approaches, focusing on argumentation and discourse, have been used to study how scientists construct theories, negotiate claims, and interpret observations in organic chemistry (Bond-Robinson & Stucky, 2005), biology (Myers, 1990), biochemistry (Knorr-Cetina, 1981), biomedical engineering (Nersessian, 2005), and many fields within physics (Collins, 1992; Pickering, 1995; Traweek, 1988). The growing body of analyses of scientific communication includes few comparative works on how scientific communication may vary among different disciplines. What these studies, and the subsequent argumentation frameworks, leave out are the fields of science that do not rely on experimental justification. These include historical sciences such as geology, evolutionary biology, and cosmology which developed different methodologies to cope with problems that cannot be solved experimentally. Many have begun to critique the idea of "the scientific method" and separate experimental methodology from justification (Gould, 1986; Mayr, 1985; Rudolph & Stewart, 1998).

In order to test whether or not scientists use distinct argumentation patterns in these two different types of science, Dodick et al. (2009) conducted a linguistic analysis of research journals in these different fields. They found that indeed the style of writing and argumentation in historical sciences is readily distinguishable from that of the experimental sciences and, furthermore, that these differences are directly related to the methodological differences. For instance, historical sciences

justify their claims based on a greater number and variety of data which are compared and contrasted. Experimental sciences, on the other hand, are primarily justified by the experimental data and the match of that data to prediction. These different methodologies and justifications for knowledge claims were shown to lead to distinct differences in their argumentation structures. The authors conclude:

*In sum, these results show clear differences between writing in historical and experimental sciences, with the most distinguishing features consistently linked with the different modes of reasoning characteristic of these different kinds of science, supporting the notion that at least two different types of methodological reasoning and argumentation are used by working scientists when communicating their results, and that these methodological types are substantially different as philosophers and historians of science have described them. (p. 997)*

Therefore, this study provides a link between the different modes of inquiry justifying experimental and historical sciences, the science studies literature, and the role of language and argumentation in science.

From the perspective of Bakhtin's social languages (1986), the differences between different disciplines of science are expected. As discourse communities within disciplines evolve, their language, methodologies, and justifications for "what counts" in that discipline would be expected to become increasingly unique. Thus, differences in argumentation patterns between disciplines would be expected. Important to this study is the question of whether or not these differences exist and can be identified in the science classroom.

*Argumentation in the Science Classroom*

As argumentation is central to the practice of science, from a sociocultural perspective, it must also be a central tool for science learning since it provides learners with the appropriation of community practices including scientific discourse (Kelly & Chen, 1999). Thus, one goal for the integration of argumentation into the science classroom is that learners can experience scientific practices that situate knowledge production in authentic contexts, which provides them with opportunities to learn not only science content and its justification, but learning about science as well including the role of language, culture, and social interaction in the process of knowledge construction (Brown, Collins, & Duguid, 1989; Driver, Newton, & Osborne, 2000).

A number of studies have been conducted to find out how successful students are when they use reasoning and argumentation in different contexts (Kelly, 2002). For example, Jimenez-Aleixandre, Bugallo-Rodriguez and Dusch (2000) conducted a study on discussions of groups of students about a genetics problem set in a practical, “real life” context. Group discussions were transcribed and analyzed in terms of the elements of Toulmin’s argument model to represent arguments as group productions and to illustrate their structure. In analyzing the arguments made by the student groups, Jimenez-Aleixandre et al. (2000) found that the arguments were very limited in complexity, often warrants were not made explicit, and conceptual confusion affected the quality of the arguments. This study indicated that students have difficulties in marshaling evidence, drawing on their conceptual understanding of the topic, and composing arguments in support of scientific knowledge claims.

In their descriptive study, Robertmond and Shirley (1996) examined the discourse of six groups of four students during planning, execution, and interpretation of student designed experiments in a 10<sup>th</sup> grade science class over a 3-month period. Students worked as “scientific detectives” on a case study of the 19th century cholera epidemic in London. The course introduced students to the nature of scientific detective work and basic concepts of cell biology. The task expected of students was to build arguments for collecting and using data in a scientifically acceptable form. The researchers indicated that:

Two elements are essential if students are to become scientifically literate--that is, if they are to understand and make effective use of scientific tools and ideas in their execution and interpretation of experiments and in their discourse with others. First, there must be an opportunity for them to develop these tools and see their usefulness across a variety of problem-solving situations. Secondly, they must have the opportunity to see how these tools may be used to construct ideas about scientific processes and then to construct models or theories based on those ideas. (p.840)

As a result of the analyzed student discourse, the authors concluded that at the beginning, students were not able to construct arguments connecting to the procedural aspects of completing their investigations. Students had difficulty distinguishing between their results and what the observation meant. They also indicated that students spent time on procedural issues with little attention for understanding the conceptual basis of the problem at hand at the beginning. At the end of the program, students showed progress in terms of level of engagement with the problems, and they produced more sophisticated arguments (Robertmond & Shirley, 1996).

Another study (Druker, Chen, & Kelly, 1996) on students' argumentation skills reported an analysis of science students' arguments in the context of solving practical performance tasks. In this study, students worked on an electrical "mystery box" to investigate what the electrical components in a set of boxes might be by designing empirical tests. Discourses and discussions of students who worked in groups were analyzed using Toulmin's argument model. Results showed that students' arguments have errors in terms of the structure of arguments. Taken together, these studies reveal a need for explicit instruction on constructing arguments in the science classroom.

#### *Teaching of Argumentation and Reasoning*

Newton et al. (1999) indicated that experimental and investigational activities may lead students to appreciate that scientific theories are human constructs, and they need to postulate possible interpretations and then examine arguments in light of evidence. They conducted a study to examine the place of argumentation in science classrooms. They observed 34 science lessons and concluded that secondary science classrooms are strongly teacher directed. Students were given very few opportunities to contribute to the process of constructing knowledge in lessons. The results of their study revealed that the primary activity in the classrooms tended to be teacher talk. They note that this was dominated by exposition and teacher-led question-and-answer interactions. In a few cases, students were given opportunities to work in groups on experimental work where little guidance was provided by the teachers. As a result of limited

first hand experiences, students faced difficulties in organizing and managing arguments. Thus, they concluded that, if science is to be taught from the perspective of the social construction of knowledge, then there are important discursive processes that also need to be incorporated into practical and investigational work (Newton et al. 1999).

Research on higher order thinking in general, and on reasoning and argumentation specifically, suggests that teaching of these skills should include explicit goals and repetitive practices. In their study, Zohar and Nemet (2002) investigated the effects of a genetic revolution unit on students' biological knowledge and reasoning; specifically, an examination of the teaching of argumentation skills in the context of dilemmas in human genetics. Before instruction, only a minority (16.2%) of the students referred to correct, specific biological knowledge in constructing arguments in the context of dilemmas in genetics. During the implementation of the unit, students explicitly were taught some principles of a good argument, followed by intensive opportunities to exercise these principles in the context of specific science content. The authors concluded that integrating explicit teaching of argumentation into the teaching of dilemmas in human genetics enhances performance in both biological knowledge and argumentation skills (Zohar & Nemet, 2002). Therefore without clear and repetitive instruction of higher order thinking skills and argumentation, use of these skills is hard for students to master.

In their study, Hogan and Maglienti (2001) concluded that to foster students' ability of scientific reasoning, students need to participate over time in

explicit discussion of the norms and criteria that underline scientific work. They examined the difference between the process of reasoning that scientists and non-scientists use to build new knowledge. Scientists, technicians, non-scientist adults and middle school students were asked to rate the validity of a set of conclusions drawn from a body of evidence in this study. The researchers found a difference between participants without extensive science backgrounds and experience and those with more extensive science backgrounds and professional experience. Their results showed that students and non-scientist adults used their personal views, inferences, and criteria for judging the plausibility of conclusions. On the other hand, the scientists mentioned how they developed epistemological criteria such as empirical consistency through becoming active contributing members to their community of practice, and described how they translate these experiences into personal knowledge that they apply to evaluate claims.

For teachers to be able to appreciate the importance of reasoning skills, they also need to have an understanding of different thinking skills in general. Zohar (1999) indicated that metacognitive knowledge of thinking skills is essential for systematic teaching of higher order thinking. In order to accomplish this, teachers must consider thinking skills as an important goal of instruction. Zohar (1999) designed the project according to the infusion approach to teaching higher order thinking. Therefore, instruction of higher order thinking was integrated into the science curriculum rather than being taught as a separate subject. The types of activities in the project were designed to foster higher order thinking. For example, activities in the project included: inquiry and critical thinking skills learning;



investigation of micro worlds; argumentation skills about bioethical dilemmas in genetics, and open ended inquiry learning (Zohar and Nemet, 1999). As a result of an in-service teacher education program about thinking skills, the author found that metacognitive knowledge about thinking skills was not a familiar topic for teachers before the in-service education program. Another main finding of the study was that although some teachers used instruction of higher order thinking skills, they were not aware of it. Zohar indicated that teachers' use of higher order thinking was more likely an unconscious intuitive activity. Most teachers who participated in the study were highly proficient in solving problems requiring procedural knowledge of some thinking skills, but they were often unable to verbalize the thinking patterns they had used during the problem solving. The study also reported that an awareness of thinking skills as potential goals of learning activities is necessary for designing learning activities. Finally, teachers' intuitive declarative metacognitive knowledge of thinking skills was found to be unsatisfactory for the purpose of teaching higher order thinking in the science classroom. Zohar concluded by emphasizing the importance of explicitly designing courses which prepare teachers for instruction of higher order thinking.

Teachers' beliefs about higher order thinking in relation to student abilities are another factor influencing the use of higher order thinking strategies in classrooms. In their study Zohar, Degani and Vaaknin (2001) interviewed 40 teachers regarding their belief about low-achieving students and higher order thinking. Results of the study showed that 45% of the teachers believed that focus on higher order thinking is not appropriate for low-achieving students. These

teachers believed that low-achieving students should be taught by a transmission of knowledge approach because cognitive demands of tasks requiring higher order thinking were beyond the capabilities of low-achieving students. Some of the teachers (29%) participating in this study, on the other hand, did not indicate any distinction between low-achieving and high-achieving students in terms of ability to complete a task which required higher order thinking skills believing higher order thinking is an equally important educational goal for all students.

These differences were connected to the teachers' views of learning. According to the authors, teachers who had a more traditional view of teaching and learning, seeing learning as progressing from simple, lower order cognitive tasks, would be more likely to think that higher order thinking is not equally appropriate for low-achieving and high-achieving students. On the other hand, teachers who hold less traditional views about teaching and learning implied that thinking should be integrated into the very early stage of the learning process and teaching higher order thinking skills is equally suitable for both low-achieving and high-achieving students (Zohar, Degani & Vaaknin, 2001).

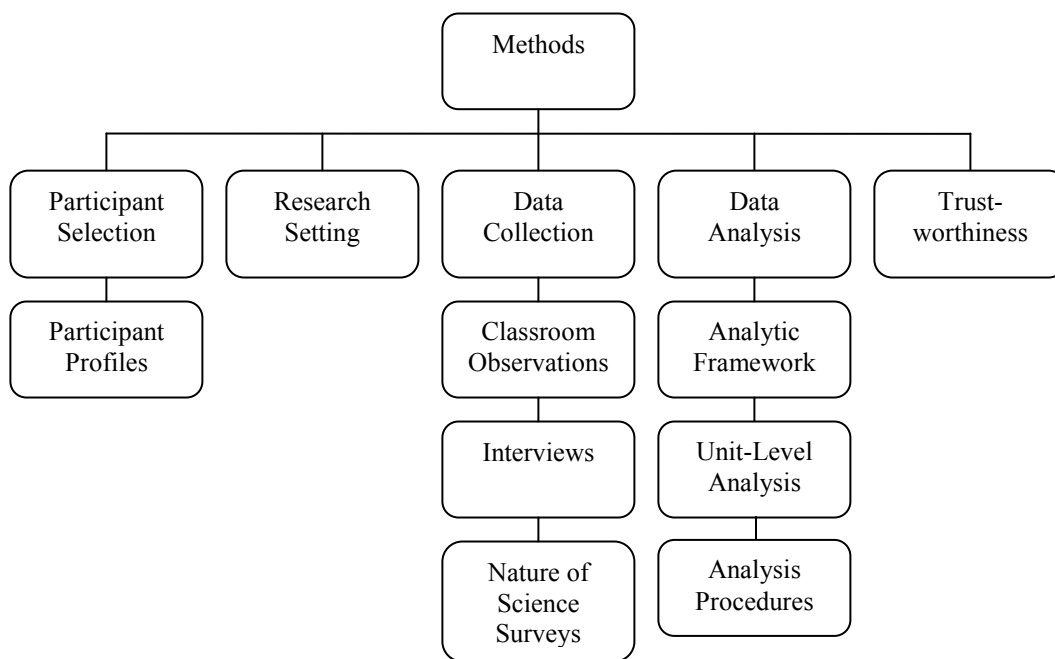
Fogarty and McTighe (1993) stated that the messages teachers send through their actions influence students' attitudes toward learning and students' perceptions of themselves as thinkers. In a strict, controlling, "one-correct-answer" classroom, students may be hesitant to ask questions or offer innovative ideas. On the other hand, a classroom which employs critical thinking skills encourages inquiry and experimentation, values unique thinking styles, honors diverse points

of view, and provides opportunities for students to choose products and methods (Fogarty & McTighe, 1993).

The social constructivist model includes opportunities for reflective interactions (e.g., through discussion and argument) to support the co-construction of knowledge. However, research indicates that few opportunities are given within lessons for activities where this can take place (Newton et al., 1999; Hacker & Rowe, 1997). Although social constructivist perspectives may predominate in the thinking of science educators, they are generally not reflected in classroom practice.

## CHAPTER 3 METHODS

This study explores the arguments constructed by a sample of secondary science teachers during instruction on topics that rely on different methods of scientific inquiry. This chapter includes a description of the a) participant selection and profiles, b) research setting, c) data collection, d) data analysis employed to develop meaning from the data, and e) trustworthiness (see Figure 3.1).



*Figure 3.1: Organization of Chapter 3*

A qualitative methodology was applied to this study in order to reach a deeper understanding of possible differences between the arguments secondary science teachers construct in the classroom for topics that rely on different modes

of scientific inquiry. Qualitative studies are emergent in nature, meaning that all phases of the process “may change or shift after the researchers enter the field and begin to collect data” (Creswell, 2007, p. 39). Using a qualitative methodology requires special attention to participant and site selection, types and collection of data, and the inductive analysis of data.

### *Participant Selection*

The teacher participants in this study were selected by purposeful sampling with no intention for generalization. In qualitative research, selection of participants has a different characteristic than within quantitative research. Qualitative researchers do not work with large populations; instead, they tend to select each of their cases purposefully (Creswell, 2007). “In qualitative research, a single case or small nonrandom sample is selected precisely because the researcher wishes to understand the particular in depth, not to find out what is generally true of the many” (Merriam, 1998). To gather in-depth information, information-Robert cases are purposefully sought in relation to issues important for the purpose of the research (Patton, 1990).

In order to examine information-rich cases, teacher participants were selected using a number of criteria. Participants who are highly experienced (minimum of 8 years of experience) high school science teachers and highly competent (additional academic and/or research experience) in their subject matter were selected. These criteria help diminish the confounding variables of content

and pedagogical knowledge. It was also important that they teach both experimental and historical science topics during the data collection period.

Among several different strategies of purposeful sampling, snowball (or chain) sampling was used in this study. Snowball sampling involves contacting and recruiting participants who fit the sampling criteria and then expanding the participant pool by adding referrals for potential new participants, provided by the existing participants (Glesne, 1999). The nature of this study required recruitment of secondary science teachers as participants. In order to locate these teachers I began with my knowledge of teachers in the area to recruit the first participants. Further participants were recruited by asking the initial participants to introduce or refer other individuals who fit the study's criteria. A total of four teachers were recruited as participants representing the most highly qualified secondary science teachers in the district.

In this study, all participants have been assigned pseudonyms. The selection process resulted in four high school science teachers being chosen for the study: Scott, Matt, Gabby, and Robert. All four teachers were currently teaching science at one of two public high schools within the same district in a mid-sized city in the Northwest. Scott and Matt teach science at West High School whereas Gabby and Robert teach at East High School. These participants were selected based on their willingness to participate and their background in teaching and science.

Three of the participating teachers, Scott, Gabby, and Robert, selected one class to be observed during both instructional units. Matt, for scheduling reasons,

selected two classes, one for each instructional unit. The principals of both schools and district officials were contacted for approval. Consent and assent forms were obtained from the teachers, students, and their parents in the classrooms observed.

### Participant Profiles

The participant profiles follow a general form. First, each participant's teaching background is described. Second, their specific background in their science subject matter is examined including relevant degrees, research experiences, and professional development experiences. These descriptions stem from multiple data sources. Most notably, the pre-instructional interviews provided the majority of the participant's background information. Other data was gathered from classroom observations, personal communications reflected in the field notes, and the post-instructional interviews.

Scott: West High School. Scott is in his 13<sup>th</sup> year of teaching and is currently the chair of the science department. He is licensed to teach biology and general science at the high school level. During his teaching career he has taught courses in general biology, honors biology, advanced placement biology, oceanography, and currently conducts a course in research science for students competing in state and national research competitions. He began his teaching career in a wealthy nearby city teaching high school biology for three years and moved to another local high school for six years before being recruited to West

High School for the past three years. All three public high schools in which Scott has taught serve primarily non-minority students from high socioeconomic backgrounds. Of the biology topics generally taught, he feels most confident teaching the nature of science, evolution, and organismal biology and least confident in cellular biology.

Outside of the classroom Scott has been actively engaged in science education as well. He has attended and participated in multiple national and regional National Association of Science Teachers (NSTA) conferences. He has also been involved with the statewide science teachers association since becoming a teacher and served as its president and coordinator of the annual conference in 2005. During many of the statewide conferences Scott has provided professional development for others in the teaching of evolution. He has also served for the past five years on the science leaders group at the state department of education shaping state science standards and drafting questions for the state science assessment. Finally, Scott has been the lead instructor for a course in science pedagogy for pre-service master's students at a local university.

As compared to the other participants in this study, Scott has an extensive background in research science. He holds a bachelor's degree in general biology, a master's degree in range ecology, and a master's degree in teaching. He specifically notes that his master's in range ecology, an applied science, had a great impact on his teaching and shaped his view of science. Scott worked for 12 years as a contractor for the Environmental Protection Agency (EPA) working on climate change research. This included studies measuring and working to mitigate



pollution. This led to research in the Philippines with the International Rice Research Institute. This project in particular was community-based and focused on the application of his research, a point he notes that partially led him into teaching. As a product of this research he led a team in writing curriculum on climate change in 1991 and culminated in an intensive seminar on climate science for teachers. During his 12 years at the EPA, 8 were as a senior scientist in charge of a research lab. He authored five peer-reviewed scientific publications during this time. He has also taken coursework on research methodology, experimental design, and the history of the scientific revolution.

Matt: West High School. At the time of this study, Matt was in his 24<sup>th</sup> year of science teaching. He was named the state's teacher of the year during the year of the study. Spending his entire teaching career in the same city, he taught at two different high schools before moving to West High School seven years ago. All three of these high schools served students of high socioeconomic backgrounds. He is licensed to teach physics, chemistry, and advanced mathematics at the high school level. During his teaching career he has taught multiple mathematics courses, general physics, freshman physical science, honors physics and chemistry, advanced placement physics and chemistry, and astronomy. He also conducts a research methods course for teams competing in state and national science competitions and coaches the school's academic decathlon team.

In addition to being named the state's teacher of the year, he has been the Disney teacher of the year and has won 10 different teaching awards over the past 19 years. He has received over \$200,000 in grants including multiple Toyota Tapestry grants. Outside of the high school classroom he has also been a planetarium lecturer, field astronomer and physics instructor at a local community college, director of education for public broadcasting's Wired Science television program, and is currently an education consultant for Disney's education productions. He has been actively involved in both state and national science teacher associations, the American Association of Physics Teachers, and has published six articles and lessons in practitioner journals.

In comparison to the other participants, Matt has the most advanced content background in his subject as evidenced by his degrees and research experiences. He has a bachelor's and master's degree in physics, a master's degree in science education, and presently is a doctoral candidate in atomic physics. In terms of research experience, he has completed graduate-level research on atomic physics including research for his dissertation which he has no plans to finish. Since becoming a teacher he has participated in a Partners in Science grant which matched him up with a physicist for research experience over three summers. He was also given grants and sabbaticals to conduct research in both Africa and Antarctica. In Antarctica he was a member of a research team taking measurements addressing quantitative ozone loss, polar stratospheric cloud nucleation, and large polar stratospheric particles and in Africa examining low-frequency atmospheric acoustics.

Gabby: East High School. In her 8<sup>th</sup> year of teaching, Gabby is licensed to teach middle and high school biology and integrated science. At East High School she teaches sophomore biology and freshman physical science. She began her teaching career at a nearby high school serving students from high socioeconomic backgrounds and recently made the move to East High School which serves students from low socioeconomic backgrounds. This transition has not been easy. She has moved from teaching International Baccalaureate biology and integrated science to general biology for largely low-performing students. Previous to the move she served as science department chair. She states that, of all of the topics she currently teaches, she feels most comfortable with molecular biology and evolution and least comfortable with physics and general earth science.

Gabby holds a bachelor's degree in biology and a master's degree in molecular biology and ecology. Three years before the study she left teaching to pursue an advanced degree in pharmacology and conducted pharmacological research until leaving the program and returning to teach at East High School. While she was teaching she earned grants or fellowships each summer to attend seminars designed to provide up-to-date science content for teachers. For example, the summer before the study she attended a two-week course on the science of evolution at the University of Texas at Austin. She has also been awarded two Wilson Fellowships for research in biomolecular modeling.

Robert: East High School. Robert has 19 years of teaching experience, the majority (16 years) at East High School. He is licensed to teach biology, integrated science, health, and technology education at the high school level. While he teaches mainly sophomore biology, he has also taught advanced placement biology, physical science, integrated science, earth and space science, natural history, field biology, and general math. As a local naturalist and birder, the topic Robert feels most confident in is ecology. He feels the least confident in his knowledge of molecular biology.

Robert has a bachelor's degree in biology and a master's degree in science education with an emphasis in biology. During his teaching career he has had three opportunities to conduct scientific research. Previously he was awarded a grant that matched him with a field geologist for three summers in which they completed and published a study of a local creek's debris flow. He also participated in the Teacher in the Woods program in which he participated in a study designed to monitor forest biodiversity. Finally, he received a grant to participate in a partnership program in which he conducted a geomorphic hazards assessment of a nearby area.

### *Research Setting*

Data collection took place in two large public schools in a mid-sized city in the Northwestern United States. The two high schools are in a large, diverse district known for serving a large range of socioeconomic backgrounds and a large migrant Hispanic population. The study's two high schools represent extremes

within the district. While comparable in size, East High School serves a population that, compared to West High School, includes more Hispanic, lower socioeconomic status students as well as a larger English language learner (ELL) population (see Table 3.1). East High School also has a lower graduation rate as well as passing rate on both the state reading and mathematics tests.

*Table 3.1: Comparison of East and West High Schools*

Indicator	East High School	West High School	District
Population	1,857	1,538	40,282
% White	55%	79%	53%
% Hispanic	31%	12%	30%
% Low SES	67%	31%	52%
% ELL	16%	6%	17%
Graduate Rate	78%	90%	85%
State reading assessment (% met)	50%	76%	61%
State mathematics assessment (% met)	35%	57%	47%

I observed three of the participants (Scott, Gabby, and Robert) during instructional units on DNA and evolution. The fourth participant (Matt) was observed during units on chemical bonding and the formation of the solar system. Class sizes ranged between 20 and 30 high school students. Three of the four classrooms were furnished with large laboratory tables holding 2-3 students each. Only Robert's classroom consisted of individual desks with a large laboratory space at the rear of the room. All classrooms had at least one computer open for student use. All teachers used laptop computers and projectors to show PowerPoint presentations during their lectures. Matt's classroom also contained

an interactive SmartBoard used to display interactive simulations and videos. In all four of the rooms I had a seat in order not to interrupt or participate in classroom activities.

### *Data Collection*

Qualitative research calls for data collection in a natural setting where the participants experience the phenomena under study (Creswell, 2007). In this study, classroom observations, the primary data source, occurred in the participants' classrooms during regular school hours. Participant surveys and interviews occurred in this setting as well. Qualitative research methodologies utilize four basic types of data: observations, interviews, documents, and audiovisual materials (Creswell, 2007). In this study, all four of these types were collected through classroom observations, field notes, reflective memos, classroom artifacts, a nature of science survey, and teacher interviews. According to Patton (1990), observations of situations allow for greater understanding of the complexities of a situation than simply interviewing participants. To absorb the language, understand the nuances of meaning, appreciate the participants' experiences, understand the importance of what happened, and feel the intensity of situation, nothing can substitute for "direct experience" (Patton, 1990, p. 262). The observations for this study occurred during instruction on both experimental and historical science topics. Field observations of the four classrooms occurred daily during the duration of the chosen units which ranged one to three weeks per unit.

### Classroom Observations

The objective for collecting observational data is to provide the reader an entrance into and an understanding of the classroom situation by providing factual, accurate, and thorough descriptions of the setting and the activities and perspectives of the participants (Patton, 1990). During the classroom observations, a camera was setup to capture the entire class. This allowed me to capture all whole-group interactions. As the data focused primarily on the teachers' dialogue, small group work was not recorded in detail. A digital audio recorder was placed near or on the teacher as well as a backup measure. The classroom observations were videotaped and transcribed verbatim.

As part of the field data, the field notes included "note taking" (Green & Dixon, 1999) in the form of thick descriptions of settings, activities, events, and classroom discourse. These included student and teacher behaviors and interactions as well as instructional methods. Thick, rich descriptions provided the foundations for analysis and reporting (Patton, 1990). Reflective memos were also written immediately following each observation. These included my feelings, interpretations, preconceptions, and questions for subsequent interviews. These were meant to inform future directions for investigation.

I conducted classroom observations for each lesson in both the experimental and historical science instructional units of each teacher (Table 3.2). This amounted to 57 individual classroom observations, or roughly 85 hours, recorded and transcribed for subsequent analysis over the course of the study. On

three occurrences I was not able to conduct the classroom observations. In these instances the participating teachers set up the video recorders to ensure that data was not lost.

*Table 3.2: Unit Topics and Duration*

Teacher	Experimental Unit Topic	Sessions / Hours	Historical Unit Topic	Sessions / Hours
Scott	DNA	7 / 10.5	Evolution	14 / 21
Matt	Chemical Bonding	8 / 12	Solar System Formation	7 / 10.5
Gabby	DNA	5 / 7.5	Evolution	3 / 4.5
Robert	DNA	3 / 4.5	Evolution	7 / 10.5

### Interviews

According to Patton (1990) interviews should be conducted to elicit the meaningful description of the respondent's life and opinions. Interviews are a Robert source of experiential data about one's beliefs, feelings, and activities. In this study I conducted both pre- and post-instructional interviews with each of the four participating teachers. Shorter informal interviews occurred often during the observational period to elicit the participating teachers' immediate reflections on the lesson.

The pre-instructional interview protocol (see Appendix A) used in this study was designed to elicit reactions regarding the teachers' opinions about their students, their role as a teacher, the impact of their students on instruction, basic pedagogy, the goals of the two units under study, and possible influences from the community that may impact instruction. These foci of the interviews were drawn



from the literature regarding teacher beliefs and practice that report factors affecting instruction (Jones and Carter, 2007).

By contrast, the post-instructional interview protocol (see Appendix B) was designed to elicit their reaction to their instruction in relation to their original goals and objectives as well as their understanding of the scientific topics of the unit, the differences in methodologies between the two topics, and their understanding of scientific inquiry. These questions were specifically not included in the pre-instructional interviews to avoid influence on their instruction. Interviews lasted between 45 and 90 minutes. All interviews were audiotaped and transcribed verbatim.

#### Nature of Science Survey

Teacher understanding of different methodologies in science is part of the larger construct of the nature of science. In order to assess the teacher participants' understandings of the nature of science a brief open-ended survey instrument (see Appendix E) was administered before the pre-instructional interviews. Lederman, Abd-El-Khalick, Bell, and Schwartz's (2002) *Views of Nature of Science Questionnaire* (VNOS-C) was used to assess understanding of specific aspects of nature of science as highlighted in current science education reform documents ([AAAS], 1990; [NRC], 1996) (Appendix C). These include the tentativeness, empirical nature, subjectivity, and social/cultural embeddedness of scientific knowledge as well as observations and inferences, theories and laws, and the diversity of scientific methods (Appendix D).

## *Data Analysis*

### Analytic Framework

Two analytic frameworks were used in this study, Toulmin's (1958) argumentation pattern and Walton's (1996) schemes for presumptive reasoning. Toulmin's (1958) argumentation pattern describes argument construction primarily as a process of using data, warrants and backings to convince others of the validity of a claim. He suggests that the statements that constitute an argument can be categorized as claims, data, warrants, backings, qualifiers and rebuttals. Accordingly, the strength of an argument is a function of the presence or absence of the structural components. This framework has been used widely and has been influential in studies of argumentation in science education. In practice, Toulmin's framework has mainly been used to show how students provide warrants for claims, when they do so, and on what basis (e.g. Jimenez-Aleixandre et al., 2000; Osborne et al., 2004). Although rare, it has been applied to examine teacher argumentation (Carlsen, 1997; Russell, 1983).

Simon, Erduran and Osborne's (2006) used Toulmin's pattern to analyze secondary school science teacher discourse before and after they participated in a workshop about developing materials and strategies to support the teaching of argumentation in science context. They indicated that using Toulmin's pattern enabled them to assess the quality of teacher arguments. In addition, using Toulmin's pattern offered teachers a language for talking about science and understanding the epistemic nature of their own discipline. In a previous study,

the same researchers worked on the development of Toulmin's pattern for analyzing science discourse (Erduran et al., 2004). They indicated that the coding of whole classroom discussions with the pattern can yield argument profiles which can act as indicators of improved performance throughout implementation of the lesson. These argument profiles provide a tool for analyzing the structure of teacher talk in the classroom.

Another influential analytical tool used to examine argumentation in science education is Walton's (1996) schemes for presumptive reasoning. He defines presumptive reasoning as that reasoning which occurs during a dialogue when a course of action must be taken and all the needed evidence is not available. While Toulmin's (1958) model emphasizes the structure of an argument, Walton's schemes focus on the content of an argument. Walton maintained that argumentation is grounded in burden of proof, presumption, and plausibility. He categorized arguments in terms of a schema of 25 common forms of reasoning. Duschl (2007) selected 9 of these as particularly relevant to the science education context in his study utilizing Walton's schemes to examine middle school students' arguments. For example, a reference to an external source of information, such as a person or text, would be categorized as an argument from expert opinion. According to Duschl (2007), this scenario of reasoning based on partial evidence reflects well what typically occurs in secondary science classrooms. Of those 9, six schemes were chosen for their applicability to this study (Table 3.3).

*Table 3.3: Adaptation of Walton's Schemes*

Argument from	Definition
Analogy	Used to argue from one case that is said to be similar to another.
Causal Inference	Infer a causal connection between two events.
Evidence to Hypothesis	Includes a hypothesis capable of being tested.
Example	Does not confirm a claim conclusively, it only gives a small weight of presumption in favor of the claim.
Expert Opinion	Reference to an expert source (e.g. person, text, etc.).
Sign	References to spoken or written claims are used to infer the existence of a property or event.

The purpose of this study was to examine both the structure and content of teachers' arguments constructed for experimental and historical science topics. A combination of both Toulmin's (1958) model and Walton's (1996) schemes is necessary for this purpose. The application of Toulmin's framework allows for an analysis of the structure of the teachers' arguments constructed in the classroom based on classification of teacher statements into predefined categories (e.g. claims, data, warrants, etc.). It is not enough, however, to only assert the frequency of these categories as a measure of teacher argumentation because the quality of the dialectical or rhetorical arguments will depend on various "appeals to" types of evidence. Walton's schemes of presumptive reasoning allows for an examination of the quality of the content of the argument. Together, these analytical tools allow for a qualitative analysis of the similarities and differences between teacher arguments for experimental and historical sciences.

In terms of structure, historical arguments have been shown to integrate and compare many disparate pieces of information on which the claim rests. The

tight causal links emphasized in experimental arguments require a smaller amount of information. These differences are likely to be revealed as structural differences in Toulmin's model. For instance, in a historical argument one would expect an increase in the amount of data used to support a claim as well as an increased frequency of warrants, backings, and rebuttals as disparate pieces of information are compared and linked to the claim. The content of the arguments, as revealed by Walton's schemes, are likely to show significant differences as well. For example, in an experimental argument one would expect an emphasis on arguments from 'causal inferences' signifying an inferential leap, whereas historical arguments should emphasize arguments from 'evidence to hypothesis' as multiple pieces of evidence are linked to form a hypothesis. Therefore, this analytical framework is likely to reveal qualitative differences in both the structure and content of experimental and historical arguments.

### Unit-Level Analysis

Data was collected and analyzed for this study at the level of the instructional unit. Previous studies utilized both the Toulmin and Walton frameworks at the level of small sections of discourse (e.g., Jimenez-Aleixandre, Rodriguez, & Duschl, 2000) or at the level of an individual class session (Erduran et al., 2004). Analysis at the level of the instructional unit was chosen for this study in order to more fully describe the scientific claims of the teachers as they most commonly occurred over multiple class sessions. For example, figure 3.4 details Scott's DNA unit. Over seven days, he detailed six claims, although none

were discussed in only one day. Claim #2, for instance, was discussed over six days. Thus, the unit-level analysis provided the appropriate level of analysis for the research questions posed.

*Figure 3.2: Scott's DNA Unit*

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Claim #1		Claim #2				
			Claim #3			
			Claim #4			
			Claim #5			
			Claim #6			

### Analysis Procedures

A general qualitative approach to analysis was used in this study (Strauss & Corbin, 1998) meaning that it was inductive and emergent from the multiple data sources collected. Qualitative data analysis consists of three concurrent flows of activity: data reduction, data display, and conclusion drawing/verification (Miles & Huberman, 1994). Data reduction for this study included transcribing, selecting, simplifying, and transforming the classroom observations, interview data, and collected documents.

After transcription, the first phase of data reduction was to “fracture” (Strauss, 1987, p. 29) the transcripts and rearrange them into categories that facilitated comparison. This consisted of reviewing the classroom observation transcripts to select appropriate areas of text in relation to the first two research questions. From these selections separate claims were determined and the remaining selections were reorganized into the claim categories. To examine the

first research question relating to the structure of the scientific arguments these claim categories were coded utilizing Toulmin's (1958) categories of claim, data, warrant, backing, qualifier, and rebuttal. To examine the second research question regarding the content of the arguments, the claim categories were coded using Walton's (1996) schemes for presumptive reasoning (see Table 3.3). These sets of data, both the structure and content analyses, were displayed in visual matrices for comparison. Direct quotes and specific concepts are presented in the matrix displays to organize, conclude and assemble the data to allow final conclusion drawing (Miles & Huberman, 1994). This occurred for each of the experimental and historical units for each of the four participating teachers. These were compared across participants as well as across unit type (experimental and historical). See Appendices E-H for an example.

To answer the third research question regarding factors influencing the teachers' arguments the interview transcriptions and nature of science surveys were examined. The instruments were analyzed to create profiles of each participant. Participants' responses were coded for each of the aspects of the nature of science assessed (Appendix D). Although each survey item focused on a certain aspect of the nature of science, I examined responses across all items to ensure consistency. Individual aspects were coded as *sophisticated*, *intermediate*, or *beginning*.

The interviews were examined to reveal possible factors influencing the creation of the teachers' arguments. Over multiple cycles, the interview transcript data was organized and coded to reveal common factors related to the results of

the structural and presumptive reasoning analyses. Combined with the nature of science profiles, these factors were matched with the results of the previous analyses in order to examine which factors may have mediated the argumentation patterns found.

### *Trustworthiness*

Member check, triangulation, and inter-rater reliability were the main tools for ensuring the credibility of this study. Member checking, or having the participating teachers and a colleague review the initial analyses, is a process “to make sure you are representing them and their ideas accurately” (Glesne, 1999, p.32). Member checking is perhaps one of the most important approaches to establishing trustworthiness. According to Lincoln and Guba (1985), member checking has several purposes: it provides an opportunity to “assess intentionality” (p.314) of the participants about how they interpreted the information that was provided. It also offers participants an “immediate opportunity to correct the errors” (p.314) that I made during interpretation of the data. In this study member checking strategy was employed during the interviews to ensure I correctly understood what participants meant. I asked for clarifications when needed and rephrased participants’ statements to confirm the meaning. This included their responses to the nature of science survey. During the interviews, participants were given their assessment and asked to explain and justify their responses. Follow-up questions were asked as needed to most fully understand the participants’



understandings of the nature of science. Member checks also occurred after the classroom observations and the initial stages of analysis were complete.

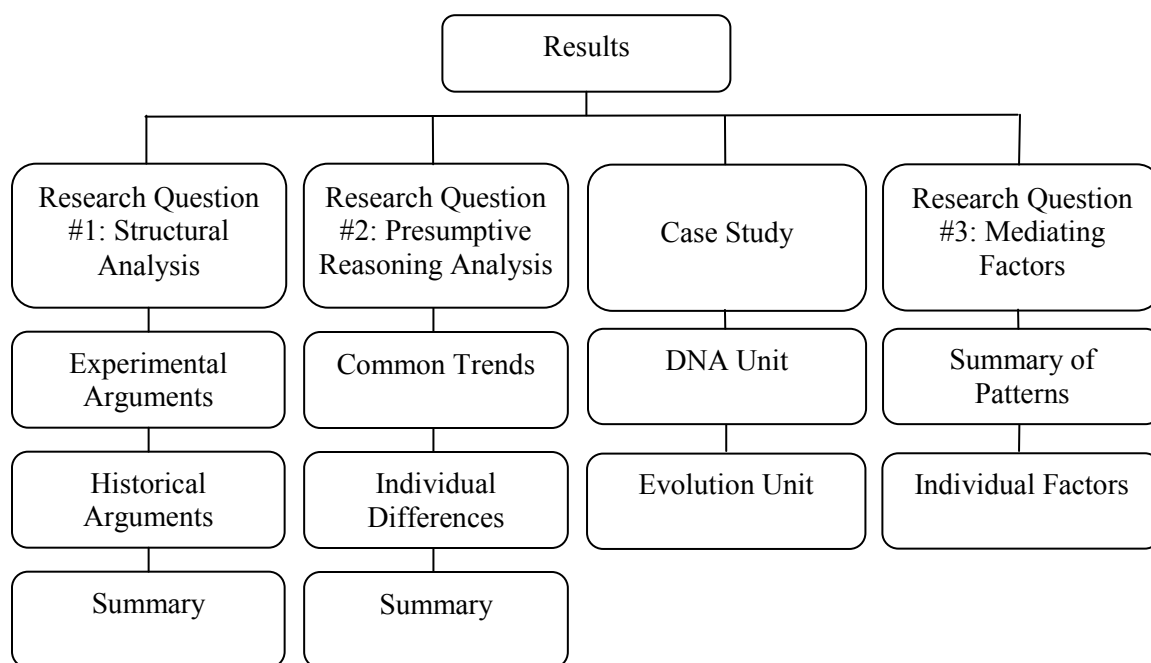
Triangulation of data was established by using multiple data sources. It is intended to add support for findings through several independent sources of data that confirm it, or at least do not contradict it (Creswell, 2007). To be trustworthy, data sources should be compiled from different methods and sources (Creswell, 2007). In this study, for example, the arguments constructed by teachers were not only determined from the classroom observation transcripts but were also verified using the interview data as well as the classroom artifacts. This reduces the risk that my conclusions reflect only the limitations of a specific source.

The third strategy that was employed to establish trustworthiness was inter-rater reliability. Mays and Pope (1995) indicate that “the analysis of qualitative data can be enhanced by organizing an independent assessment of transcripts by additional skilled qualitative researchers and comparing agreement between the raters” (p.110). Inter-rater can be described as “a process of exposing oneself to a disinterested peer in a manner paralleling an analytic session and for the purpose of exploring aspects of the inquiry that might otherwise remain only implicit within the inquirer’s mind” (Lincoln & Guba, 1985, p. 308). According to Lincoln and Guba (1985) the researcher’s peer should be someone who is a peer in every sense and one has a great understanding of “substantive area of the inquiry and the methodological issues” (p.308). A colleague of the researcher who holds a Ph.D. in Science Education provided an initial sounding board for the analysis and independently coded initial teacher arguments to ensure reliability. Independent

coding resulted in 92% reliability between the two researchers. The few discrepancies that did exist resulted in further discussion about the definition of analogies which were resolved and the data recoded.

## CHAPTER 4 RESULTS

The purpose of this chapter is to present the results of the study and to connect these results to the research questions outlined in Chapter One (Figure 4.1). This study had three main objectives defined by the research questions. The first objective was to compare the structure of secondary science teachers' scientific arguments for experimental and historical science topics. The second objective was to compare the types and/or frequency of presumptive reasoning schemes in their arguments. The third objective was to examine the possible factors that lead to differences in these arguments.



*Figure 4.1: Summary of Chapter 4*

*Research Question #1: A Structural Analysis of the Arguments*

The purpose of the first research question was to compare the structure of the arguments participating teachers' constructed during instructional units on experimental and historical science topics. For each teacher this required first to identify the scientific arguments and then to code the teacher talk from each of the two instructional units using Toulmin's categories: claim, data, warrant, backing, qualifier, and rebuttal. In the analysis, arguments that had data statements considered scientific in nature were included. For example, Scott provided multiple data statements as evidence of the claim that DNA is shaped like a double helix. One, that Rosalind Franklin's x-ray crystallography photograph provided Watson and Crick evidence "to figure out the structure of DNA" (experimental observation), is scientific in nature. By comparison, his statement that DNA is "just a ladder, a twisted ladder" (experimental observation), an analogy, is not scientific in nature. The focus of the analysis is a comparison between the manner in which scientific data is used and warranted in the construction of arguments for the two different modes of scientific inquiry.

#### Experimental science unit

For their experimental science topic, the three biology teachers (Scott, Gabby, and Robert) were all observed during their unit on the structure and function of DNA. The physical science teacher, Matt, was observed in his physical science class during a unit on chemical bonding. What the topics of these two units share is a justification based on methodologies that rely on the manipulation of nature through experimentation. All four teachers taught these

units over 3 to 8 instructional days. During the experimental science unit, the four teachers used very little scientific data to evidence their claims.

The arguments constructed during the four experimental science units showed a range in the number of scientific claims made (Table 4.1). For instance, Gabby's unit consisted of only four scientific claims: DNA is shaped like a double-helix, it contains the instructions for making proteins, proteins regulate the chemistry in your body, and DNA is common to all organisms. Matt's unit on chemical bonding, on the other hand, consisted of 14 specific scientific claims such as "the structure of the atom is due to physical laws" and "electrons are like waves and have spin." Both Scott and Robert provided six scientific claims during this unit.

*Table 4.1: Toulmin Analysis Data (Experimental Science Unit)*

Teacher	Days	Claims	Data	Data per Claim (avg.)	Warrants	Backings	Qualifiers	Rebuttals
Gabby	5	4	4	1.00	4	1	0	0
Robert	3	6	7	1.17	5	2	0	0
Matt	8	14	4	0.29	4	0	0	0
Scott	7	6	4	0.67	4	0	0	0
Average	5.75	7.5	4.75	0.63	4.25	0.75	0	0

These claims were only partially backed up with scientific data. Gabby, Matt, and Scott all produced only four pieces of scientific data for all of their scientific claims during this unit. Robert produced seven during his DNA unit. The average number of data given for each claim was less than 1 (0.63) indicating

that some claims were not evidenced with any scientific data. The data that was included in the teachers' arguments consisted of data from classroom demonstrations or laboratory exercises and from the history of science. For example, for the claim that "DNA is in all living things" (experimental observation), Robert used a DNA extraction laboratory activity as data. To back up the claim that "DNA is shaped like a double helix," he used two pieces of historical data:

In 1952, a woman did a very important thing. She found in 1952 that by using x-ray diffraction...it looked kind of like this shape right here. Rosalind Franklin used an x-ray beam to figure out the shape of that. (Robert, experimental observation)

...let me tell you about Chargaff's rules. He found that when he took a lot of DNA and sampled it, he found that the percentage of adenine was the same as the percentage of what? Thymine. Whenever he tested he found that they were always matching. (Robert, experimental observation)

Both of these historical data are scientifically valid and support the claim.

In Toulmin's argumentation pattern, data statements must be linked to the claim either explicitly (with warrants) or implicitly (with backings). The four teachers were consistent during this unit in using limited number of both warrants and backings (Table 4.1). While the amount of data statements linked to the claims was limited, all four teachers warranted their data the majority (89%) of the time. For example, Gabby warranted the data involving Franklin's x-ray crystallography photograph to the claim about the structure of DNA by stating that "...this shape told Maurice, Rosaline, and James... that DNA was a spiral"

(experimental observation). The remaining elements of Toulmin's pattern, qualifiers and rebuttals, were not used during these units (Table 4.1).

In summary, the four participating teachers used very little scientific data to back up their claims. In other words, while their instruction may have led to increased understanding of the concepts on the part of students, the students were not shown how those scientific knowledge claims were constructed and justified. Instead, they were mainly discussed as final form science with little reference to the manner by which scientists justify that knowledge. However, when the teachers used scientific data to evidence their claims, they warranted that data to the claim in nearly every instance. In other words, they did not just mention the data but discussed how it related to the scientific claim under study.

#### Historical science unit

For their historical science topics, the three biology teachers (Scott, Gabby, and Robert) were all observed during their unit on evolution. The physical science teacher participant, Matt, was observed in an astronomy class during a unit on the formation of the solar system. What the topics of these two units share is a justification based not on predictive reasoning but on reconstructive reasoning based on past events. All four teachers taught these units over 7 to 27 instructional days. Gabby taught the longest unit at 27 days due to instructional concerns. The amount of content, however, was similar to that of the other two biology teachers. The data shows that during these units, the participating teachers highly evidenced their claims with scientific evidence.

Like the experimental science units, the arguments made during the four historical science units showed a range in the number of scientific claims made. For instance, Gabby’s unit consisted of seven scientific claims whereas Scott’s unit consisted of 16 claims (Table 4.2). These included such claims as “natural selection explains how things change to adapt to local conditions”, “all species are variable in their characteristics”, and “characteristics exist for a reason and because organisms have these traits that make them well suited to the environment tend to be successful” (historical observation).

*Table 4.2: Toulmin Analysis Data (Historical Science Unit)*

Teacher	Days	Claims	Data	Data per Claim (avg.)	Warrants	Backings	Qualifiers	Rebuttals
Gabby	27	7	34	4.86	30	5	0	0
Robert	7	13	38	2.92	35	4	0	0
Matt	7	6	36	6.00	26	10	0	3
Scott	14	16	57	3.56	49	9	0	0
Average	13.75	10.5	41.25	3.93	35	7	0	0.75

The amount of data statements used as evidence for each claim was much higher during the historical science units as compared to those of the experimental science units. The four participants averaged 41.25 pieces of scientific data during their unit, nearly ten times more than during the experimental science units (Table 4.2). This averages out to roughly 4 pieces of scientific data per claim. For example, during his evolution unit, Scott claimed that “all species are variable in their characteristics” (historical observation). As scientific data he showed the variability in hand length and peanut size using a measurement activity as well as



the variation in size of the people in the room. All three are scientifically valid evidence of variation. In addition, these data statements were highly linked to the claim through warrants (35 average) and backings (7 average).

In summary, the teachers' arguments consisted of a high number of scientific data used to back up their scientific claims during the historical science units. In other words, their instruction was laden with evidence similar to what scientists use in constructing their arguments. Therefore, the justification of these science topics was evident in the teachers' arguments. In addition, the scientific data used was highly warranted and therefore linked explicitly to the claims.

### Summary

By comparison, the participating teachers' arguments constructed for historical science topics involved slightly more scientific claims than those constructed for experimental science topics. The number of scientific data, warrants, and backings, however, was much higher. Thus, the overall structure of the arguments for these two modes of scientific inquiry was markedly different. Specifically, a higher number of scientific data were used to evidence scientific claims in the historical science units. The pattern of increased scientific data used in the construction of scientific arguments and the subsequent warranting and backing of that data is uniformly seen across the four participants. This implies that the structural difference was more likely because of the difference in modes of inquiry and less due to teaching styles.

### *Research Question #2: Analysis of Presumptive Arguments*

The purpose of the second research question was to compare the presumptive reasoning schemes participating teachers' used when constructing arguments during instructional units on experimental and historical science topics. Unlike the structural analysis above, these included both scientific and non-scientific arguments (e.g. analogies). Walton's (1996) argumentation schemes for presumptive reasoning were used for the analysis. Of the 25 original schemes, 6 were chosen for their applicability to the data in this study (see Table 3.3). As compared to the previous analysis which showed common trends in the structure of the participants' arguments, the results of this analysis were more individualized, although common trends were found. This analysis does not include Gabby's arguments as her evolution unit was not recorded due to the duration of the unit.

#### Common Trends

Three common trends stand out when comparing the content of the three participants' arguments constructed during their experimental and historical units (Table 4.2). First, the number of 'analogy' schemes used to explain the claim decreased greatly between the experimental and historical units. Across the three teachers, the amount of this scheme used during their experimental units was 3 times higher on average. Included in this scheme are similes, metaphors, models,

representative images, and imaginary situations. For example, the following were coded as ‘analogy’ in the analysis:

Double helix. It looks like a ladder that has been twisted. (Robert, experimental observation)

The electron that is going around here actually has something that we call angular momentum. Like the bicycle wheel spinning, right? (Matt, experimental observation)

This is an amateur, but reasonably effective, model of DNA [holds up model]. (Scott, experimental observation)

*Table 4.3: Walton Analysis Data*

Teacher	Unit	Claims	Analogy	Causal Inference	Evidence to Hypothesis	Example	Expert Opinion	Sign
Scott	Experimental	6	6	7	1	14	1	11
	Historical	16	0	8	10	50	1	18
Matt	Experimental	14	16	11	1	<b>15</b>	<b>11</b>	13
	Historical	6	6	7	32	<b>10</b>	<b>8</b>	10
Robert	Experimental	6	9	7	<b>6</b>	1	2	9
	Historical	13	3	7	<b>3</b>	40	2	2
Average	Experimental	7.5	10.3	8	2.5	9.5	3.5	10.3
	Historical	11.7	3	7.33	15	33.3	3.67	10

In comparison to the trend found with the ‘analogy’ scheme, both the ‘sign’ and ‘causal inference’ schemes remained relatively unchanged for all participants over both the experimental and historical science units. Statements coded as ‘sign’ were simply stated with no further reference. For example, the following statements were coded as ‘sign’:

Isotopes mean you have a different number of neutrons in here but an ion means that you're going to either add or subtract an electron. (Matt, experimental observation)

Every single thing in biology basically corresponds to a bell curve. Every single measurement has the ability to vary. Variation is really what is important here. (Scott, historical observation)

Your DNA is protected. It stays inside the nucleus. (Robert, experimental observation)

These statements are not backed up by evidence but rather rely on the authority of the teacher for their justification.

Similarly, the number of statements coded as 'causal inference' remained relatively stable for all participants as well. These statements showed a causal connection between two or more things. For example, the following were coded as 'causal inference':

These chemical things occur because there are chemical attractions. There are bond things that make it want to come there. (Robert, experimental observation)

One of the reasons why it is considered to be a reasonably bad idea to marry your cousin and all of your cousins marry their cousins and on and on and on is because you accumulate genetic variation. (Scott, historical observation)

If you take something with completely filled outer shells and you bring it next to something with a completely filled outer shell they don't want to share anything... They just can't share their electrons. (Matt, experimental observation)

While the 'analogy' scheme increased over the units, the two schemes of 'sign' and 'causal inference' showed little variability amongst the participants and across the instructional units.

### Individualized Differences

In contrast to the common trends above, the participants showed individualized differences in their use of other presumptive reasoning schemes used. Most striking is the use of the ‘example’ scheme to illustrate their claims. The two biology teachers, Scott and Robert, utilized many more examples in their historical science units than in their experimental science units (Table 4.3). Whereas Robert only used one example when discussing DNA, he used 40 examples to illustrate his claims about evolution. For instance, in demonstrating his claim that natural selection is the mechanism for evolution, Robert used the examples of Widow birds, the Oregon newt, peppered moths, and bees. In contrast, Matt, the study’s only physical science teacher, used the ‘example’ scheme in his unit on chemical bonding more than in his unit on the formation of the solar system (15 to 10 respectively). In this regard, Matt’s use of this scheme differs as compared with the other participants.

Another scheme that showed differences among the participants is the use of the ‘evidence to hypothesis’ scheme (Table 4.3). Statements were coded as such if they included evidence that leads to a testable hypothesis. Both Scott and Matt utilized this scheme far more in the historical science units than in the experimental science units. For example, Matt used the scheme one time in his chemical bonding unit and 32 times in his formation of the solar system unit. In illustrating his claim that the sun is spinning, the following were coded as ‘evidence to hypothesis’:

The reason we can tell that it’s spinning is because of these dots right here. These are called sun spots, little colder areas in the sun from magnetic fields. You can watch these sunspots and they

actually go around and around so we can time it. We can see how long it takes for the sun to go around. (Matt, historical observation)

When the sun is spinning it is spitting so fast that we can actually take a picture and see that there's a little bit of a color difference. It has to do with the same thing of a police car coming towards you. When the siren is on or an ambulance is coming toward you hear the siren at a higher pitch than when it's going away from you. Or when it is going away from you, you hear it at a lower pitch. (Matt, historical observation)

In both cases, these data provide evidence for the hypothesis that the sun is spinning. Robert, on the other hand, used slightly more 'evidence to hypothesis' statements in his experimental science unit than his historical science unit (6 to 3 respectively). The majority of these stemmed from a discussion of the experimental evidence leading to the discovery of DNA, which he highlighted more than the others.

The use of the 'expert opinion' scheme is defined by the reference to an expert source, whether a person, an organization, or a text. For example, the following statements were coded as 'expert opinion':

In 1960 is Brenner and this is what Brenner discovered. He discovered that messenger RNA is the way that the DNA gets its message out of the nucleus. (Robert, experimental observation)

There's a guy that is featured early on who is a research scientists that looks at dog evolution. He suggests that they evolve from wolves that tolerated being around people. (Scott, historical observation)

Take a look at this animation about what it was 5 billion years ago. That is a cloud of dust that an artist has drawn out. And look as the thing evolves here. This is how scientists think that cloud of dust came into the current solar system. (Matt, historical observation)

In all three of these examples a reference is made to an expert. Whereas both Scott and Robert used this scheme sparingly, Matt used it eleven times in his experimental science unit and eight times in his historical science unit. In other words, instead of simply stating something as fact, he routinely referenced scientists (e.g., “They thought that it came from a cloud of dust somehow” (historical observation)) and texts, or in this case, the periodic table (e.g., “Sodium, if you look in the periodic table, has only one electron in its outer shell” (experimental observation)).

### Summary

The analysis of the three teachers’ arguments constructed during experiential and historical science units using Walton’s schemes for presumptive reasoning revealed interesting patterns. First, the use of the ‘analogy’ scheme across all participants was much greater during the experimental science unit. On the other hand, the use of the ‘causal inference’ and ‘sign’ schemes remained relatively stable between the two units. In contrast to these patterns common to the teachers, there were differences among the teachers’ arguments as well. While the use of the ‘example’ scheme was much higher for Scott and Robert during their historical science units, Matt showed the opposite trend indicating that he relied more heavily on examples during his chemical bonding unit than his unit on the formation of the solar system. Matt also stood out among the other participants in his increased use of the ‘expert opinion’ scheme, a scheme rarely used by the other participants. Lastly, Scott and Matt both utilized the ‘evidence to

hypothesis' scheme much more heavily during their historical science units whereas Robert relied on it more during his experimental science unit. Taken together, these results indicate that in some instances a clear trend can be seen among the teachers' arguments for topics employing different modes of inquiry. In others, however, individual differences may be related to differences in teaching styles, understanding of the nature of science, or other possible mediating factors.

### *Case study*

The purpose of this case is to illustrate the patterns found during the structural and presumptive reasoning analyses in terms of one teacher's units. Scott was selected for case study analysis as he was the most representative of the specific argumentation patterns found. As the unit of analysis was the entire instructional unit and claims were evidenced over multiple days, one specific claim will be examined in detail for each of Scott's DNA and evolution units. A discussion highlighting the patterns seen in the structural analysis will follow each unit. As for the relevant presumptive reasoning schemes, coding of the schemes will be noted in parentheses.

### DNA unit

According to Scott, the purpose of his DNA unit is for students to understand that "DNA is simply the recipe that allows us to make proteins" (pre-instructional interview). From this he designed a seven day unit focusing on the structure and function of DNA. This included six distinct claims which were all



evidenced over multiple days. One claim, that “its [shape] is a double helix,” was evidenced over five of the seven instructional days. Scott began this claim on day three by holding up a “reasonably effective model of DNA” (analogy scheme) to the students and stating that “this is the only molecule in all of biochemistry... that has this particular shape” (sign scheme). He planned to leave the model up in front during the unit “so the idea of that double helix, that spiral staircase look,” (analogy scheme) is always present. Then, in order that the students “understand how we ever came to this question about DNA,” Scott began telling the story of the history of the discovery of DNA. After a far ranging discussion on why scientists came to study DNA in the first place, he focused on the story of Watson and Crick. Specifically, he focused on the x-ray crystallography photograph taken by Rosalind Franklin that “they used... to figure out the structure of DNA” (evidence to hypothesis scheme). He provided a copy of the image and explained that “by measuring the distance between the bands, you can actually work out the structure of the molecule the x-ray hit.” With this, Watson and Crick had “solved the big question in biological sciences at the time.” This led to an activity in which the students constructed a model of DNA from colored strips of paper.

The model building activity led to a discussion of Chargaff’s base pairing rule, the “key to everything” regarding the structure of DNA. According to Scott, the fact that adenine always bonds with thymine and cytosine always binds with guanine means that the “DNA will only hold together if these things are true”. Therefore, the “key to the stability of the DNA molecule is that the base pairing rule applies,” and the “shape is just because of the molecular interactions” (causal

inference scheme). At the end of day three, Scott concluded the discussion by showing “a computer-generated image of DNA” (analogy scheme).

Although much of the discussion regarding the claim of the double helix structure of DNA occurred on day three, Scott referenced back to it over the next four instructional days. On day four, for instance, he reviewed the previous evidence and emphasized the importance of the four nucleotides: “those four kinds of chemical bases, A, T, C, and G, are the ones that decide whether or not you carry the DNA for a banana slug or a human being, for a redwood tree or for a gut bacteria” (causal inference scheme). On day five, Scott reviewed the computer-generated image of DNA and stated that, inside the nucleus, the structure of DNA allows it to be “coiled and coiled and coiled into what are called supercoils” (sign scheme). After this, the students watched a video on Rosalind Franklin in which the importance of her x-ray crystallography photograph was reviewed. The evidence was once again summarized on day six. On day seven, the final day of the unit, Scott discussed the Human Genome Project. Specifically linked to the structure of DNA, he showed a printout of one page of the human genome which he had gone “to the Human Genome Project and just downloaded a page” (expert opinion scheme) to attain.

For the claim of the double helix structure of DNA, therefore, a total of ten of Walton’s schemes were identified. As for scientific data, only one was identified: the x-ray crystallography photograph. To convince his students of the structure of DNA, Scott relied on other presumptive reasoning schemes, especially analogies.

### Evolution unit

Scott presented his evolution unit over a fourteen day period which included sixteen individual claims. In the pre-instructional interview, he described the purpose of the unit:

I think for evolution the big idea is that life changes all the time. The flow of life changes over time due to adaptation, the mechanism that we call that is natural selection. And that we have abundant, independent lines of evidence that point us to that. That's the big idea-- things change over time. And I think that's it-- I think that's the key to evolution.

Of the sixteen claims presented, the claim that “natural selection explains how things change to adapt to local conditions” was chosen for further illustration.

While this claim was also supported by evidence over multiple days, the natural selection claim differs in the manner in which it was presented. Specifically, Scott presented the evidence for natural selection before stating the claim outright. Therefore the evidence was built up over many days to reveal the claim.

Discussion relating to natural selection began on day three. Scott began by discussing the concept of success in terms of biology. He stated that, “being successful... means that you can find food, you can find mates and leave more baby organisms behind you” (sign scheme). He used humans as an example. Having “10 to 25 children... would be bad in the long run for our species, but in fact for most creatures having 10 or 15 babies is a good thing because many of them out in the wild aren't likely to survive” (example scheme). This led into a

discussion of eugenics on the following day which is, according to Scott, “exactly the same thing in purebred dogs” (example scheme).

Also on day four, Scott utilized seven specific examples as evidence during a discussion of artificial selection including the creation of dog breeds. He showed a video on the evolution of dogs featuring a scientist who suggests that dogs “evolved from wolves that tolerated being around people” (expert opinion scheme). This was addressed further with a discussion of the Siberian Fox experiment in which many of the traits associated with domestication appeared simply by breeding for tameness. Scott related this to natural selection: “It wasn’t explainable but if something like that had happened in the wild or as wolves began to associate with humans and tameness was the thing that got them more food, more changes to reproduce, then that is what natural selection would act on and that is the origin of so many traits” (example scheme).

Scott became more specific regarding natural selection on day five during a discussion of the differences between Lamarckian and Darwinian explanations for the mechanism of evolution. He discussed the example of the evolution of giraffes from both perspectives. He explains the Darwinian perspective:

When times are hard and there is not a lot of food the giraffes had to struggle to reach more food. He did not say that they strained and stretched. What he said was those giraffes that naturally had slightly longer necks, because of random mutations, they got more food. They did better. They were not doing it better. They just happen to have slightly longer necks. And because the food was getting limited those ones with slightly longer necks tended to get more food. If you get more food you are healthier. If you're healthy you are more attractive to mates or you stay alive longer and you can mother or father more babies. Those genes, the longer necks, then in the next generation, there are just more of them

because more of those giraffes manage to have and maintain babies.  
Same thing in the next generation and the next and the next.  
(causal inference scheme)

To further illustrate the concept Scott provided an example of a family becoming more and more muscular over time from both perspectives as well (example scheme).

In summary, Scott presented two pieces of scientific data as evidence for this claim: the domestication of the dog and the Siberian fox experiment. Otherwise, he relied on presumptive reasoning schemes to convince his students of the concept of natural selection. Similar patterns are apparent in his other claims for this unit.

For the claim of natural selection as the mechanism for evolution, therefore, a total of six of Walton's schemes were identified. As for scientific data, two were identified: the domestication of the dog and the Siberian fox experiment. To convince his students of natural selection, Scott relied on other presumptive reasoning schemes, especially examples. While this specific case represents many of the patterns found, one area in which it does not illustrate the patterns is in the increased use of scientific data as evidence. Scott's other claims, however, utilized scientific data more heavily to evidence the claim.

### *Research Question #3: Factors Mediating Teacher Argumentation*

The purpose of the third research question was to identify factors that mediate the patterns revealed in the two previous analyses (Table 4.4). Data from pre-instructional interviews, post-instructional interviews, classroom observations,

and the nature of science surveys was examined and coded to identify possible factors relating to the patterns. Five factors were revealed during the analysis: teacher views of the nature of science, the nature of the topic, teacher personal factors, teacher views of students, and pedagogical decisions. While these factors are examined independently in this analysis, in actuality they often overlap as contributing factors.

*Table 4.4: Factors mediating structural and presumptive reasoning patterns*

<b>Structural Analysis Pattern</b>	<b>Mediating Factors</b>
<i>Pattern #1:</i> Increased use of scientific data to evidence scientific claims during the historical science units	<b>Nature of Science Pedagogical Decisions</b>
<b>Presumptive Reasoning Analysis Patterns</b>	<b>Mediating Factors</b>
<i>Pattern #2:</i> Increased use of ‘analogy’ scheme during the experimental science units	<b>Pedagogical Decisions</b>
<i>Pattern #3:</i> Discrepancy in use of ‘evidence to hypothesis’ scheme	<b>Pedagogical Decisions Teacher Personal Factors</b>
<i>Pattern #4:</i> Discrepancy in use of ‘example’ scheme	<b>Nature of Topic View of Students Pedagogical Decisions</b>
<i>Pattern #5:</i> Discrepancy in use of ‘expert opinion’ scheme	<b>Teacher Personal Factors Pedagogical Decisions</b>

### *Summary of Patterns*

In the analyses of the teachers’ arguments, five patterns to the teachers’ argumentation during the experimental and historical science units were found (Table 4.4). Two patterns were consistent over all participants. In addition, the structural analysis revealed a pattern of increased use of scientific data to evidence the scientific claims made during the historical science units. The presumptive reasoning analysis revealed a greatly increased use of the ‘analogy’ scheme in the experimental science units. This analysis also revealed three patterns that were not consistent across all participants. While Scott and Matt utilized the ‘evidence to

hypothesis' scheme heavily during the historical science unit, Robert used this scheme sparingly. Scott and Robert utilized the 'example' scheme far more in the historical science unit, whereas Matt used it more during the experimental science unit. Finally, Matt utilized the 'expert opinions' scheme more heavily in both units in contrast to Scott and Robert's sparse use of the scheme. These five patterns seemed to be mediated by a combination of the five factors described below.

#### *View of the Nature of Science*

Participants' views on the nature of science (NOS) were assessed using the *Views of Nature of Science* (VNOS) survey (Lederman et al., 2002) in conjunction with their responses during the pre- and post-instructional interviews. Taken together, these data allowed me to create a profile for each participant in terms of their general understanding of NOS (Table 4.5). Scott and Gabby had the most sophisticated understandings of NOS as compared to Matt and Robert who, on certain aspects, had intermediate understandings. See Appendix D for descriptions of these aspects.

*Table 4.5: Participant Views of the Nature of Science*

Aspect of NOS	Scott	Matt	Gabby	Robert
Tentativeness	Sophisticated	Intermediate	Sophisticated	Intermediate
<b>Empirical Basis</b>	<b>Sophisticated</b>	<b>Sophisticated</b>	<b>Sophisticated</b>	<b>Sophisticated</b>
Subjectivity	Sophisticated	Intermediate	Sophisticated	Intermediate
Creativity	Sophisticated	Intermediate	Sophisticated	Sophisticated
Social/Cultural Embeddedness	Sophisticated	Intermediate	Sophisticated	Intermediate
Observations and Inferences	Sophisticated	Sophisticated	Sophisticated	Intermediate
Theories and Laws	Sophisticated	Intermediate	Sophisticated	Intermediate
<b>Diversity of Methods</b>	<b>Sophisticated</b>	<b>Intermediate</b>	<b>Intermediate</b>	<b>Sophisticated</b>

In terms of the participants' understanding of the differences in methodologies used to justify scientific knowledge between experimental and historical sciences, all four participants had at least an intermediate understanding. Scott, for example, had a very sophisticated understanding of these differences. He understood an experiment to involve answering "a question by manipulating conditions or situations" (NOS survey), but did not believe that this type of methodology was necessary for all topics in science. Instead, while "direct manipulation (experimentation) seems to be the gold standard" to many in science, he sees experimentation as simply "one of the tools that can be used." Therefore, he thinks that "things that can perhaps only be modeled, or only be observed... are no more or less scientific than something that can be manipulated." Instead, "manipulation allows us to ask a different sort of category of question, 'if then' kinds of questions, rather than 'what' [kinds of questions]" (NOS survey). Matt, on the other hand, expressed a bias towards manipulation of nature as found in the



experimental sciences. He did, however, underscore the importance of other methodologies in science:

An experiment is... a method of finding the results of an interaction... An example like that would be in the standard model of physics they had the Omega-minus particle that they couldn't find. They saw a pattern of all the other particles and there was this like hole and they knew something should be there. So they did an experiment to find it. If you're a paleontologist and you have this thing and this thing and then those guys they just go out and they go digging around until they find things. So if you call that digging up stuff an experiment. I guess it would be an experiment in the sense that they have to locate an area that would be highly probable to find that. So that's experimental in that sense. That's an interesting question because for physics you know that there must be a particle there-- you know the energy, you know the mass, you know what kind of collision you have to make in order to do it, so you do an experiment to find it. So paleontologists they know that there's something that should be existing there they would go out and they're not going to find it on an island, because the island's too new, so they know the age of... So I guess that would be considered an experiment in my belief. (NOS survey)

Scott and Matt, therefore, show the range in understandings of the differences between experimental and historical sciences among the participants.

These understandings directly relate to the pattern found in the structural analysis (pattern #1). For all four participants, the amount of scientific data used to evidence their scientific claims was far greater in the arguments constructed during the historical science units. The fact that this pattern held for all four participants shows that, while some participants held more sophisticated understandings of NOS than others, all of their understandings were sufficient in affecting their argumentation during these two units.

*Nature of the Topic*

While the broad differences between experimental and historical sciences provided a focus for this study, the differences in individual topics within each of those sciences was important as well. For example, while evolution and the formation of the solar system are examples of historical sciences and are similarly justified, other aspects of these two topics affect the construction of arguments in the classroom. One such difference is the number of possible examples readily accessible to the teachers. Teaching evolution, for example, offers an almost limitless supply of examples. Teaching the formation of the solar system, on the other hand, provides very few. This is due to the fact that we have sufficient data on only our own solar system and minimal amounts of data on others. As Matt stated, the evidence “is just based on one solar system—it’s hardly any evidence at all” (post-instructional interview). Similar differences are seen in the two experimental science topics included in this study. Teaching the structure and function of DNA allows for few examples as it is focused on a single molecule. On the other hand, a unit on chemical bonding provides as many examples as there are molecular combinations. Therefore, even though these topics are justified by a similar mode of inquiry, the uniqueness of the topic of study differs.

These differences relate directly to the discrepancy seen in the participants’ use of the ‘example’ scheme (pattern #4). While Scott and Robert both used the scheme far more in their historical science units, Matt used it more in his experimental unit. The nature of their topics differed. Scott and Robert both taught experimental science units on DNA (few possible examples) and historical science units on evolution (many possible examples) whereas Matt, the physical

science teacher, taught an experimental science unit on chemical bonding (many possible examples) and a historical science unit on the formation of the solar system (few possible examples). Thus the discrepancy seen in this pattern can be explained by the nature of the topics themselves rather than the mode of inquiry used in different sciences.

### *Teacher Personal Factors*

Personal factors relating to the participants' perceived content knowledge, opinions about the disciplines under study, and concern about teaching controversial topics also factored into the patterns revealed in the previous analyses. These factors largely revolved around Matt, the physical science teacher. For instance, as compared to the other participants who felt they were well-versed in the content of their units, Matt expressed regret that he didn't "know enough about [the formation of the solar system]" (post-instructional interview), a statement that he repeated throughout the unit to his students (e.g., "My problem is that I have not read enough recently..." (historical observation)). Therefore, although Matt did show a relatively high understanding of the topic during his interviews, he perceived his content knowledge as low whereas in his chemical bonding unit he perceived his content knowledge as high. In his experimental science unit, though, he was very frank about his negative opinion of the discipline. During his unit he referred to the "voodoo land of chemistry" that is "just a dead subject" (experimental observation) among other disparaging remarks against the discipline. He explains:

And I think they get my disdain for chemistry-- I think they picked that up. But I think there's validity to that in that chemistry really is a set of rules that's continuously being broken. And that makes it very different from physics where these rules - conservation of momentum, conservation of... - are never broken. Whereas these rules that they make up, it's just like to help them to...I don't even know if they use these rules to predict. I think they predict a little bit about what will bond with what, but honestly we learn these things in chemistry and it's kind of frustrating the way these textbooks put it together because it's not very coherent, to be honest. These chemistry textbooks are just not very coherent. And it falls into this we're constantly breaking rules that we set. And it's confusing in that way. (post-instructional interview)

Therefore, Matt perceives he has low content knowledge in his historical science unit and strong negative opinions of the discipline in his experimental science unit.

These personal beliefs or opinions affected the way he constructed arguments while teaching.

The two historical science topics, evolution and the formation of the solar system, are controversial in nature. Of the four participants, Matt and Robert expressed hesitancy in teaching these topics. For example, Matt commented:

I want to respect the parents. I want to respect people's religions. And that's a parental thing... I have influence from parents at open house-- I sense their strong religious views and I sense it from the students. You know it's not my job to create any conflict in my classroom and I will avoid that. So when I do my lesson I want to choose my words carefully-- I don't not want to say "the creation of the universe." (pre-instructional interview)

Robert expressed concerns about teaching evolution as well. He talked about “not wanting to get into it” (post-instructional interview) with the students in reference to creationist beliefs in the classroom. While both Matt and Robert expressed concern in teaching a controversial topic, their concerns were somewhat different. Matt focused on “watching his words carefully” but did not mention changing the

content of his unit. Robert, on the other hand, was less worried about challenging students' or their parents' beliefs and was instead worried about "getting into it" with students.

The personal factors relating to the participants' perceived content knowledge, opinions about the disciplines under study, and hesitancy about teaching controversial topics factored into two of the patterns revealed through the previous analyses. First, Matt's low content knowledge in his historical science unit, his negative opinion of chemistry in his experimental science unit, and his concern for upsetting the beliefs of his students partially explain the discrepancy in the use of the 'expert opinion' scheme (pattern #5). While the other two participants used this scheme sparingly in either unit, Matt used substantially more in his experimental and historical units (11 and 8 respectively). In his chemical bonding unit, this seemed to have increased reference to outside authority may partially stem from his dislike of the subject, distancing himself from the topic. In his formation of the solar system unit, his desire not to question his students' beliefs is manifested as an increased use of the 'expert opinion' scheme as well allowing him to once again distance himself from the topic. For example, he states that "they thought that it came from a cloud of dust somehow" (historical observation), referring to the scientists in the field as 'they'. The references to expert opinions may also be affected by his acknowledged lack of content knowledge in the topic resulting in references to scientists, texts, and websites used in instruction.

Whereas Matt's desire not to question students' beliefs affected his use of the 'expert opinion' scheme, Robert's desire not to engage with the students' beliefs during the evolution unit affected his use of the 'evidence to hypothesis' scheme (pattern #3). He provided far less evidence to support evolution than did the other biology teacher, Scott (10 to 3 respectively). Therefore, Robert's desire not to engage with students' beliefs manifested itself in providing less evidence to justify evolutionary theory even though he knowledgeably described the evidence in his interviews.

#### *View of Students*

The participants' views of their students had varying impacts on their argumentation in the classroom. Of the participants, Matt's views were most relevant to explaining the patterns seen. While the other participants were only observed during one class of students for both units, Matt was observed in an honors level 9<sup>th</sup> grade physical science class for the experimental science unit and an upper-level astronomy class for the historical science unit allowing for a comparison. He described his physical science class as consisting of mainly gifted students who are "bright, non-stop talkers" and "definitely college bound" (pre-instructional interview). The class was low in diversity and consisted of students who are "all middle class." He describes his astronomy students coming from "a huge socioeconomic strata" consisting of some high-achieving students taking it "because they thought it was cool" to some low socioeconomic students needing

credit recovery. Matt therefore sees the students in his two classes quite differently.

This difference helps explain the discrepancy in the use of the ‘example’ scheme where, unlike the other participants, Matt used more examples in his experimental science unit than in his historical science unit (pattern #4). Consequently, in the honors class in which he feels he should “get the content as high as [he] can” (pre-instructional interview), he provided more examples of the topic. Conversely, in the regular astronomy class in which he feels he has to “play sort of a soft game” with the students, he used fewer examples to make the lessons more straightforward by reducing the complexity of his arguments. Therefore, teacher personal factors help explain two of the patterns found in the analysis.

### *Pedagogical Decisions*

The four factors described above often resulted in specific pedagogical decisions in the classroom. For example, the participants’ understanding of NOS clearly affected the number of scientific data used to evidence their claims (pattern #1). However, the nature of these topics led to pedagogical decisions that affected the amount of scientific data referenced as well. According to Scott, he spent much less time and provided less evidence during his DNA unit because “everything except evolution has to some degree got a higher mundane quality to it” (post-instructional interview). Matt agreed that during his chemical bonding unit he “was not so concerned with saying, ‘oh we have evidence for this,’ because it seems so old hat... whereas in [astronomy he] really wanted to provide

evidence” (post-instructional interview). Therefore, the belief that students’ would take the existence of DNA or chemical bonding for granted, not requiring evidence, resulted in pedagogical decisions limiting the amount of scientific data used as evidence in the experimental science units.

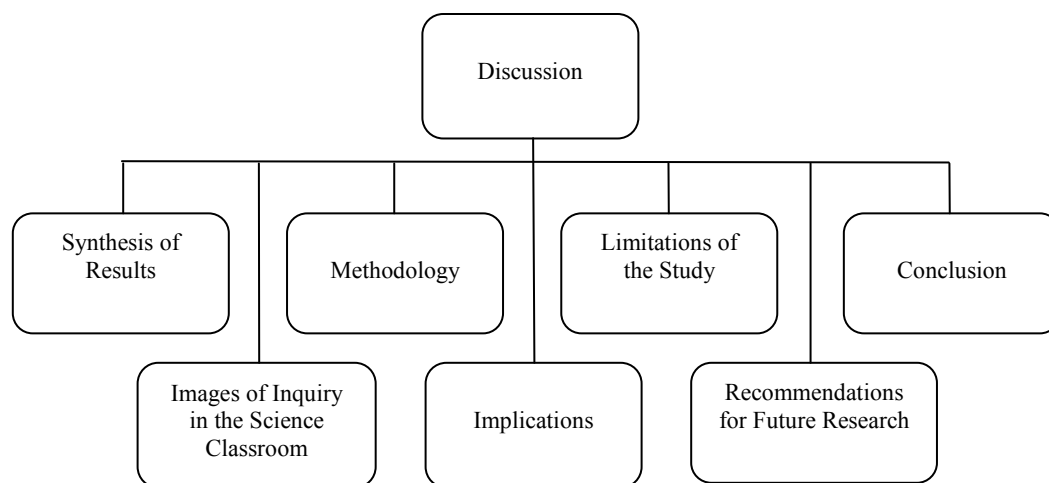
Similarly, the participants saw the experimental science topics as not just more “mundane”, but more factual in nature leading to other pedagogical decisions. For instance, in reference to the DNA unit, Robert does not “see it as... really a theory or anything, it just is what it is” (post-instructional interview). So, “even though there's a lot of proof there it's sort of abstract.” Likewise Scott argues that DNA “is really an abstract concept in the sense that while we can experimentally determine As, Gs, Ts, and Cs, and all the stuff that I'm talking about, it's not directly observable” in the science classroom. The participants’ view of these experimental topics as abstract and difficult to illustrate with scientific evidence in the classroom directly relates to the increased use of the ‘analogies’ scheme during the experimental science units (pattern #2). The use of analogies is a pedagogical decision used to help illustrate abstract concepts not easily shown in the classroom. Therefore the participants all utilized this scheme far more in the experimental units.

Finally, the difference in Matt’s view of his students’ abilities between his two classes is manifested in a pedagogical decision to moderate the use of the ‘example’ scheme (pattern #4). During his unit on chemical bonding in his honors physical science class, he made a pedagogical decision to “get the content as high as [he] can” (pre-instructional interview) and increased the amount of the



examples further illustrating the topic. Conversely, his view that the astronomy students needed a more limited content affected the use of the 'example' scheme by reducing the amount of examples used during the unit.

## CHAPTER 5 DISCUSSION



*Figure 5.1: Organization of Chapter 5*

The purpose of this study was to examine the qualitative differences between the arguments secondary science teachers constructed in the classroom for science topics that rely on different modes of inquiry as well as the factors mediating those differences. Specifically, the teachers' arguments were examined for patterns in their structure and use of presumptive reasoning schemes during units on both experimental and historical science topics. In alignment with this focus, research questions were developed to investigate these differences.

The first research question focused on the structural differences of the teachers' arguments. Specifically, what structural differences exist between scientific arguments constructed by secondary science teachers for experimental and historical science topics? Examination of the data using Toulmin's (1958) argumentation pattern as an analytical framework revealed a common trend toward a greater amount of scientific data used to evidence scientific claims in the historical science units.

The second research question focused on the use of presumptive reasoning schemes employed by the teachers while constructing their arguments. This question asked: What differences exist in terms of the types and/or frequency of presumptive reasoning schemes in arguments constructed by secondary science teachers for experimental and historical topics? Walton's (1996) schemes for presumptive reasoning was used as the analytic framework to answer this question. While some schemes remained stable across the two units (e.g., 'causal inferences' and 'sign' schemes), others revealed different patterns of use across the units. These included the use of the 'analogy', 'evidence to hypothesis', 'example', and 'expert opinion' schemes.

The third research question focused on the possible factors mediating these patterns. Specifically, what factors affected the arguments constructed by secondary science teachers constructed for experimental and historical topics? Examination of the interview and survey data revealed five specific factors affecting the arguments constructed by the teachers: view of the nature of science, nature of the topic, teacher personal factors, view of students, and pedagogical decisions.

### *Synthesis of Results*

Current reform efforts call for an emphasis on the nature of science and scientific inquiry in the science classroom ([AAAS], 1990; [NRC], 1996). Among other things, this emphasis includes a more sophisticated understanding of the diverse range of methods used to justify scientific knowledge claims. This entails teachers providing a deeper understanding of the different modes of inquiry underlying the experimental and historical sciences. In this study, the three

research questions were designed to provide a better understanding of the images highly experienced science teachers present to their students of topics justified by these two different modes of inquiry. It was the assumption that different modes of inquiry would be revealed in the patterns of scientific arguments constructed in the classroom.

When Toulmin's argumentation pattern was applied to the teachers' arguments it revealed structural differences between the units based on the two modes of inquiry. Based on our understanding of scientists' argumentation and the nature of these two modes of inquiry themselves, certain differences were expected. For instance, historical sciences justify their claims based on a greater number and variety of data which are compared and contrasted. Experimental sciences, on the other hand, are primarily justified by a smaller number of experimental data and the match of that data to prediction. Therefore, we could logically expect arguments for historical sciences to contain more data linked to the claim by more warrants. In addition, a greater amount of qualifiers and rebuttals would be expected as historical sciences often have multiple hypotheses under examination.

The teachers in this study did provide reasonably authentic images of the justification of both experiential and historical scientific knowledge claims. In terms of the number of scientific data utilized in the two units, the results from this study show that teachers' argumentation was consistent with the mode of inquiry used in the topic they taught. As expected, the teachers utilized a much greater

number of scientific data during their historical science units. They warranted those data to their claims far more as well.

It seems as though the teachers did provide authentic simple arguments, but were either unable or chose not to provide more complex arguments. According to Toulmin, a claim evidenced by data linked by a warrant constitutes a simple argument. More complex arguments include qualifiers and rebuttals. No qualifiers and few rebuttals were used by the teachers in this study for either unit. More complex arguments would have qualified their data and provided possible rebuttals to the claims as multiple sources of evidence were combined and connected to the hypotheses.

Walton's (1996) schemes for presumptive reasoning provided an examination of the persuasive aspects of the teachers' arguments. As opposed to capturing only the scientific data, the presumptive reasoning schemes reveal other ways in which teachers seek to convince students of their claims. For instance, a teacher can simply state a fact with either no outside reference ('sign' scheme) or reference to an authority ('expert opinion' scheme). The teacher can illustrate the concept with examples ('example' scheme) or by using an analogy ('analogy' scheme). If scientific data is used, the teacher can show its relation to other evidence to support a hypothesis ('evidence to hypothesis' scheme) or show a direct causal link between that data and an effect ('causal inference' scheme).

The teachers in this study utilized these different schemes in different ways. As seen in the structural analysis, they used scientific data in both units to evidence their claims. The majority of these references were 'causal inferences'.

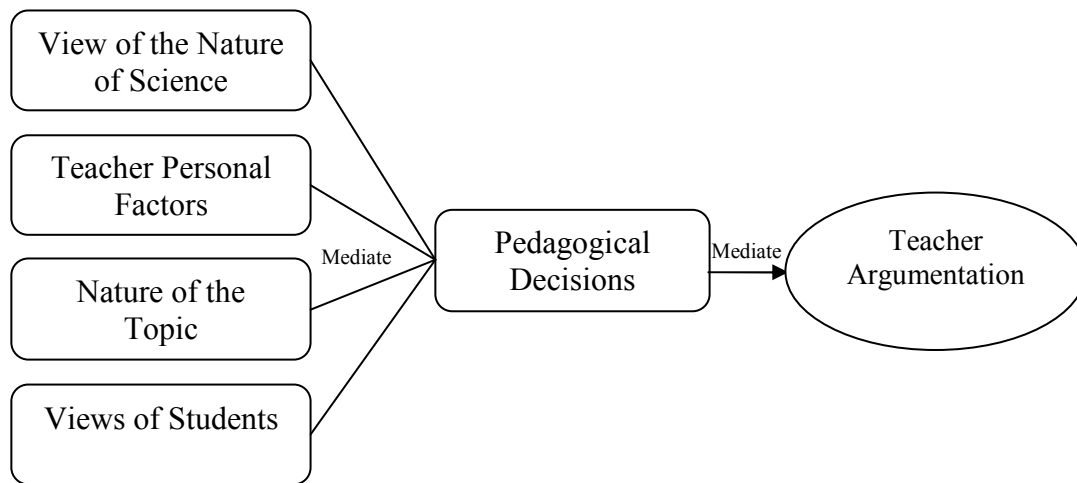
However, they presented much more evidence used to support a hypothesis during the historical science units. This maps well with our understanding of the role of evidence in the historical sciences. This pattern did not hold for Robert, however, as he intended to not “prove” evolution to his students in order to avoid conflict in his classroom. This led to the pedagogical decision to simply state evolution as fact. Thus the teachers properly evidenced their historical scientific claims except when concerned with engaging with the students during a controversial subject.

When the teachers did not provide scientific data they used persuasive techniques instead. All participants used far more analogies in their experimental science units due to the abstract nature of experimental science concepts and the difficulty in illustrating the concepts in the classroom. They also utilized examples to illustrate their concepts. The examples, however, were mediated by the nature of the topics under study. While some topics lent themselves to illustration by example (evolution and chemical bonding), others did not (DNA and the formation of the solar system). Therefore, the use of the ‘analogy’ scheme could be used to distinguish between the two modes of inquiry. The ‘example’ scheme, however, is more dependent on the nature of the topic itself and revealed no pattern of use across the modes of inquiry.

Finally, much of the information from the unit was simply stated as fact with little backing therefore relying solely on the authority of the teacher or outside experts. The majority of the participants utilized the ‘sign’ scheme, relying on their authority as the teacher. Matt, on the other hand, often used the ‘expert opinion’ scheme due to his lack of content knowledge in his historical

science unit and his negative opinion of his experimental science topic. The use of this scheme therefore relies on the authority of experts, whether that be a scientist, text, or, as was common in Matt's chemical bonding unit, the periodic table.

Taken together, the results of these two analyses show that the highly experienced and knowledgeable teachers in this study were able to construct simplified, yet authentic arguments for their topics. They had sophisticated enough understandings of the modes of inquiry used to justify their two units that these differences appeared in their arguments, although in a simplified manner. These arguments, however, were heavily influenced by four other overlapping factors. In addition to their understanding of the nature of science, other personal factors (perceived content knowledge, opinions of the disciplines under study, and concern about teaching controversial topics), views of their students, the nature of the topics, and pedagogical decisions mediated their arguments (Figure 5.2). As a result, the teachers' arguments constructed in the classroom are not a direct representation of their understanding of the two modes of inquiry as they are mediated by confounding factors leading to changes in the pattern of their arguments.



*Figure 5.2: Factors mediating teacher argumentation*

### *Images of Inquiry in the Science Classroom*

Driver et al. (2000) state that “science in school is commonly portrayed from a ‘positivist perspective’ as a subject in which there are clear ‘right answers’ and where data lead without controversy to agreed conclusions” (p. 288). This leads to a ‘rhetoric of conclusion’, as Schwab (1962) put it, in which scientific knowledge is conveyed as literal truth. As Duschl (1990) points out, this emphasis on ‘final form’ science remains unchanged in today’s science classrooms. The task of the science teacher is still seen as one of persuading his or her students of the validity of the scientific worldview (Ogborn, Kress, Martins, and McGillicuddy, 1996; Millar, 1998; Osborne, 2001). Research has shown that whole class discourse is, more often than not, dominated by a teacher-led structure that focuses on the ‘facts’ (Lemke, 1990). Therefore, in this context of teacher-



dominated discourse aimed at persuading students of the validity of science, what images of the diverse modes of scientific inquiry are the students presented?

This study is an initial step in answering just that question. These units were typical secondary high school science units dominated by teacher discourse. Whereas all of the units included activities, none were inquiry-based or student-directed. Therefore, students were given very few opportunities to contribute to the process of constructing knowledge in the lessons. Thus, the arguments the teachers constructed to justify the scientific knowledge claims under study are a major source of the image students perceived of these topics. This study shows that highly experienced and knowledgeable teachers present arguments to their students that, while simple in structure, do reflect somewhat authentic images of the two main modes of inquiry. This is most profound in the amount of evidence used to justify the claims.

These images, however authentic, are implicit in nature. They appear under careful scrutiny and analysis, but are not explicitly described by the teachers to the students putting the responsibility on the students to understand these implicit messages. This is similar to Zohar and Nemet's (1999) findings that, while teachers often used higher order thinking skills in the classroom, they were not often aware of it. Similarly, the differences in arguments were more like an unconscious intuitive activity. Therefore, the authentic arguments may only have a minimal educational effect on students in showing different modes of inquiry to the students.

### *Methodology*

This study marks the first attempt at using argumentation analysis at the level of an instructional unit. Previously, the majority of studies have concentrated on the analysis of argumentation at the level of particular segments of classroom discourse. Erduran et al. (2004) extended this to include whole-classroom conversation in their study of middle-level science teachers before and after an intervention on the teaching of argumentation to students. The authors utilized Toulmin's (1958) argumentation pattern to create argument profiles which could be used as indicators of improved performance across lessons. Consequently, their scheme moved the use of argumentation analysis to the level where argumentation in entire lessons could be traced and examined in detail.

This study attempts to move the use of argumentation analysis one step further to the level where an entire instructional unit can be examined in detail. This increase in the level of analysis presents specific difficulties. Whereas an analysis of the argumentation during a small segment of a class or even an entire class session tends to focus on one claim, analysis of an entire instructional unit contains multiple claims with data, warrants, backings, qualifiers, and rebuttals spread throughout multiple days. Pulling these together into a coherent argument for analysis was challenging as they were often regularly repeated and not always explicitly referenced back to the claim. Therefore a decision had to be made as to whether a particular data statement, for instance, should be included as data for a claim if it was not obviously linked to that claim for the students. Another difficulty involved the pulling apart of the statements for each claim for the

presumptive reasoning analysis. Teachers would often mix these schemes together. For example, a teacher might provide an analogy while simultaneously providing multiple examples and signs. These separate schemes needed to be teased apart for analysis.

In terms of the analytic framework, I found Toulmin's framework to be limited in detail. For example, while the structural analysis showed that the teachers utilized more scientific data during their historical science units, Walton's framework provided increased detail by breaking these data into 'causal inference' and 'evidence to hypothesis' schemes. This revealed that a specific type of evidence, that which is combined with other evidence to back up a claim, was more prevalent in the historical science units whereas teachers used a similar amount of 'causal inference' schemes in their experimental units. In other words, the analysis using Walton's schemes provided increased detail, particularly at the level of the instructional unit.

This conclusion is similar to Duschl's (2007) conclusion about his study involving the analysis of student discourse in a middle-level classroom. Duschl (2007) analyzed his data using both Toulmin's (1958) argumentation pattern and Walton's (1996) argumentation schemes for presumptive reasoning as well. He found that the use of Walton's schemes "more adequately fit the discourse structures (e.g., dialectical and rhetorical) and reasoning sequences of the [data]" (p. 169). For Duschl, Toulmin's argumentation pattern uses too broadly defined categories to characterize arguments. During argumentation, the students in his study would frequently make "appeals" to specific positions such as an appeal to

authority or to analogy. He found that the examination of the content or focus of the “appeals” enabled an analysis that “gets closer to the epistemic criteria being used to establish and justify the quality and strength of the argument” (p. 164). Therefore, he switched to Walton’s schemes for presumptive reasoning in his analysis as it provided, he felt, a more nuanced and detailed framework for monitoring how students were employing evidence in the construction of explanations.

### *Implications*

The results of this study have implications for classroom practice, teacher education, and research. In terms of classroom practice, the reform movement in science education may have had a significant impact on the nature and type of investigational and practical activities, but these developments have had little impact on the pattern of discourse of science teachers. From a social constructivist perspective in which language and thinking are intertwined (Vygotsky, 1978; Bakhtin, 1986), the discourse of teachers becomes paramount as the teacher and students co-construct scientific knowledge claims in the classroom. The authenticity of those knowledge claims, therefore, depends on the authenticity of the teachers’ arguments in a teacher-dominated class. By using these results as a guide as to the implications of differing modes of inquiry in argumentation teachers can be more explicit in their argumentation thereby presenting a more authentic image of scientific practice.

The results have implications for science teacher education as well. The results identify strengths and weaknesses of expert teachers' argumentation in regards to experimental and historical sciences. The teachers' views on the nature of science were an important mediating factor in the differences seen in the patterns of their arguments for these two categories of science. Thus, improving preservice teachers' understanding of the nature of science, and in the diversity of methods utilized in science in particular, is paramount in affecting the images these teachers will present to their students for years to come.

Finally, this study has implications for the science education research community as well. Specifically, the results revealed the ability to utilize argumentation analysis to assess argumentation at the level of the instructional unit. Therefore, a combination of Toulmin's (1958) argumentation pattern and Walton's (1996) schemes for presumptive reasoning can be used by the research community to examine other questions relating to teacher argumentation at that level. In addition, the results show a link between a teachers' understanding of the nature of science and the diversity of methodologies employed by scientists to justify their knowledge claims and their arguments constructed for their students. The results also revealed specific factors mediating the construction of these arguments. This information can be used to design further, more specific studies of secondary science teacher argumentation.

### *Limitations of the Study*

This study has limitations in terms of the generalization of its findings. Only highly experienced and qualified participants were included in the sample. Therefore the sample is not representative of the population of secondary science teachers. As opposed to content and pedagogical knowledge assessments, proxy data such as education background, years teaching and reputation were used to recruit participants. In addition, a total of four participants were recruited. This relatively small number is necessary to provide Robert descriptions of their teaching backgrounds and classroom argumentation required for qualitative inquiry. These limitations make drawing conclusions to the general population of secondary science teachers problematic. As an exploratory study, however, the findings provide insight into the manner by which expert teachers construct arguments for science topics that rely on different modes of inquiry and guide further study as described below.

#### *Recommendations for Future Research*

As an exploratory study this research was designed to lead to further research. The study begins to fill gaps in the research literature regarding images of inquiry presented to students for science topics relying on different modes of inquiry. As this study utilized highly experienced teachers in terms of their teaching and content backgrounds, further research could begin to examine the ability of novice teachers to construct such arguments. For instance, what role does teaching experience play in the construction of these arguments? Or, conversely, what role does content knowledge and research background play?

While this study did identify five factors mediating the teachers' arguments, it did not explore the effect of content knowledge on their argumentation in detail, although Matt's case provides evidence for a possible effect.

One goal of science education research, including this study, is to improve students' understanding of the diversity of modes of inquiry that justify scientific knowledge. This study did not take into account what effect the arguments studied had on student understanding. Research linking teacher argumentation to understanding of 'how we know what we know' by students is an essential next step.

Finally, studies are needed examining specific interventions for preservice and inservice teachers designed to help teachers construct authentic arguments for the science topics they are teaching and to present these arguments in a more explicit way. The results of this study offer a baseline for future studies in these and other possible areas.

### *Conclusion*

The current reform documents ([AAAS], 1990; ([NRC], 1996) in science education call for a more authentic representation of science in our classrooms. They ask teachers to go beyond teaching merely 'final form' science (Duschl, 1994) and provide students with understandings of what authentic science is, how it works, and how it is justified. Concurrent to these reforms, research in science studies has begun to broaden our understanding of how science develops. Specifically, researchers have focused on the ways in which diverse fields of

science construct and justify their knowledge claims revealing two distinct modes of inquiry, those of experimental and historical sciences.

This study marks an initial attempt to translate these new understandings of what authentic science among the different disciplines looks like to the science classroom. The results of this study provide a baseline for future studies using argumentation, so central to both science and the science classroom, as a metric in examining the images teachers present to their students of how we know what we know. Hopefully the specific patterns in the way expert teachers construct these arguments and the factors that act to mediate them revealed in this study will contribute in some meaningful way to the practice of teachers, teacher educators, and science education researchers in the years to come.



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APPENDICES

## APPENDIX A

**Pre-Instruction Interview Protocol**

- Follow-up questions on NOS questionnaire.

Students

1. How would you describe the student population at your school?
2. How would you describe the students in your physics (and astronomy) class? (Ability range, socioeconomics, diversity, motivation, etc.)

Teaching and teacher

3. How do you see your role as a science teacher?

Students and pedagogy

4. Does your impression of the students ever influence your teaching? Can you provide any examples? What sorts of adaptations do you make?

Teaching

5. What does a typical unit of yours look like? What instructional strategies do you often use?

Content and goals

6. What are your general goals for teaching? What do you want your students to achieve by taking your course?
7. Your next units are about the formation of the solar system and basic chemistry. What are your objectives for the unit?
8. Why are these units important? In relation to other units? To students?
9. What is your general plan for the units?
10. Why do you teach these units the way you do? Have they evolved over time?
11. How do students traditionally do in these units? Are some topics in the units more difficult for them than others?

Community Context

12. Has the community, the school, your colleagues, or students' parents influenced the way you teach this unit?

## APPENDIX B

**Post-Instruction Interview Protocol**

1. Before the unit you stated that your main goals for units unit were \_\_\_\_\_. Did those goals change over the unit?
2. How well do you think your students did at reaching those goals? Were there any parts of your instruction that were more or less efficient at helping students reach these goals?
3. Before the unit you discussed your plan for the unit. Did you ever feel the need to adapt that plan? If so, what made you decide to change?
4. (Use assessment big ideas). For the following big ideas, what evidence do you think supports these claims?
5. In terms of the science itself (not teaching the topics), what do you see as the difference between these two topics?
6. If these two topics are categorically different from each other, how did that effect the organization and strategies used during instruction? Or: If they were the same, what accounts for the difference in instruction between these two units?
7. Did you feel any constraints teaching either of these units? If you had twice the amount of time, would the unit differ? How?
8. How would you define scientific inquiry? Does it look different in different fields of study? If so, how?
9. Are there any parts of these units that you would categorize as inquiry?

**To get:** post-assessments, teacher's post-assessments, instructional materials, class roster with grades.

## APPENDIX C

## Nature of Science Survey

Instructions

- Please answer each of the following questions. Include relevant examples whenever possible. Please type into the space beneath each answer (the font should be in red). These are meant to be short-answer questions.
  - There are no “right” or “wrong” answers to the following questions. I am only interested in your opinion on a number of issues about science.
1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?
  2. What is an experiment?
  3. Does the development of scientific knowledge **require** experiments?
    - If yes, explain why. Give an example to defend your position.
    - If no, explain why. Give an example to defend your position.
  4. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence, or types of evidence, do you think scientists used to determine what an atom looks like?
  5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
  6. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
    - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
    - If you believe that scientific theories do change:
      - a) Explain why theories change.
      - b) Explain why we bother to learn scientific theories. Defend your answer with examples.
  7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what a species is?

8. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
  - If yes, then at which stages of the investigations do you believe that scientists use their imagination and creativity: planning and design; data collection; after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
  - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.
  
9. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?
  
10. Scientists from all disciplines utilize a diverse array of methods to answer many types of scientific questions. Are there major differences between the disciplines of science (e.g. biology, physics, geology, etc.) in the methods they employ or the types of questions they ask?
  - If you believe there are major differences between the disciplines, explain what those differences are in terms of methods and questions. Defend your response with examples.
  - If you do not believe there are major differences between the disciplines, explain why. Defend your response with examples.
  
11. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.
  - If you believe that science reflects social and cultural values, explain why and how. Defend your answer with examples.
  - If you believe that science is universal, explain why and how. Defend your answer with examples.

## APPENDIX D

## Nature of Science Aspect Descriptions

<b>Tentativeness</b>	Scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations.
<b>Empirical Basis</b>	Scientific knowledge is based on and/or derived from observations of the natural world.
<b>Subjectivity</b>	Science is influenced and driven by the presently accepted scientific theories and laws. The development of questions, investigations, and interpretations of data are filtered through the lens of current theory. This is an unavoidable subjectivity that allows science to progress and remain consistent, yet also contributes to change in science when previous evidence is examined from the perspective of new knowledge. Personal subjectivity is also unavoidable. Personal values, agendas, and prior experiences dictate what and how scientists conduct their work.
<b>Creativity</b>	Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world.
<b>Social/Cultural Embeddedness</b>	Science is a human endeavor and, as such, is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.
<b>Observations and Inferences</b>	Science is based on both observations and inferences. Observations are gathered through human senses or extensions of those senses. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.
<b>Theories and Laws</b>	Theories and laws are different kinds of scientific knowledge. Laws describe relationships, observed or perceived, of phenomena in nature. Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena. Hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Theories and laws do not progress into one and another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge.
<b>Diversity of Methods</b>	Science uses a range of methods and approaches and there is no one scientific method or approach. Different fields of science require different methods as they ask different types of questions.

## APPENDIX E

### Toulmin Analysis (Robert / Experimental)

Scientific Claim	Scientific Data	Warrant
#1: DNA is in all living things	DNA extraction lab	“Now we’re actually going to look at some DNA today.”
#2: DNA is protected in the nucleus.	Use of soap in DNA extraction lab	“It breaks all that apart and that allows the cytoplasm and stuff to come out. And then you can break down the nuclear membrane too.”
#3: DNA is shaped like a double helix.	“In 1952, a woman did a very important thing. She found in 1952 that by using x-ray diffraction that she showed it looked kind of like this shape right there. ... Rosalind Franklin used in x-ray beam to figure out the shape of that.”	“Now as soon as she did that it made it a lot easier for 2 people that are credited with figuring out the DNA structure.”
	“Let me tell you about Chargaff’s rules. He found that when he took a lot of DNA and sampled it, he found that the % of adenine was the same as the % of what? ... [S] Thymine. ... Whenever he tested he found that they were always matching.”	
#4: Messenger RNA is used to send messages out of the nucleus.	“So 1960 is Brenner and this is what Brenner discovered. He discovered that messenger RNA is the way that the DNA gets its message out of the nucleus.”	
#5: Proteins are created from DNA through transcription and translation.		
#6: DNA is the blueprint for all	“Oswald Avery ... Some of the molecules they knew	“that’s where they discovered it was DNA.”

cells.	is they knew RNA, proteins, fats, carbohydrates. He would destroy those various ones to see if it still worked and it always still worked even though he destroyed those molecules.”	
	Alfred Hershey and Martha Chase studied viruses ... They were trying to figure out which part of the virus entered an infected cell. ... They found that some of these bacteria had sulfur in them and so that was in the protein coat and so they tried to see if they could get that and they found that none of it went into the cell. ... Then they took another one with phosphorous, a different kind of phosphorus, and they put that on and sure enough it went in there.”	“So from that they confirmed that it was the DNA that was being put in there, not some other part of the bacterial phage. So that gave them some more information and some more support for their idea of how it all works.”



APPENDIX F

Toulmin Analysis (Robert / Historical)

Scientific Claim	Scientific Data	Warrant
<p>“Artificial selection is the process by which [species change] doesn’t happen naturally.” (438)</p>	<p>[Dogs] “As it turns out every one of those dogs you just looked at is the same species. There’s just a tremendous variety.” (432)</p>	<p>“With the dog picture that is not the case because we are artificially breeding them.” (545)</p>
	<p>Farm animals (545)</p>	<p>“Most critters that we have in our farmland have been selectively bred.”</p>
<p>Natural selection “In the natural world it is survival of the fittest so the ones that are best fit can make it.” (536)</p> <p>“...the most fit and healthy live to reproduce. If you don’t get to reproduce then you are not going to pass on your genes. ... it is all about the genes.” (1165)</p>	<p>Widow birds (495)</p>	<p>“The natural selection of that is they are saying that is the best bird. ... And if I use that bird to have my offspring then my offspring are going to be stronger, they’re going to have better genes, and they’re going to have a better change to survive.” (507)</p>
	<p>Honey Bees (521)</p>	<p>“But the whole goal is still that reproductive idea that you pass on genes and they keep going down through time.” (536)</p>
	<p>Oregon rough-skinned newt (573)</p>	<p>“Anyway the idea here was that the two were driving each other. Because the snake started to be able to withstand the toxins and then they could prey on them so it was an advantage to the newts to have more of that poison.” (596)</p>
		<p>“Those ones with the gene that made more of the toxin would survive better and if they survive better they have more offspring because they get to mate more.” (599)</p>

	Peppered moths: “The peppered moths were over in Europe and the idea here was that it is a white moth with black spots and there are lighter ones and darker ones.” (817)	“...in population studies it is obvious that things that are able to reproduce more often are going to pass on their genes more.” (830)
“Warning coloration is when something has real bright obvious colors so that one thinks that it is a danger to them.” (644)	Oregon rough skinned newt: “Why do they have the bright orange belly? ... They want to warn.” (572)	“It could flip over and flash so that predators would realize that’s something nasty.” (642)
	Poison dart frog: “You probably have all seen pictures of the poison dart frogs.” (643)	“... which are usually very brightly colored.” (643)
	Skunks: “Skunks are only black and white though so you would think ‘well, that isn’t very bright...’” (646)	“Why would only black and white be alright if you’re talking about a wolf for a dog or something? They’re colorblind. They only see in black and white so the black and white stripe they can see well.” (647)
Mimicry: “You’re imitating something to defend or I supposed some of them do it to get food.” (1220)	Viceroy butterfly: “The viceroy actually mimics, it looks very similar to that but it is not poisonous.” (672)	“...so it actually gets protection by mimicking the monarch butterfly.” (672)
	Rattlesnake and gopher snakes: “The gopher snakes look a lot like rattlesnakes.” (674)	“When the gopher snake is being harassed it will coil up like a rattlesnake and wiggle its tail in the leaves so it kind of makes a rattling sound but they are not poisonous and they would be susceptible to predation so that is why they mimic the rattle.” (677)
“Camouflage generally means that you’re trying to make yourself invisible.” (693)	“We started out with the chameleon...” (687)	“...because they can change colors.” (688)
	“What he is talking about are those moths that have what looks like eyes on their wings.” (690)	“Some predator comes for them and they just flash that and they think there is an owl there.” (691)
	Flounders: “The flounders they sit down on the bottom.”	

	Peppered moths: “The peppered moths were over in Europe and the idea here was that it is a white moth with black spots and there are lighter ones and darker ones.” (817)	“...the lighter ones tended to be camouflaged from the bird predators a lot more because they blended in with the bark more but when the pollution from all of the burning coal mostly caused the trees to get black the black moths with the darker traits that used to get picked off way quicker survived better.” (826)
“Genetic drift just means that over time the gene pool changes and the traits sort of alter with time...” (838)	Peppered moths: “The peppered moths were over in Europe and the idea here was that it is a white moth with black spots and there are lighter ones and darker ones.” (817)	“In this case after a while the dark ones did better and the white ones started getting picked off and so just like your little activity the genetics changed.” (831)
	Microbial antibiotic resistance: (video hepatitis prison example) (862)	“...they have to change flu shots all of the time because those microbes will alter their genetics and after a year or so it won't have the same effect anymore.” (867)
	Swine flu: “Actually it fits in very well with our evolution unit because obviously this thing has evolved in very recent times.” (925)	“...every year they make a new flu shot, we talked about this last week. Because the viruses can evolve and change and so you have to have a different thing to try to fight it.” (936)
“...extinctions reduce genetic diversity...” (1128)		
Stabilizing selection: “... if something works there is no pressure from evolution to make a change because it work...” (1168)	Crocodiles, sharks, and lizards	“Those are all patterns that have proven to work very well over time and so they stay. ... You're not going to mess with the design because those genes keep getting passed on and they keep working.” (1179)
Directional selection: “...means there is a lot of change [in one	Long-tailed birds (from video): “...the one with the best display would get to mate and pass on	“...it causes a genetic drift over time to make the tales longer and longer.” (1194)

direction].” (1183)	their genes.” (1193)	
	Extinct elk: “What happened was they think these elk would only get a mate if they had the biggest rack...” (1200)	“... so they kept growing bigger and bigger...” (1200)
	Peacock: “Another bird that you can think of is probably the peacock.” (1206)	
Disruptive selection: “...is when organisms split and select two extremes.” (1208)		
Vestigial structures: “...a remnant of a physical feature that is reduced and often useless.” (1242)	Whale pelvis (1231)	“We all have a backbone and then we have two girdles. You have a pelvic girdle which is down here by your pelvis and then you have a pectoral girdle which is up here by your shoulders.” (1237)
	Human tailbone (1234)	
	Snake pelvis (1238)	“We all have a backbone and then we have two girdles. You have a pelvic girdle which is down here by your pelvis and then you have a pectoral girdle which is up here by your shoulders.” (1237)
	Appendix (1247)	
	Cave fish (1250)	“over time they lose their eyes and maybe they still have vestigial eyes but they don’t actually function anymore because there’s no use for the critters to put all that energy into having something that is unusable anyway.” (1250)
Reproductive isolation “is separate mating at different times.” (1277)	“If you’re a frog and you mate in the spring or you mate in the fall if you use the same lake to mate	“So even though they’re using the same facility, the pond, in the same year they’re not

“If you mate at different times, you’re different.” (1277)	you’re never going to mix your genes if you mate in the spring you’re never going to mix your genes with the frogs that mate in the fall.(1260)	mating at the same time so ... they are isolated.” (1263)
	Salmon (1265)	“But those two different runs of fish, even though they are the same species, are reproductively isolated. Over time the gene pools change ... “ (1266)
	“There are a lot of plants that bloom at different times.” (1569)	“...they cannot mix their genes.” (1572)
Geographic isolation “separate gene pools because of the different locales.” (1281)	Dark-eyed Junco: “Look at this bird and you will see that they are very similar. This bird has yellow shafts on the feathers and this one is red. This one was on the Western side of the United States and this one was in the Eastern United States.” (1300)	“This bird in particular is a classic example of geographic isolation...” (1330)
	Common Flickers: “So there was this huge expanse of prairie that blocked the east from the west where these birds live in the east coast and these on the western side of the rocky mountains.” (1338)	“What happened over time settlers started moving west [planting trees]. These yellow ones started moving across the prairie... and they found that these will mate with these...” (1342)
	Woodpecker (1348)	“The idea is that these were probably the same birds at one time that they separated geographically and so over time as their gene pool changes and they mated with their group they changed and then they are different.” (1351)
	Titmice (1373): “Look at all the variety.” (1373)	“So they’re all separated geographically.” (1375)
	Warblers (1382)	“We have both of these here and they mate with each other so now they just call hem one

		species...” (1385)
	Baltimore Oriole (1386)	“Now we don’t even have Baltimore orioles. We now have northern orioles because these two will mate with each other and again they are separated.” (1386)
	Canadian Geese: “In the Canadian Geese we have several different varieties. They are way different in size and shape and color...” (1391)	“... we have four major flyways in the United States. ... The geese all come here to the valley and they mix up but they stay separated as races for this reason. They do not pick their mates here... So over time the geese have changed and in fact just in the last year they have officially made these two new species.” (1397)
	Ducks: “We also have ducks that come here in the winter...” (1390)	“and they mix up in the winter but there are no races of duck.” (1390)

## APPENIDX G

### Walton Analysis (Robert / Experimental)

Scientific Claim	Evidence	Scheme
#1: DNA is in all living things	DNA extraction lab: "Now we're actually going to look at some DNA today."	<i>Example</i>
#2: DNA is protected in the nucleus.	Use of soap in DNA extraction lab: "it breaks all that apart and that allows the cytoplasm and stuff to come out. And then you can break down the nuclear membrane too."	<i>Causal Inference</i>
	But when the construction's going on it's rainy and muddy, they're digging out there, and this is precious stuff, this plan right here. So when the plumbers come, say some plumbers come on a rainy day to lay the pipes before they pour the cement and say hey, we need to know where the pipes go. Well, how do they figure that out? They have to have a plan. So do you think the guy in the office there is going to say "oh, here's the page that shows you that. While you take this out there in the rain in the mud and figure it out." No, he's not going to do that. This stuff's precious. So it's help inside the nucleus in the office. What he does instead is he makes a copy of this and he says "here's the plan, take it" and they go put on a piece of wood out there and it gets all muddy and no big deal because it's just a copy.	<i>Analogy</i>
	Your DNA is protected. It stays inside the nucleus	<i>Sign</i>
#3: DNA is shaped like a double helix.	"In 1952, a woman did a very important thing. She found in 1952 that by using x-ray diffraction that she showed it looked kind of like this shape right there. ... Rosalind Franklin used in x-ray beam to figure out the shape of that."	<i>Evidence to Hypothesis</i>
	"let me tell you about Chargaff's rules. He found that when he took a lot of DNA and sampled it, he found that the % of adenine was the same as the %	<i>Evidence to Hypothesis</i>

	of what? ... [S] Thymine. ... Whenever he tested he found that they were always matching.”	
	Double helix. It looks like a ladder that has been twisted. Double helix.	<i>Analogy</i>
	So, this double helix thing is made up of two strands and they're little nitrogen bases here that are connecting...	<i>Sign</i>
	For RNA, Uracil replaces thymine. So only U can hook up with the A. There is no thymine. So on a test which you will get, and on the state test too, whenever you see a U immediately you know that has to be strand of the RNA.	<i>Sign</i>
	They separate at their base pairs. And what makes them separate? It starts with an E. [S] Enzymes. ... Enzymes. Yes. It makes that thing unzip	<i>Causal Inference</i>
	Remember that this thing is held together by chemical bonds and so you have to keep in mind that there are enzymes that cells use to break those chemical bonds. Those bonds are pretty weak. They are hydrogen bonds.	<i>Causal Inference</i>
	These chemical things occur because there are chemical attractions. There are bond things that make it want to come there.	<i>Causal Inference</i>
	It's like a magnet that pulls it.	<i>Analogy</i>
	The mRNA slides along the ribosome. So this ribosome is actually an organelle in them that causes these reactions to occur and it allows a things to come and break things. Another tRNA brings an amino acid that connects by a peptide bond. Not going to make you memorize the kinds of bonds and stuff but it brings it in and attaches by peptide bonds to the first amino acid. So we had one amino acid now another one connected there. And look. All the other stuff goes on or does other things or becomes defunct. The whole goal there was to bring that amino acid.	<i>Sign</i>
#4: Messenger RNA is used to send messages out of the nucleus.	“So 1960 is Brenner and this is what Brenner discovered. He discovered that messenger RNA is the way that the DNA gets its message out of the nucleus.”	<i>Expert Opinion</i>



	That little strand of RNA and it's called messenger RNA, mRNA. It means the messenger and it's going outside of the office out into the cruel world to do work. But the precious DNA is stored in the nucleus and it never comes out of there. It's staying in there so it can be protected, but the cell has to do work. So all of the other workers come and they keep doing work and say the plumber loses his plan or some kids are skipping at lunch and they go take the plan and make paper airplanes. Does that mean we're not going to have plumbing in the floor and the kids ten years later I run to say you know they don't have bathrooms in that school because the plumber lost his plan? No, they can just make another copy so another messenger RNA can go out of the nucleus to go do work. Those are expendable. Those of the copies that are meant to go do work.	<i>Analogy</i>
	The mRNA leaves the nucleus and where does it go? To the cytoplasm.	<i>Sign</i>
#5: Proteins are created from DNA through transcription and translation.	Because for today we're going to say that it has to be uncoiled to do work and it also has to be uncoiled to be copied. So you'll see how it gets copied right now. So this is part one, just how it gets copied. [Shows Glencoe DNA Replication video]	<i>Expert Opinion</i>
	Imagine in a cell, you know that cytoplasm that fills up the rest of the cell? Imagine that that's full of little legos floating around in those Legos are these things. So that when it opens you can build those legos to build new ones.	<i>Analogy</i>
	Remember Cs go with Gs and As always go with Ts.	<i>Sign</i>
	It's a process called translation. It's like you have that in a different language and now it has to get translated to something they can be used. And what cells use as those are proteins.	<i>Analogy</i>
	So again, enzymes unzipped it. ... [S] What do enzymes do? ... They break the chemical bond that held it together. And then it opens. But in this case it's not opening the whole thing because it only needs to open the section or a gene because we're trying to make a gene. We're not trying to make a	<i>Causal Inference</i>

	whole chromosome.	
	The mRNA. What does the m stand for? Messenger. It's the messenger RNA. ... The mRNA attaches to a what? To a ribosome. Good. And then we'll get ready for our next step. ... [Video] ... Alright.	<i>Sign</i>
	The next thing is the transfer RNA. That's the tRNA. It bring a what? Two As. ... [S] Amino acids. ... Transfer RNA brings an amino acid to attach. ... [S] How?	<i>Sign</i>
	... it's not like they have little vehicles that are driving around.	<i>Analogy</i>
	Another tRNA brings an amino acid that connects by a peptide bond. Not going to make you memorize the kinds of bonds and stuff but it brings it in and attaches by peptide bonds to the first amino acid. So we had one amino acid now another one connected there. And look. All the other stuff goes on or does other things or becomes defunct. The whole goal there was to bring that amino acid.	<i>Causal Inference</i>
	How many of you have taken amino acid supplements to predicate more muscle? He lifts weights. Maybe do amino acids stuff to try to get more proteins. So the last one is: a protein is formed.	<i>Analogy</i>
	There are 64 different varieties of letters you can get if you pick any four of those and put them in threes.	<i>Sign</i>
	So we have DNA and we've always heard the DNA makes stuff for us, it runs the show, we'll actually, all it does is make RNA and then this RNA is actually attaching to this other molecule that has a chemical affinity to pick up an amino acid and bring it here. And the whole point of this you're going to see is not to have the east or this or that or anything else, is to make a chain of amino acids.	<i>Causal Inference</i>
#6: DNA is the blueprint for all cells.	“Oswald Avery ... Some of the molecules they knew is they knew RNA, proteins, fats, carbohydrates. He would destroy those various ones to see if it still worked and it always still worked even though he destroyed those molecules.”	<i>Evidence to Hypothesis</i>

	<p>Alfred Hershey and Martha Chase studied viruses ... They were trying to figure out which part of the virus entered an infected cell. ... They found that some of these bacteria had sulfur in them and so that was in the protein coat and so they tried to see if they could get that and they found that none of it went into the cell. ... Then they took another one with phosphorous, a different kind of phosphorus, and they put that on and sure enough it went in there.”</p>	<p><i>Evidence to Hypothesis</i></p>
	<p>[building blueprint metaphor] This construction this plan is like the DNA of the cell.</p>	<p><i>Analogy</i></p>
	<p>So this Griffith was a British scientist did some work with transformation. He was figuring out how certain types of bacteria cause pneumonia. He found two kinds of bacteria. What he found was that one bacteria would cause pneumonia and the other wouldn't. What he did was he made some observations. He took the disease causing one, found they had smooth colonies, and he took these harmless ones and found that they had rough edges around the colonies and he made this little experiment. ... Bacteria are prokaryotes which means they don't have a nucleus to protect that so what happens in their is they does have those loop of DNA in the cell and these bacteria are one so what happens is when they reproduce they make a copy of that and then bacteria splits into two and they each get a copy. Then you have two bacteria. These bacteria, since this loop is like that it's a lot easier to have this happen. what basically happened is this loop of DNA in the bacteria was somewhat destroyed and probably broken apart but there were segments of it that were still in tact. The A,C, G, T stuff. Because bacteria have the same ACGT that we do and so these little particles got into the live bacteria cells that were harmless and this DNA segment got incorporated, this strand of DNA allowed it to be inserted in there, and so this gene got stuck in there. And that's how they figure this whole thing out about genes that a gene could get put in there and now it works for this bacteria that was harmless so it was a gene splicing or deal that got that</p>	<p><i>Evidence to Hypothesis</i></p>

	<p>piece of DNA in there and it did it on its own ... He figured out that there was something in there that could cause this. But they didn't know yet if it was DNA or not.</p>	
	<p>Then we had Alfred Hershey and Martha Chase studied viruses, nonliving particles that are smaller than a cell, that affect living things, bacterial phages. I don't want to get into those right now. They were trying to figure out which part of the virus entered an infected cell. ... They found that some of these bacteria had sulfur in them and so that was in the protein coat and so they tried to see if they could get that and they found that none of it went into the cell. So from that they figured out it couldn't be what? What did they figure out from this experiment? [S] It couldn't be the protein. ... Yes, it couldn't be the protein. Then they took another one with phosphorous, a different kind of phosphorus, and they put that on and sure enough it went in there. So from that they confirmed that it was the DNA that was being put in there, not some other part of the bacterial phage. So that gave them some more information and some more support for their idea of how it all works.</p>	<p><i>Evidence to Hypothesis</i></p>

## APPENIDX H

### Walton Analysis (Robert / Historical)

Scientific Claim	Evidence	Scheme
<p>“Artificial selection is the process by which [species change] doesn’t happen naturally.” (438)</p>	[Dogs] “As it turns out every one of those dogs you just looked at is the same species. There’s just a tremendous variety.” (432)	<i>Example</i>
	Farm animals (545): “Most critters that we have in our farmland have been selectively bred.”	<i>Example</i>
	Now obviously an Irish wolfhound and a Pekingese are going to be able to mate. Just because it is physically not going to happen. But actually some of the breeds, we just got a new biology book this year but in the biology book we had last year there's actually a picture in here of any English bulldog that was bred to become a specific breed but it is so locked into the little physical traits it has it can't even physically mate with another dog.	<i>Example</i>
<p>Natural selection “In the natural world it is survival of the fittest so the ones that are best fit can make it.” (536)</p> <p>“...the most fit and healthy live to reproduce. If you don’t’ get to reproduce then you are not going to pass on your genes. ... it is all about the genes.” (1165)</p>	Widow birds (495) “The natural selection of that is they are saying that is the best bird. ... And if I use that bird to have my offspring then my offspring are going to be stronger, they’re going to have better genes, and they’re going to have a better change to survive.” (507)	<i>Example</i>
	“But the whole goal is still that reproductive idea that you pass on genes and they keep going down through time.” (536)	<i>Sign</i>
	“Anyway the idea here was that the two were driving each other. Because the snake started to be able to withstand the toxins and then they could prey on them so it was an advantage to the newts to have more of that poison.” (596)	<i>Example</i>
	Peppered moths: “The peppered moths were over in Europe and the idea here was that it is a white moth with black spots and there are lighter ones and darker ones.” (817)	<i>Example</i>
	So the thing with passing on your genetic code is to be able to mate. If you	<i>Causal Inference</i>

	don't mate your genes end.	
	A weird one is bees. When honeybees are out working what sex are the workers? They're all females. And they're all sisters and in some case double sisters of the queen. None of those worker bees ever get to mate and have babies. Only the queen gets too. However they do that work because it is still hopeful to passing on their genes because she is like a double sister to them so in helping the hive they are still getting their genes passed on to the next generation. The Males don't do anything. They are called drones and they hang around the high as and when the queen needs to make they fly up in the air and she spirals in flight way up and the air and they fly after her. Then she picks the strongest one that made it highest and they mate and the males fall down and die and that's their life.	<i>Example</i>
	If they are changes that are detrimental they will probably die out because they are not very beneficial.	<i>Causal Inference</i>
	Let's say that starting next year there would be a decree around the world that unless you were 6'4" as the mail and 5'10" as a female you would not be allowed to have children and those that would try as they would go around and sterilize. So we would only have fairly tall people having babies. Then over the next generation day what amp it up by little bit. They could say that by the year 2050 you must be at least 6'8" if you are a male and at least 6'0' if you're a female or you cannot have any kids. So you see what would happen over time. Only the genes for tall people would be propagated and people would get tolerant or. You can do with the other way and you could suppress growth by saying if you're over 6 feet sorry no kids for you because we don't have the resources on the earth to make enough close for you.	<i>Analogy</i>
	Why is it so important if you're taking antibiotics that you take the whole set? If you don't and you don't finish the thing off then it can evolve to a different form and be resistant so that is important that people take their	<i>Evidence to Hypothesis</i>

	drugs to the end.	
	What other things that happen, some of you know about flu shots, every year they make a new flu shot, we talked about this last week. Because the viruses can evolve and change and so you have to have a different thing to try to fight it.	<i>Evidence to Hypothesis</i>
	The other thing about this whole virus thing is that it is important to recognize bacteria, viruses, humans, we all have the same little pieces of DNA. And so when you look in all organisms and the entire existence of the world's they all have the same DNA. And so the changes in that DNA are what make changes over time.	<i>Evidence to Hypothesis</i>
	If you have a genetic code that make you weak or incapable of reproducing as much or being as strong or being susceptible to disease then those genes do not get passed on because you're not going to be reproducing.	<i>Causal Inference</i>
“Warning coloration is when something has real bright obvious colors so that one thinks that it is a danger to them.” (644)	Oregon rough skinned newt: “Why do they have the bright orange belly? ... They want to warn.” (572)	<i>Example</i>
	Poison dart frog: “You probably have all seen pictures of the poison dart frogs.” (643)	<i>Example</i>
	Skunks: “Skunks are only black and white though so you would think ‘well, that isn’t very bright...’” (646)	<i>Example</i>
Mimicry: “You’re imitating something to defend or I supposed some of them do it to get food.” (1220)	Viceroy butterfly: “The viceroy actually mimics, it looks very similar to that but it is not poisonous.” (672)	<i>Example</i>
	Rattlesnake and gopher snakes: “The gopher snakes look a lot like rattlesnakes.” (674)	<i>Example</i>
“Camouflage generally means that you’re trying to make yourself invisible.” (693)	“We started out with the chameleon...” (687)	<i>Example</i>
	“What he is talking about are those moths that have what looks like eyes on their wings.” (690)	<i>Example</i>
	Flounders: “The flounders they sit down on the bottom.”	<i>Example</i>
	Peppered moths: “The peppered moths were over in Europe and the idea here was that it is a white moth with black spots and there are lighter ones	<i>Example</i>

	and darker ones.” (817)	
	Natural Selection activity (696): “We’re looking for the ones that were better adapted for that particular habitat by virtue of their camouflaged. And if they weren’t very well adapted you notice they went extinct.”	<i>Example</i>
	Adaptations is an external characteristics and physical features of organisms. So I had on my notes that the aid in organism somewhere but they do not always aid them. If they are an adaptation that is beneficial I guess they're going to aid them. I don't know if you call a feature that isn't beneficial an adaptation because adaptations help things get along better in their environment so I guess that would mean probably not.	<i>Sign</i>
“Genetic drift just means that over time the gene pool changes and the traits sort of alter with time...” (838)	Peppered moths: “The peppered moths were over in Europe and the idea here was that it is a white moth with black spots and there are lighter ones and darker ones.” (817)	<i>Example</i>
	Microbial antibiotic resistance: (video hepatitis prison example) (862)	<i>Example</i>
	Swine flu: “Actually it fits in very well with our evolution unit because obviously this thing has evolved in very recent times.” (925)	<i>Example</i>
	Remember what we called it in the activity we did last week with the dots? What did we call it when the population changed color over time? Genetic drift. So genetic drift was an example of that.	<i>Example</i>
	You learned all about genes and how they being passed on our what gives us the genetics of the population. So we can change over time based on conditions.	<i>Expert Opinion</i>
“...extinctions reduce genetic diversity...” (1128)	Natural Selection Activity: “How many had one go extinct in the first two generations and when you got the new habitat they would have worked really well there but there were any because it was extinct? Anybody have that happen? So that make sense. So you see that actually applies to the natural world.	<i>Analogy</i>
	Genetic diversity is very important. When something changes and then you don't have the genetic diversity to help someone be suited for that then your	<i>Causal Inference</i>



	population is going to be hurt because say you are read by anybody getting you're on the green one and then you got selected for, you got eaten. Instead of being selected to be survivors then you can see where the issue comes in.”	
	And we learned the other day that extinctions reduced genetic diversity and that can be a bad thing.	<i>Causal Inference</i>
Stabilizing selection: “... if something works there is no pressure from evolution to make a change because it work...” (1168)	Crocodiles, sharks, and lizards: “Those are all patterns that have proven to work very well over time and so they stay. ... You’re not going to mess with the design because those genes keep getting passed on and they keep working.” (1179)	<i>Example</i>
Directional selection: “...means there is a lot of change [in one direction].” (1183)	Long-tailed birds (from video): “...the one with the best display would get to mate and pass on their genes.” (1193)	<i>Example</i>
	Extinct elk: “What happened was they think these elk would only get a mate if they had the biggest rack...” (1200)	<i>Example</i>
	Peacock: “Another bird that you can think of is probably the peacock.” (1206)	<i>Example</i>
	You could do this artificially with people if we made a rule that unless you were 6'4" as a guy and 5'10" as a girl you could not have any kids and then we do that for a couple of generations and then we say hey let's up this thing and now you have to be taller. And you can see over a number of generations we would become as very tall group. That would be directional selection.	<i>Causal Inference</i>
Disruptive selection: “...is when organisms split and select two extremes.” (1208)	So let's say there is a mutations and something looks different and so any population over time you have two varieties. Well after a while one variety is only get a mate with that variety in the other ideas only going to mate with that variety and overtime you're going to spread apart until they won't even mate with each other and then have separate species. So is a way of disrupting two separate groups.	<i>Causal Inference</i>
Vestigial structures: “...a remnant of	Whale pelvis (1231)” “We all have a backbone and then we have two	<i>Example</i>

a physical feature that is reduced and often useless.” (1242)	girdles. You have a pelvic girdle which is down here by your pelvis and then you have a pectoral girdle which is up here by your shoulders.” (1237)	
	Human tailbone (1234)	<i>Example</i>
	Snake pelvis (1238): “We all have a backbone and then we have two girdles. You have a pelvic girdle which is down here by your pelvis and then you have a pectoral girdle which is up here by your shoulders.” (1237)	<i>Example</i>
	Appendix (1247)	<i>Example</i>
	Cave fish (1250): “over time they lose their eyes and maybe they still have vestigial eyes but they don’t actually function anymore because there’s no use for the critters to put all that energy into having something that is unusable anyway.” (1250)	<i>Example</i>
Reproductive isolation “is separate mating at different times.” (1277) “If you mate at different times, you’re different.” (1277)	“If you’re a frog and you mate in the spring or you mate in the fall if you use the same lake to mate you’re never going to mix your genes if you mate in the spring you’re never going to mix your genes with the frogs that mate in the fall.(1260)	<i>Analogy</i>
	Salmon (1265) : “But those two different runs of fish, even though they are the same species, are reproductively isolated. Over time the gene pools change ... “ (1266)	<i>Example</i>
	“There are a lot of plants that bloom at different times.” (1569)	<i>Example</i>
	That they would have bred with the ones here and he didn't want to artificially mix the gene pool because he was an entomologist and that is what he studies and he did not want to artificially mess with something that he thought was working.	<i>Expert Opinion</i>
Geographic isolation “separate gene pools because of the different locales.” (1281)	Dark-eyed Junco: “Look at this bird and you will see that they are very similar. This bird has yellow shafts on the feathers and this one is red. This one was on the Western side of the United States and this one was in the Eastern United States.” (1300)	<i>Example</i>
	Common Flickers: “So there was this huge expanse of prairie that blocked the east from the west where these birds life in the east coast and these on the	<i>Example</i>

	western side of the rocky mountains.” (1338)	
	Woodpecker (1348): “The idea is that these were probably the same birds at one time that they separated geographically and so over time as their gene pool changes and they mated with their group they changed and then they are different.” (1351)	<i>Example</i>
	Titmice (1373): “Look at all the variety.” (1373)	<i>Example</i>
	Warblers (1382): “We have both of these here and they mate with each other so now they just call hem one species...” (1385)	<i>Example</i>
	Baltimore Oriole (1386): “Now we don’t even have Baltimore orioles. We now have northern orioles because these two will mate with each other and again they are separated.” (1386)	<i>Example</i>
	Canadian Geese: “In the Canadian Geese we have several different varieties. They are way different in size and shape and color...” (1391)	<i>Example</i>
	Ducks: “We also have ducks that come here in the winter...” (1390)	<i>Example</i>